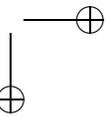
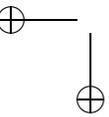
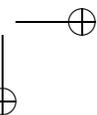
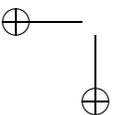
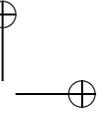
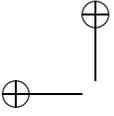


# An Introduction to Stata Programming



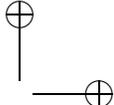
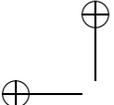


# An Introduction to Stata Programming

Christopher F. Baum  
*Boston College*



A Stata Press Publication  
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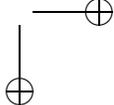
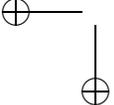
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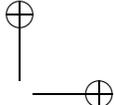
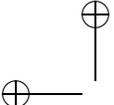
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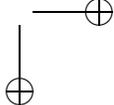
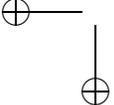
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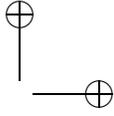
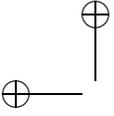
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I am deeply grateful to my wife Paula Arnold for graciously coping with my seemingly 24–7 efforts in completing this manuscript.

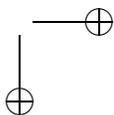
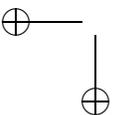
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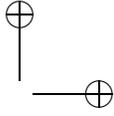
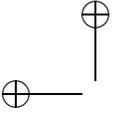
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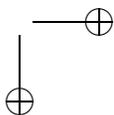
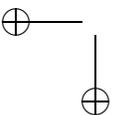
To Paula





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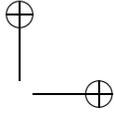
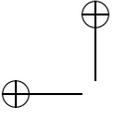
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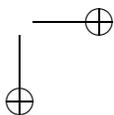
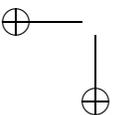
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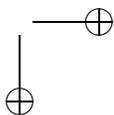
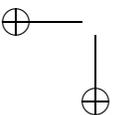
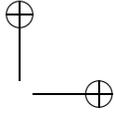
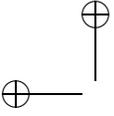
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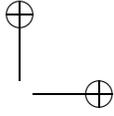
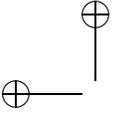


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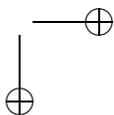
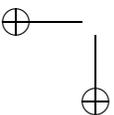


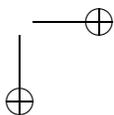
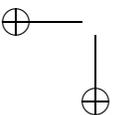
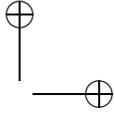
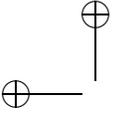


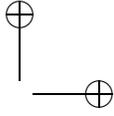
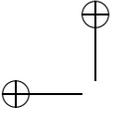


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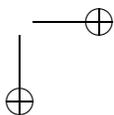
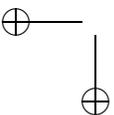
# Preface

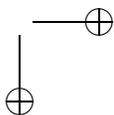
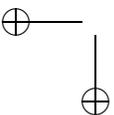
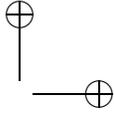
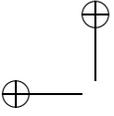
This book is a concise introduction to the art of Stata programming. It covers three types of programming that may be used in working with Stata: do-file programming, ado-file programming and writing Mata functions that work in conjunction with do- and ado-files. Its emphasis is on the automation of your work with Stata, and how programming on one or more of these levels can help you use Stata more effectively.

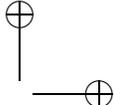
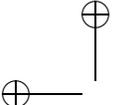
The development of these concepts does not assume that you have prior experience with Stata programming, although familiarity with the command-line interface is very helpful. Examples are drawn from a number of disciplines, although my own background as an applied econometrician may be evident in the selection of some sample problems. The introductory chapter motivates the *why*: why should you invest time and effort in learning Stata programming? Chapter 2 discusses elementary concepts of the command-line interface and describes some commonly-used tools for working with programs and datasets.

The format of the book may be unfamiliar to readers who have some familiarity with other books that help you learn how to use Stata. Beginning with Chapter 3, each odd-numbered chapter is followed by a *cookbook* chapter containing several *recipes*: 40 in total. These recipes pose a problem: how may I perform a certain task with Stata programming? They then provide a complete worked solution to the problem, and discuss how the features presented in the previous chapter may be put to good use. As in the kitchen, you may rarely want to exactly follow a recipe from the cookbook. But just as in cuisine, a minor variation on the recipe may meet your needs, or the techniques presented in that recipe may help you see how Stata programming may apply to your specific problem.

Most Stata users who delve into programming will make use of do-files to automate and document their work. Consequently, the major focus of the book is do-file programming, covered in Chapters 3, 5, 7, and 9. Some users will find that writing formal Stata programs, or ado-files, meets their needs. Chapter 11 is a concise summary of ado-file programming, with the following cookbook chapter presenting several recipes that contain developed ado-files. Stata's matrix programming language, Mata, may also be very helpful in automating certain tasks. Chapter 13 presents a summary of Mata concepts and the key features that allow interchange of variables, scalars, macros and matrices. The last chapter presents a number of examples of Mata functions developed to work with ado-files. All of the do-files, ado-files, Mata functions and datasets used in the book's examples and recipes are available from the Stata Press website, as discussed in Section 1.2.







## Notation and Typography

In this book we assume that you are somewhat familiar with Stata, that you know how to input data and to use previously created datasets, create new variables, run regressions, and the like.

We designed this book for you to learn by doing, so we expect you to read this book while sitting at a computer so you can try using the sequences of commands contained in the book to replicate our results. In this way, you will be able to generalize these sequences to suit your own needs.

Generally, we use the typewriter font `command` to refer to Stata commands, syntax, and variables. A “dot” prompt followed by a command indicates that you can type verbatim what is displayed after the dot (in context) to replicate the results in the book.

Except for some very small expository datasets, all the data we use in this book are freely available for you to download using Stata from the Stata Press website, <http://www.stata-press.com>. In fact, when we introduce new datasets, we merely load them into Stata the same way that you would. For example,

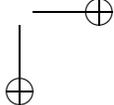
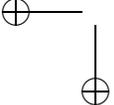
```
. use http://www.stata-press.com/data/itisp/urates.dta, clear
```

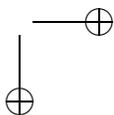
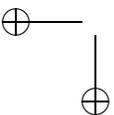
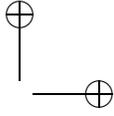
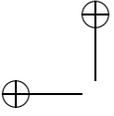
Try it. In addition, the ado-files (not the do-files) used may be obtained by typing

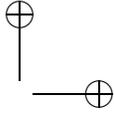
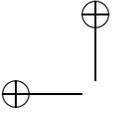
```
. net from http://www.stata-press.com/data/itisp
  (output omitted)
. net install itisp
  (output omitted)
. !!!!!
  (output omitted)
```

The `itisp` command will copy the sample ado-files to your current working directory, where you can look at them and use them. I suggest that you create a new directory and copy the materials there.

This text complements the material in the Stata manuals but does not replace it, so we often refer to the Stata manuals using [R], [P], etc. For example, [R] `xi` refers to the *Stata Reference Manual* entry for `xi`, and [P] `syntax` refers to the entry for `syntax` in the *Stata Programming Manual*.







# 1 Why should you become a Stata programmer?

This book provides an introduction to the several contexts of *Stata programming*. We must first define what we mean by *programming*. You can consider yourself a Stata programmer if you write *do-files*: sequences of Stata commands which you can execute with the `do` command, by double-clicking on the file or by running in the Do-file Editor. You might also write what Stata formally defines as a *program*: a set of Stata commands that includes the `program` ([P] **program**) statement. A Stata program, stored in an *ado-file*, defines a new Stata command. You may also use Stata's matrix programming language, Mata, to write routines in that language that are called by *ado-files*. Any of these tasks involves *Stata programming*.<sup>1</sup>

With that set of definitions in mind, we must deal with the *why*: why should you become a Stata programmer? After answering that essential question, this text takes up the *how*: how you can become a more efficient user of Stata by making use of programming techniques, be they simple or complex.

Using any computer program or language is all about *efficiency*: getting the computer to do the work that can be routinely automated, allowing you to make more efficient use of your time and reducing human errors. Computers are excellent at performing repetitive tasks while humans are not. One of the strongest rationales for learning how to use programming techniques in Stata is the potential to shift more of the repetitive burden of data management, statistical analysis and the production of graphics to the computer. Let's consider several specific advantages of using Stata programming techniques in the three contexts enumerated above.

## Do-file programming

Using a *do-file* to automate a specific data management or statistical task leads to reproducible research and the ability to document the empirical research process. This

---

1. There are also specialized forms of Stata programming, such as *dialog programming*, *scheme programming* and *class programming*. A user-written program may present a dialog, like any official Stata command, if its author writes a dialog file. The command may also be added to the User menu of Stata's graphical interface. For more information, see [P] **dialog programming** and [P] **window programming**. Graphics users may write their own *schemes* to set graphics defaults. See [G] **schemes intro** for details. *Class programming* allows you to write object-oriented programs in Stata. As [P] **class** indicates, this has primarily been used in Stata's graphics subsystem and graphical user interface. I do not consider these specialized forms of programming in this book.

reduces the effort needed to perform a similar task at a later point, or to document the specific steps you followed for your co-workers or supervisor. Ideally, your entire research project should be defined by a set of do-files which execute every step from input of the raw data to production of the final tables and graphs. As a do-file can call another do-file (and so on), a hierarchy of do-files can be used to handle a quite complex project.

The beauty of this approach is its flexibility. If you find an error in an earlier stage of the project, you need only modify the code and rerun that do-file and those following to bring the project up to date. For instance, a researcher may need to respond to a review of her paper—submitted months ago to an academic journal—by revising the specification of variables in a set of estimated models and estimating new statistical results. If all the steps producing the final results are documented by a set of do-files, her task becomes straightforward. I argue that all serious users of Stata should gain some facility with do-files and the Stata commands that support repetitive use of commands.

That advice does not imply that Stata’s interactive capabilities should be shunned. Stata is a powerful and effective tool for exploratory data analysis and *ad hoc* queries about your data. But data management tasks and the statistical analyses leading to tabulated results should not be performed with “point-and-click” tools which leave you without an audit trail of the steps you have taken.

### Ado-file programming

On a second level, you may find that despite the breadth of Stata’s official and user-written commands, there are tasks that you must repeatedly perform that involve variations on the same do-file. You would like Stata to have a *command* to perform those tasks. At that point, you should consider Stata’s *ado-file* programming capabilities. Stata has great flexibility: a Stata command need be no more than a few lines of Stata code, and once defined that command becomes a “first-class citizen.” You can easily write a Stata program, stored in an ado-file, that handles all the features of official Stata commands such as *if exp*, *in range* and command options. You can (and should) write a help file that documents its operation for your benefit and for those with whom you share the code. Although ado-file programming requires that you learn how to use some additional commands used in that context, it may help you become more efficient in performing the data management, statistical or graphical tasks that you face.

### Mata programming for ado-files

On a third level, your ado-files may perform some complicated tasks which involve many invocations of the same commands. Stata’s ado-file language is easy to read and write, but it is *interpreted*: Stata must evaluate each statement and translate it into machine code. The Mata programming language (`help mata`) creates *compiled* code which can run much faster than ado-file code. Your ado-file can call a Mata routine to carry out

a computationally intensive task and return the results in the form of Stata variables, scalars or matrices. Although you may think of Mata solely as a matrix language, it is actually a general-purpose programming language, suitable for many non-matrix-oriented tasks such as text processing and list management.

The level of Stata programming that you choose to attain and master depends on your needs and skills. As I have argued, the vast majority of interactive Stata users can and should take the next step of learning how to use do-files efficiently in order to take full advantage of Stata's capabilities and save time. A few hours of investment in understanding the rudiments of do-file programming—as covered in the chapters to follow—should save you days or weeks over the course of a sizable research project.

A smaller fraction of users may choose to develop ado-files. Many users may find that those features lacking in official Stata are adequately provided by the work of members of the Stata user community who have developed and documented ado-files, sharing them via the *Stata Journal*, SSC Archive<sup>2</sup> or their own user site. However, developing a reading knowledge of ado-file code is highly useful for many Stata users. It permits you to scrutinize ado-file code—either that of official Stata or user-written code—and more fully understand how it performs its function. In many cases, minor modifications to existing code may meet your needs.

Mata was new to Stata as of version 9. It has already been embraced by a number of user-programmers wishing to take advantage of its many features and speed advantages. As an introduction to Stata programming, this book places the least emphasis on Mata subroutines for ado-file programming, but discusses the basic elements of that environment. I do not discuss interactive use of Mata in this book.

## 1.1 Plan of the book

The chapters of this book present the details of the three types of Stata programming discussed above, placing the greatest emphasis on the first topic: effective use of do-file programming. Each fairly brief chapter on the structure of programming techniques is followed by a *cookbook* chapter. These chapters contain a number of recipes for the solution of a particular, commonly encountered problem, illustrating the necessary programming techniques. Like a cookbook, the recipes are illustrative examples. You are free to modify the ingredients to produce a somewhat different dish. The recipes may not address your precise problem, but should prove helpful in devising that solution as a variation on the same theme.

## 1.2 Installing the necessary software

This book uses Stata to illustrate many aspects of programming. Stata's capabilities are not limited to the commands of official Stata documented in the manuals and in

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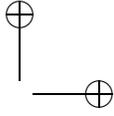
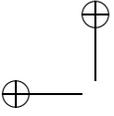
2. For details on the SSC (“Boston College”) archive of user-contributed routines, `help ssc`.

on-line help, but include a wealth of commands documented in the *Stata Journal*, *Stata Technical Bulletin* and the SSC Archive.<sup>3</sup> Those commands will not be available in your copy of Stata unless you have already located and installed them. To locate a user-written command (such as *thatcmd*), use `findit thatcmd` (see [R] **search**).

Newer versions of the user-written commands that you install today may become available. The official Stata command `adoupdate` ([R] **adoupdate**), which you may use at any time, will check to see whether newer versions of any of these user-written commands are available. Just as the command `update query` will determine whether your Stata executable and official ado-files are up to date, `adoupdate` will perform the same check for user-written commands installed in your copy of Stata.

---

3. `help ssc` for information on the SSC (“Boston College”) Archive.



## 2 Some elementary concepts and tools

### 2.1 Introduction

This chapter lays out some of the basics that you will need to be an effective Stata programmer. The first section discusses navigation and organizational issues: how do you organize your files? How will Stata find a do-file or ado-file? The following sections discuss editing, data types, several useful commands for programmers, and some guidelines for Stata programming style. The penultimate section suggests how you may seek help for your programming problems.

#### 2.1.1 What you should learn from this chapter

- Know where your files are: master the current working directory and the `adopath`
- Learn how to edit do- and ado-files effectively
- Use appropriate data types for your variables: use `compress` when useful
- Use time-series operators effectively
- Use `capture`, `preserve`, and `restore` to work efficiently
- Use Stata's data input commands effectively
- Adopt a good style for do-file programming and internal documentation
- Know where (and when!) to seek help with your Stata programming
- Know how to trace your do-file's execution to diagnose errors

### 2.2 Navigation and organizational issues

We are all familiar with the colleague whose computer screen resembles a physical desk in a cluttered office: a computer with icons covering the screen in seemingly random order. If you only use Stata interactively, storing data files on the desktop might seem like a reasonable idea. But when you start to use do-files to manage a project or write your own ado-file, those files' locations become crucial: they won't work if they're in the wrong place on your computer. This section of the chapter discusses those navigation and organizational issues to help you ensure that your files are in the best places.

### 2.2.1 The current working directory and `profile.do`

Like most programs, Stata has a concept of the *current working directory* or *cwd*. At any point in time, Stata is referencing a specific directory or folder accessible from your computer. It may be a directory on your own hard disk, or located on a network drive or removable disk. In interactive mode, Stata displays the *cwd* in its toolbar. Why is the *cwd* important? If you save a file—a `.dta` file or log file—it will be placed in the *cwd* unless you provide a full *file specification* directing it to another directory. That is, `save myfile, replace` will save that file in the *cwd*. Likewise, if you attempt to use a file with the syntax `use myfile, clear`, it will search for that file in the *cwd*, and return an error if the file is not located.

One of the most common problems beginning users of Stata face is saving a data file and not knowing where it was saved. Of course, if you never change the *cwd*, all of your materials will be in the same place, but do you really want everything related to your research to be located in a single directory? On my computer, the directory is `/Users/baum/Documents`, and I would rather not commingle documents with Stata data files, log files, and graph files. Therefore, you probably should change the *cwd* to a directory or folder dedicated to your research project and set up multiple directories for separate projects. You may change your current working directory with the `cd` command: for instance, `cd /data/city`, or `cd d:/project`, or `cd "My Documents/project1"`.<sup>1</sup> You can use the `pwd` command to display the *cwd* at any time. Both `cd` and `pwd` are described in [D] `cd`.

You may want Stata to automatically change the working directory to your preferred location when you start Stata. You can accomplish this with `profile.do`. This file, placed in your home directory,<sup>2</sup> will execute a set of commands when you invoke Stata. You might place the command `cd c:/data/NIHproject` in `profile.do` to direct Stata to automatically change the working directory to that location.

### 2.2.2 Locating important directories: `sysdir` and `adopath`

The `sysdir` command provides a list of seven directories or folders on your computer that are important to Stata. The `STATA`, `UPDATES` and `BASE` directories contain the Stata program itself and the official ado-files that make up most of Stata. You should not tamper with the files in these directories. Stata's `update` ([R] `update`) command will automatically modify the contents of these three directories. The `SITE` directory may reference a network drive in a university or corporate setting where a system administrator places ado-files to be shared by a number of users.

---

1. Even in a Windows environment, you may use the forward slash (/) as a directory separator. The backslash (\) usually used in Windows file specifications can be problematic in Stata do-files, as Stata interprets the backslash as an escape character, modifying its handling of the following character. You can avoid problems (and enhance cross-platform compatibility of your programs) by using the forward slash (/) directory separator in all Stata programs.

2. See `help profilew` (Windows), `help profilem` (Mac OS X) or `help profileu` (Unix/Linux) for operating system-specific details.

The PLUS directory is automatically created when you download any user-written materials. If you use `findit` to locate and install user-written programs from the *Stata Journal* or *Stata Technical Bulletin*, their ado-files and help files will be located in a subdirectory of the PLUS directory.<sup>3</sup> If you use the `ssc` ([R] `ssc`) command to download user-written materials from the SSC (“Boston College”) Archive, or `net install` to download materials from a user’s site, they will also be placed in a subdirectory of the PLUS directory.

The PERSONAL directory is, as its name suggests, personal. You may place your own ado-files in that directory. If you want to modify an official Stata ado-file, you should make a copy of it, change its name (for instance, rename `sureg.ado` to `sureg2.ado`) and place it in your PERSONAL directory.<sup>4</sup>

Why are there all these different places for Stata’s ado-files? The answer lies in the information provided by the `adopath` command:

```
. adopath
[1] (UPDATES)  "/Applications/Stata/ado/updates/"
[2] (BASE)     "/Applications/Stata/ado/base/"
[3] (SITE)     "/Applications/Stata/ado/site/"
[4]           "."
[5] (PERSONAL) "~/Library/Application Support/Stata/ado/personal/"
[6] (PLUS)     "~/Library/Application Support/Stata/ado/plus/"
[7] (OLDPLACE) "~/ado/"
```

Like `sysdir`, this command lists seven directories. The order of these directories is important for it defines how Stata will search for a command. It will attempt to find `foo.ado` in UPDATES, then in BASE: the possible locations for Stata’s official ado-files.<sup>5</sup> The fourth directory is “.”: that is, the current working directory. The fifth is PERSONAL, while the sixth is PLUS.<sup>6</sup> This pecking order implies that if `foo.ado` is not to be found among Stata’s official ado-files or the SITE directory, Stata will examine the *cwd*. If that fails, it will look for `foo.ado` in PERSONAL (and its subdirectories). If that fails, it will look in PLUS (and its subdirectories) and as a last resort in OLDPLACE. If `foo.ado` is nowhere to be found, Stata will generate an `unrecognized command` error.

This search hierarchy indicates that you may locate an ado-file in one of several places. In the next section, we discuss how you might choose to organize ado-files, as well as do-files and data files related to your research project.

### 2.2.3 Organization of do-, ado- and data files

It is crucially important that you place ado-files on the `adopath`. You can place them in your current working directory ([4] above in the `adopath` listing) but that is generally

3. For instance, if `sysdir` shows that PLUS is `~/Library/Application Support/Stata/ado/plus/`, `foo.ado` and `foo.hlp` will be placed in `~/Library/Application Support/Stata/ado/plus/f`.

4. The OLDPLACE directory exists only for historical reasons.

5. As mentioned above, we may ignore SITE unless you are accessing Stata in a networked environment.

6. We also ignore OLDPLACE, which is only of historical interest.

a bad idea for if you work in any other directory, those ado-files will not be found. If the ado-files are your own or have been written by a co-worker, place them in **PERSONAL**. If you download ado-files from the SSC Archive, please heed the advice that you should always use Stata—not a web browser!—to perform the download and locate the files in the correct directory (in **PLUS**).

What about your do-files, data files and log files? It makes great sense to create a directory, or folder, in your home directory for each separate project, and store all project-related files in that directory. You may always fully qualify a data file when you **use** it in a do-file, but if you move that do-file to another computer the do-file will fail to find it. Referencing files in the same directory simplifies making a copy of that directory for a co-worker or collaborator, and makes it possible to run the do-files from an external drive such as a flash disk or “memory key.”

It is also a good idea to place a **cd** command at the top of each do-file referencing the current directory. Although this command would have to be altered if you moved the directory to a different computer, it will prevent a common mistake: saving data files or log files to a directory other than the project directory.

You might also have several projects that depend on one or two key data files. Rather than duplicating possibly large data files in each project directory, you can refer to them with a relative file specification. Say that your research directory is **d:/data/research** with subdirectories **d:/data/research/project1** and **d:/data/research/project2**. Place the key data file **master.dta** in the **research** directory, and refer to it in the project directories with **use ../master, clear**. The double-dot indicates that the file is to be found in the parent (enclosing) directory, while allowing you to move your research directory to a different drive (or even to a Mac OS X or Linux computer) without having to alter the **use** statement.

## 2.3 Editing Stata do- and ado-files

If a do-file or ado-file is relatively small<sup>7</sup> and you are working in Stata’s graphical user interface, you should use Stata’s Do-file editor to create or modify the file. The Do-file editor has an advantage over most external editors: it allows you to execute only a section of the file by selecting those lines and hitting the Do icon.

You should recognize that do- and ado-files are merely text files with filetypes of **.do** or **.ado** rather than **.txt**. As such, it is a very poor idea to edit them in a word processor such as Microsoft Word. A word processor must read the text file and convert it into its own binary format, and when the file is saved it must reverse the process.<sup>8</sup> Furthermore, a word processor will usually present the file in a variable-width character format which is harder to read. But the biggest objection to word processing a do-file

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7. You may edit files less than 128 kilobytes if you are on a Windows system. There are no limits in Stata for Macintosh or Stata for Unix/Linux.

8. This is the same translation process that takes place when you **insheet** a text file and **outsheet** it back to text within Stata.

or ado-file is the waste of your time: it is considerably faster to edit a file in the Do-file editor and execute it immediately without the need to translate it back into text.

What if the file is too large to be edited in the Do-file editor? Every operating system supports a variety of text editors, many of them free. A useful compendium of information on text editors has been collected and organized by Nicholas J. Cox and is available from the SSC Archive as `texteditors`, a HTML document. You may also view the latest version of that regularly-updated document in your web browser.<sup>9</sup> Many of the text editors described in the document have “Stata editing modes” which will colorize Stata commands, indicate different elements of syntax and even flag apparent errors in the code. In any text editor, it is not necessary to close the file after modifying it. You merely save the file, and its revised version may then be executed by Stata.

## 2.4 Data types

Stata, as a programming language, supports more data types than do many statistical packages. The major distinction to consider is between numeric and string data types. Data management tasks often involve conversions between numeric and string variables. For instance, data read from a text file (such as a `.csv` or tab-delimited file created by a spreadsheet) will often be considered to be a string variable by Stata even though most of its contents are numeric. The commands `destring` ([D] `destring`) and `tostring` are helpful in this regard, as are `encode` ([D] `encode`) and `decode`.

String variables may hold values up to 244 characters in length, one byte for each character. You usually need not declare their length, for Stata’s string functions (`help string functions`) will generate a string variable long enough to hold the contents of any `generate` ([D] `generate`) operation. They require as many bytes of storage per observation as their declaration. For instance, a `str20` variable requires 20 bytes per observation.

Stata’s numeric data types include `byte`, `int`, `long`, `float` and `double`. The `byte`, `int` and `long` data types can only hold integer contents. In summary:

Table 2.1: Numeric data types

Storage type	Minimum	Maximum	Bytes
<code>byte</code>	−127	100	1
<code>int</code>	−32,767	32,740	2
<code>long</code>	−2,147,483,647	2,147,483,620	4
<code>float</code>	$-1.701 \times 10^{38}$	$1.701 \times 10^{38}$	4
<code>double</code>	$-8.988 \times 10^{307}$	$8.988 \times 10^{307}$	8

The `long` integer data type can hold all signed nine-digit integers, but only some ten-

9. <http://ideas.repec.org/c/boc/bocode/s423801.html>

digit integers. Integers are held in their exact representation by Stata so that you may store a nine-digit integer (such as a U.S. Social Security number) as a `long`. However, lengthy identification numbers can also be stored as a `double` data type or as a string variable. In many cases that will be a wise course of action, as then you need not worry about possible truncation of values. You will also find it useful to use string variables when a particular identification code could contain characters. For instance, the CUSIP code used to identify U.S. securities issues used to be wholly numeric, but now may contain one or more non-numeric characters. Storing CUSIP values as strings avoids later problems with numeric missing values.

As displayed above, the two floating-point data types, `float` and `double`, can hold very large numbers. But many users encounter problems with much smaller floating-point values if they mistakenly assume that floating-point arithmetic operations are exact. Floating-point numbers (those held as mantissa and exponent, such as  $1.056 \times 10^3$ ), expressed in base 10, must be stored as base 2 (binary) numbers. Although  $1/10$  is a rational fraction in base 10, it is not so in the binary number system used in a computer:

```
. display %21x 1/10
+1.999999999999999aX-004
```

Further details of this issue can be found in [U] **12.2.2 Numeric storage types**, Gould (2006b) and Cox (2006a). The implications should be clear: an `if` condition that tests some floating-point value for equality, such as `if diff == 0.01`, is likely to fail when you expect that it would succeed.<sup>10</sup> A `float` contains approximately seven significant digits in its mantissa. This implies that if you read a set of nine-digit U.S. Social Security numbers into a `float`, they will not be held exactly. A `double` contains approximately 15 significant digits. We know that residuals computed from a linear regression using `regress` and `predict eps, residual` should sum to exactly zero. In Stata's finite-precision computer arithmetic using the default `float` data type, residuals from such a regression will sum to a value in the range of  $10^{-7}$  rather than 0.0. Thus, discussions of the `predict ([R] predict)` command often advise using `predict double eps, residual` to compute more accurate residuals.

What are the implications of finite-precision arithmetic for Stata programming?

1. You should store ID numbers with many digits as string variables, not as integers, floats or doubles.
2. You should not rely on exact tests of a floating-point value against a constant: not even zero. The `reldif()` function (`help math functions`) may be used to test for approximate equality.
3. As suggested above, use `double` floating-point values for any generated series where a loss of precision might be problematic, such as residuals, predicted values, scores, and the like.

10. The alternative syntax `if diff == float(0.01)` will solve this problem.

4. You should be wary of variables' values having very different scales, particularly when a nonlinear estimation method is employed. Any regression of `price` from the venerable `auto.dta` reference data set on a set of regressors will display extremely large sums of squares in the ANOVA table. Scaling `price` from dollars to thousands of dollars obviates this problem. The scale of this variable does not affect the precision of linear regression, but it could be problematic for nonlinear estimation techniques.
5. Use integer data types where it is appropriate to do so. Storing values as `byte` or `int` data types when feasible saves disk space and memory.

### 2.4.1 Storing data efficiently: the `compress` command

A very useful command, particularly when working with data sets acquired from other statistical packages, is `compress` ([D] `compress`). This command will examine each variable in memory and determine whether it may be stored more efficiently. It is guaranteed never to lose information nor reduce the precision of measurements. The advantage of storing indicator (0/1) variables as `byte` data type rather than as four-byte `long` data types is substantial for many survey data sets with numerous indicator variables. It is an excellent idea to apply `compress` when performing the initial analysis of a new data set. Alternatively, if you are using the third-party Stat/Transfer application to convert data from SAS or SPSS format, use the Stat/Transfer optimize option.

### 2.4.2 Date and time handling

Stata does not have a separate data type for calendar dates. Dates are represented, as they are in a spreadsheet program, by numbers known as `%t values` measuring the time interval from a reference date or *epoch*: in the case of Stata (and SAS), midnight on 1 January 1960.<sup>11</sup> Days following that date have positive integer values, while days prior have negative integer values. These are known as `%td` values. Other calendar frequencies are represented by the number of weeks, months, quarters or half-years since that reference date: `%tw`, `%tm`, `%tq` and `%th` values, respectively. The year is represented as a `%ty` value, ranging from 100 to 9999 A.D. For time-series data represented by other calendar schemes (e.g., business-daily data) you may use consecutive integers and the *generic* form, as `%tg`.

As of version 10, Stata provides support for very accurate intra-daily measurements of time, down to the millisecond. A date and time variable is known as a `%tc` (clock) value, and it may be defined to any intra-day granularity: hours, minutes, seconds, and milliseconds.<sup>12</sup> For more information, see [U] **12.3 Dates and times**.

It is very important when working with variables containing dates and times to ensure that the proper Stata data type is used for their storage. Weekly and lower-

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11. The Unix epoch starts at midnight on 1 January 1970.

12. There are also `%tC` values which take account of *leap seconds* for very precise measurement of time intervals.

frequency values (including generic values) may be stored as data type `int` or as data type `float`. Daily (`%td`) values should be stored as data type `long` or as data type `float`. If the `int` data type is used, dates more than 32,740 days from 1 January 1960 (such as beyond 21 August 2049) cannot be stored.

Much more stringent requirements apply to clock (date and time) values. These values *must* be stored as data type `double` to avoid overflow conditions. Clock values, like other time values, are integers, and there are 86,400,000 milliseconds in a day. The `double` data type is capable of precisely storing date and time measurements within the range of years (100–9999 A.D.) defined in Stata.

Although it is important to use the appropriate data type for date and time values, you should avoid using a larger data type than needed. The `int` data type requires only two bytes per observation; `long` and `float` data types require four bytes; and the `double` data type requires eight bytes. Although every date and time value could be stored as a `double`, that would be very wasteful of memory and disk storage, particularly in a data set with many observations.

A suite of functions (see `help dates and times`) is available to handle the definition of date variables and date/time arithmetic. Display of date variables in calendar formats (such as 08 Nov 2006) and date and time variables with the desired intraday precision is handled by the definition of proper formats. As with numeric variables, you should distinguish between the content or value of a date/time variable and the format in which it will be displayed.

One helpful hint: if you are preparing to move data from a spreadsheet into Stata with the `insheet` ([D] `insheet`) command, make sure that any date variables in the spreadsheet display as four-digit years. It is possible to deal with two-digit years such as 11/08/06 in Stata, but it is easier to format the dates with four-digit years (for example, 11/08/2006) before reading those data into Stata.

### 2.4.3 Time-series operators

Stata provides *time-series operators* `L.`, `F.`, `D.`, `S.` which allow specification of *lags*, *leads* (forward values), *differences* and *seasonal differences*, respectively.<sup>13</sup> The time-series operators make it unnecessary to create a new variable in order to use a lag, difference or lead. When combined with a *numlist*, they allow the specification of a set of these constructs in a single expression. Consider the lag operator, `L.`, which when prepended to a variable name refers to the (first-)lagged value of that variable: `L.x`. A number may follow the operator, so that `L4.x` would refer to the fourth lag of `x`. More generally, a *numlist* may be used, so that `L(1/4).x` refers to the first through fourth lags of `x`, and `L(1/4).(x y z)` defines a list of four lagged values of each of the variables `x`, `y` and `z`. These expressions may be used anywhere that a *varlist* is required.

Similar to the lag operator, the lead operator `F.` allows specification of future values

13. This section is adapted from Section 3.2.1 of Baum (2006a).

of one or more variables. Strictly speaking, the lead operator is unnecessary, since a lead is a negative lag, and an expression such as `L(-4/4).x` will work, labeling the negative lags as leads. The difference operator, `D.`, may be used to generate differences of any order. The first difference, `D.x`, is  $\Delta x$  or  $x_t - x_{t-1}$ . The second difference, `D2.x`, is not  $x_t - x_{t-2}$ , but rather  $\Delta(\Delta x_t)$ : that is,  $\Delta(x_t - x_{t-1})$ , or  $x_t - 2x_{t-1} + x_{t-2}$ . You can also combine the time-series operators so that `LD.x` is the lag of the first difference of `x` (that is,  $x_{t-1} - x_{t-2}$ ), and refers to the same expression as does `DL.x`. The seasonal difference `S.` is used to compute the difference between the value in the current period and the period one year ago. For quarterly data, `S.x` would generate  $x_t - x_{t-4}$ , and `S2.x` generates  $x_t - x_{t-8}$ .

In addition to being easy to use, time-series operators will never misclassify an observation. You could refer to a lagged value as `x[_n-1]`, or a first difference as `x[_n] - x[_n-1]`, but that construction is not only cumbersome but also dangerous. Consider an annual time-series dataset in which the 1981 and 1982 data are followed by the data for 1984, 1985, ..., with the 1983 data not appearing in the dataset (i.e., not recorded as missing values, but physically absent). The observation-number constructs above will misinterpret the lagged value of 1984 to be 1982, and the first difference for 1984 will incorrectly span the two-year gap. The time-series operators will not make this mistake. As `[TS] tsset` has been used to define `year` as the time-series calendar variable, the lagged value or first difference for 1984 will be properly coded as missing whether or not the 1983 data are stored as missing in the dataset. Thus you should always use the time-series operators when referring to past or future values or computing differences in a time-series dataset.

The time-series operators also provide an important benefit in the context of *longitudinal* or *panel* datasets (`[XT] xt`) in which each observation,  $x_{i,t}$ , is identified with both an  $i$  and a  $t$  subscript. If those data are `xtset` (`[XT] xtset`) or `tsset` (`[TS] tsset`), using the time-series operators will ensure that references will not span panels. For instance, `z[_n-1]` in a panel context will allow you to reference  $z_{1,T}$  (the last observation of panel 1) as the prior value of  $z_{2,1}$  (the first observation of panel 2). In contrast, `L.z` (or `D.z`) will never span panel boundaries. Panel data should always be `xtset` or `tsset`, and any time-series references should make use of the time-series operators.

## 2.5 Handling errors: the capture command

When an error is encountered in an interactive Stata session it is displayed on the screen. When a do-file is being executed, however, Stata's default behavior causes the do-file to abort when an error occurs.<sup>14</sup> There are circumstances when a Stata error should be ignored: for instance, calculating a measure from each `by`-group which can only be computed if there are more than 10 observations in the `by`-group. Rather than programming conditional logic that prevents that calculation from taking place with insufficient observations, you could use `capture` (`[P] capture`) as a prefix on that

14. The `nostop` option of the `do` (`[R] do`) command can be used to prevent termination. However, there is no way to invoke this option if you launch the do-file by double-clicking on it.

command. For instance, `capture regress y x1-x12` will prevent the failure of one regression from aborting the do-file. If you still would like to see the regression results for those regressions which are feasible, use `noisily capture...` The `capture` command may also be used to surround a block of statements, as in

```
capture {
  regress y x1-x12
  regress y x13-x24
  regress y x25-x36
}
```

rather than having to repeat `capture` on each `regress` command.

## 2.6 Protecting the data in memory: the `preserve` and `restore` commands

A number of Stata commands replace the data in memory with a new dataset. For instance, the `collapse` ([D] **collapse**) command makes a dataset of summary statistics, while `contract` ([D] **contract**) makes a dataset of frequencies or percentages. In a program, you may want to invoke one of these commands, but may want to retain the existing contents of memory for further use in the do-file. You need the `preserve` ([D] **preserve**) and `restore` ([D] **restore**) commands, which will allow you to set aside the current contents of memory in a temporary file and bring them back when needed. As an example:

```
. sysuse auto, clear
(1978 Automobile Data)
. generate lprice = log(price)
. preserve
. collapse (max) max_lprice=lprice max_mpg=mpg ///
> (iqr) iqr_lprice=lprice iqr_mpg=mpg if !missing(rep78), by(rep78)
. sort rep78
. save repstats, replace
file repstats.dta saved
```

We use and modify the `auto.dta` dataset, then `preserve` the modified file. The `collapse` command creates a dataset with one observation for each value of `rep78`, the `by`-variable. We `sort` that data set of summary statistics and save it. We are now ready to return to our main dataset:

```
. restore
. sort rep78
. merge rep78 using repstats, unquising
variable rep78 does not uniquely identify observations in the master data
. summarize lprice max_lprice iqr_lprice
```

Variable	Obs	Mean	Std. Dev.	Min	Max
lprice	74	8.640633	.3921059	8.098947	9.674452

max_lprice	69	9.456724	.2643769	8.503905	9.674452
iqr_lprice	69	.4019202	.0425909	.1622562	.4187889

The `restore` command brings the `preserved` dataset back into memory. We `sort` by `rep78` and use `merge` to combine the individual automobile data in memory with the summary statistics from `repstats.dta`. Although these computations could have been performed without `collapse`,<sup>15</sup> the convenience of that command should be clear. The ability to set the current dataset aside (without having to explicitly `save` it) and bring it back into memory when needed is a very useful feature.

## 2.7 Getting your data into Stata

This section discusses data input and manipulation issues.<sup>16</sup> Source data may be downloaded from a web site, acquired in spreadsheet format, or may be made available in the format of some other statistical package. The two subsections deal with those variations.

### 2.7.1 Inputting data from ASCII text files and spreadsheets

Before carrying out statistical analysis with Stata, many researchers must face a number of thorny issues in converting their foreign data into Stata-usable form. These range from the mundane (e.g., a text-file dataset may have coded missing values as 99) to the challenging (e.g., a text-file dataset may be in a *hierarchical* format, with master records and detail records). Although a brief guide to these issues cannot possibly cover all of the ways in which external data may be organized and transformed for use in Stata, several rules apply:

- You should familiarize yourself with the various Stata commands for data input. Each has its use, and in the spirit of “don’t pound nails with a screwdriver,” data handling is much simpler if you use the correct tool. Reading [U] **Commands to input data** section is well worth the investment of your time.
- When you need to manipulate a text file, use a text editor, not a word processor or spreadsheet.
- It is always useful to get the data into Stata as early in the process as you can, and perform all manipulations via well-documented do-files that may be edited and re-executed if need be (or if a similar dataset is encountered). Given this exhortation, we will not discuss `input` ([D] **input**) nor the Data Editor which allow interactive entry of data, nor various copy and paste strategies involving simultaneous use of a spreadsheet and Stata. Such strategies are not reproducible, and should be avoided.

15. The commands `egen max_lprice = max(lprice), by(rep78)` and `egen iqr_lprice = iqr(lprice), by(rep78)` can be used to generate these new variables in place. See Section 3.4.

16. This section is adapted from Appendix A of Baum (2006a).

- Keeping track of multiple steps of a data input and manipulation process requires good documentation. If you ever need to replicate or audit the data manipulation process, you will regret that documentation did not receive the proper attention.
- Working with anything but a simple rectangular data array will almost always require the use of [D] **append**, [D] **merge** or [D] **reshape**. You should review the discussion of those commands in Chapter 5 and understand their capabilities.

### Handling text files

Text files—often described as ASCII files—are the most common source of raw data in microeconomic research. Text files may have any file extension: they may be labelled **.raw** (as Stata would prefer), **.txt**, **.csv**, or **.asc**. The point is that a text file is just that: *text!* Word processing programs like Microsoft Word are inappropriate tools for working with text files since they have their own native, binary format and generally use features such as proportional spacing which will cause columns to be misaligned. A word processor uses a considerable amount of computing power to translate a text file into its own native format before it can display it on the screen. The inverse of that transformation must be used to create a text file that can be subsequently read by Stata.

Stata does not read binary files other than those in its own **.dta** format.<sup>17</sup> The second rule above thus counsels the use of a *text editor*, rather than a word processor or spreadsheet, when manipulating text files. Every operating system supports a variety of text editors, many of which are freely available. A very useful summary of text editors of interest to Stata users is edited by Nicholas J. Cox and is available as a web page from [R] **ssc** as the package **texteditors**. You will find that a good text editor—one without the memory limitations present in Stata’s do-file editor or the built-in routines in some operating systems—is much faster than a word processor when scrolling through a large data file. Many text editors colorize Stata commands, making them very useful for Stata program development. Text editors are also extremely useful when working with large microeconomic survey datasets that are accompanied with machine-readable codebooks, often many megabytes in size. Searching those codebooks for particular keywords with a robust text editor is very efficient.

### Free format vs. fixed format

Text files may be *free format* or *fixed format*. A free format file contains a number of fields per record, separated by *delimiters*: characters which are not to be found within the fields. A purely numeric file (or one with simple string variables such as U.S. state codes) may be *space delimited*: that is, successive fields in the record are separated by one or more space characters:

```
AK 12.34 0.09 262000
```

17. Exceptions to that rule: the **fdause** command ([R] **fdause**) can read a SAS Transport (**.xpt**) file, and the [TS] **haver** command can read Haver Analytics datasets on the Windows platform.

```
AL 9.02 0.075 378000
AZ 102.4 0.1 545250
```

Note that the columns in the file need not be aligned. These data may be read from a text file (by default with extension `.raw`) with Stata's `infile` command, which must assign names (and if necessary data types) to the variables:

```
. clear
. infile str2 state members prop potential using appA_1
(3 observations read)
. list
```

	state	members	prop	potent-1
1.	AK	12.34	.09	262000
2.	AL	9.02	.075	378000
3.	AZ	102.4	.1	545250

In this case, we must indicate that the first variable is a string variable of maximum length 2 characters (`str2`), or every record will generate an error that `state` cannot be read as a number. We may even have a string variable with contents of varying length in the record:

```
. clear
. infile str2 state members prop potential str20 state_name key using appA_2
(3 observations read)
. list
```

	state	members	prop	potent-1	state_~e	key
1.	AK	12.34	.09	262000	Alaska	1
2.	AL	9.02	.075	378000	Alabama	2
3.	AZ	102.4	.1	545250	Arizona	3

However, this scheme will break down as soon as we hit New Hampshire. The space within the state name will be taken as a delimiter, and Stata will become quite befuddled. If string variables with embedded spaces are to be used in a space-delimited file, they themselves must be delimited (usually with quotation marks in the text file):

```
. clear
. type appA_3.raw
AK 12.34 0.09 262000 Alaska 1
AL 9.02 0.075 378000 Alabama 2
AZ 102.4 0.1 545250 Arizona 3
NH 14.9 0.02 212000 "New Hampshire" 4

. infile str2 state members prop potential str20 state_name key using appA_3
(4 observations read)
. list
```

```
_____
```

	state	members	prop	potent-1	state_name	key
1.	AK	12.34	.09	262000	Alaska	1
2.	AL	9.02	.075	378000	Alabama	2
3.	AZ	102.4	.1	545250	Arizona	3
4.	NH	14.9	.02	212000	New Hampshire	4

So what should you do if your text file is space-delimited and contains string variables with embedded spaces? That is a difficult question, since no mechanical transformation will generally solve this problem. For instance, using a text editor to change multiple spaces to a single space and then each single space to a tab character will not help, since it will then place a tab between New and Hampshire.

If the data are downloadable from a web page that offers formatting choices, you should choose *tab-delimited* rather than *space-delimited* format. The other option, comma delimited text or *comma separated values* (*.csv*) has its own difficulties. Consider field contents (without quotation marks) such as “College Station, TX”, “J. Arthur Jones, Jr.”, “F. Lee Bailey, Esq.”, or “T. Frank Kennedy, S.J.”. If every city name is followed by a comma, no problem, since the city and state can then be read as separate variables: but if some are written without commas (“Brighton MA”), the problem returns. In any case, parsing proper names with embedded commas is problematic. Tab-delimited text avoids most of these problems.

### The `insheet` command

If we are to read tab-delimited text files, the `infile` ([D] `infile`) command no longer is the right tool for the job: we now should employ `insheet` ([D] `insheet`). Two caveats: `insheet`, despite its name, does not read binary spreadsheet files (e.g. files of type `.xls`), and it reads a tab-delimited (or comma-delimited) text file whether or not a spreadsheet program was involved in its creation. For instance, most database programs contain an option to generate a tab-delimited or comma-delimited export file, and many datasets available for web download are in one of these formats.

The `insheet` command is very handy. As long as one observation in your target Stata dataset is contained on a single record with tab or comma delimiters this is the command to use. Stata will automatically try to determine which delimiter is in use (but options `tab` and `comma` are available), or any ASCII character may be specified as a delimiter with the `delimiter(char)` option. For instance, some European database exports use semicolon (;) delimiters, since standard European numeric formats use comma as the decimal separator. If the first line of the `.raw` file contains valid Stata variable names, they will be used. This is very useful because if data are being extracted from a spreadsheet, they will often have that format. To use the sample dataset above, now tab delimited with a header record of variable names:

```
. clear
. insheet using appA_4
```

```
(6 vars, 4 obs)
. list
```

	state	members	prop	potent-1	state_name	key
1.	AK	12.34	.09	262000	Alaska	1
2.	AL	9.02	.075	378000	Alabama	2
3.	AZ	102.4	.1	545250	Arizona	3
4.	NH	14.9	.02	212000	New Hampshire	4

The issue of embedded spaces or commas no longer arises in tab-delimited data, and you can rely on the first line of the file to define the variable names.

It is particularly important to heed any informational or error messages produced by the data input commands. If you know how many observations are present in the text file, check to see that the number Stata reports is correct. Likewise, the **summarize** command should be used to discern whether the number of observations, minimum and maximum for each numeric variable is sensible. Data entry errors can often be detected by noting that a particular variable takes on nonsensical values, usually denoting the omission of one or more fields on that record. Such an omission may also trigger one or more error messages. For instance, leaving out a numeric field on a particular record will move an adjacent string field into that variable. Stata will then complain that it cannot read the string as a number. A distinct advantage of the tab- or comma-delimited formats is that missing values may be coded with two successive delimiters. As discussed in Chapter 5, [R] **assert** can be used to good advantage to ensure that reasonable values appear in the data.

An additional distinction exists between **infile** and **insheet**: the former command may be used with **if exp** and **in range** qualifiers to selectively input data. For instance, with a very large text-file dataset, you could use **in 1/1000** to read only the first 1,000 observations and verify that the input process is working properly. Using **if gender=="M"**, we could read only the male observations; or by using **if runiform() <= 0.15** we could read each observation with probability 0.15. These qualifiers may not be used with **insheet**: but unless the text-file data set is huge and the computer slow, you could always read the entire dataset and apply [R] **keep** or [R] **drop** conditions to mimic the action of **infile**.

### Accessing data stored in spreadsheets

In the third rule above, we counseled that copy-and-paste techniques should not be used to transfer data from another application directly to Stata. Such a technique cannot be reliably replicated. How do you know that the first and last rows or columns of a spreadsheet were selected and copied to the clipboard, without any loss of data or extraneous inclusion of unwanted data? If the data are presently in a spreadsheet, the appropriate portion of that spreadsheet should be copied and pasted (in Excel, *Paste Special* to ensure that only values are stored) into a new blank sheet. If Stata variable

names are to be added, leave the first row blank so that they may be filled in. Save that sheet, and that sheet alone, as *Text Only – Tab delimited* to a new filename. If you use the file extension `.raw` it will simplify reading the file into Stata.

Two caveats regarding dates. Both Excel and Stata work with the notion that calendar dates are successive integers from an arbitrary starting point. In order to read the dates into a Stata date variable, they must be formatted with a four-digit year, preferably in a format with delimiters (e.g., 12/6/2004 or 6-Dec-2004). It is much easier to make these changes in the spreadsheet program before reading the data into Stata. Second, Macintosh OS X users of Excel should note that Excel’s default is the 1904 Date System. If the spreadsheet was produced in Excel for Windows, and the steps above are used to create a new sheet with the desired data, the dates will be off by four years (the difference between Excel for Macintosh and Excel for Windows defaults). Uncheck the preference *Use 1904 Date System* before saving the file as text.

### Fixed format data files

Many text-file datasets are composed of *fixed format* records: those obeying a strict columnar format in which a variable appears in a specific location in each record of the dataset. Such datasets are accompanied by *codebooks*, which define each variable’s name, data type, location in the record and possibly other information such as missing values, value labels, or frequencies for integer variables.<sup>18</sup> We present a fragment of the codebook for the study “National Survey of Hispanic Elderly People, 1988”, available from the Inter-University Consortium for Political and Social Research (ICPSR).<sup>19</sup>

VAR 0001	ICPSR STUDY NUMBER-9289			NO MISSING DATA CODES			
	REF 0001	LOC	1	WIDTH 4	DK	1 COL	3- 6
VAR 0002	ICPSR EDITION NUMBER-2			NO MISSING DATA CODES			
	REF 0002	LOC	5	WIDTH 1	DK	1 COL	7
VAR 0003	ICPSR PART NUMBER-001			NO MISSING DATA CODES			
	REF 0003	LOC	6	WIDTH 3	DK	1 COL	8-10
VAR 0004	ICPSR ID			NO MISSING DATA CODES			
	REF 0004	LOC	9	WIDTH 4	DK	1 COL	11-14
VAR 0005	ORIGINAL ID			NO MISSING DATA CODES			
	REF 0005	LOC	13	WIDTH 4	DK	1 COL	15-18
VAR 0006	PROXY			NO MISSING DATA CODES			
	REF 0006	LOC	17	WIDTH 1	DK	1 COL	19
VAR 0007	TIME BEGUN-HOUR				MD=99		
	REF 0007	LOC	18	WIDTH 2	DK	1 COL	20-21
VAR 0008	TIME BEGUN-MINUTE				MD=99		
	REF 0008	LOC	20	WIDTH 2	DK	1 COL	22-23
VAR 0009	TIME BEGUN-AM/PM				MD=9		

18. Stata itself has the ability to produce a codebook from a Stata dataset via the `[D] codebook` command.

19. Study no. 9289, <http://webapp.icpsr.umich.edu/cocoon/ICPSR-STUDY/09289.xml>

	REF 0009	LOC	22	WIDTH	1	DK	1	COL	24
VAR 0010	AGE					NO MISSING DATA CODES			
	REF 0010	LOC	23	WIDTH	3	DK	1	COL	25-27
VAR 0011	HISPANIC GROUP					NO MISSING DATA CODES			
	REF 0011	LOC	26	WIDTH	1	DK	1	COL	28
VAR 0012	HISPANIC GROUP-OTHER					MD=99			
	REF 0012	LOC	27	WIDTH	2	DK	1	COL	29-30
VAR 0013	MARITAL STATUS					NO MISSING DATA CODES			
	REF 0013	LOC	29	WIDTH	1	DK	1	COL	31

Q.A3. ARE YOU NOW MARRIED, WIDOWED, DIVORCED, SEPARATED, OR  
HAVE YOU NEVER MARRIED?

-----

1083	1.	MARRIED
815	2.	WIDOWED
160	3.	DIVORCED
99	4.	SEPARATED
14	5.	NOT MARRIED, LIVING WITH PARTNER
128	6.	NEVER MARRIED

VAR 0014	MARITAL STATUS-YEARS					MD=97 OR GE	98		
	REF 0014	LOC	30	WIDTH	2	DK	1	COL	32-33
VAR 0015	RESIDENCE TYPE					MD=7			
	REF 0015	LOC	32	WIDTH	1	DK	1	COL	34
VAR 0016	RESIDENCE TYPE-OTHER					MD=GE	99		
	REF 0016	LOC	33	WIDTH	2	DK	1	COL	35-36
VAR 0017	OWN/RENT					MD=7			
	REF 0017	LOC	35	WIDTH	1	DK	1	COL	37
VAR 0018	OWN/RENT-OTHER					MD=99			
	REF 0018	LOC	36	WIDTH	2	DK	1	COL	38-39
VAR 0019	LIVE ALONE					NO MISSING DATA CODES			
	REF 0019	LOC	38	WIDTH	1	DK	1	COL	40
VAR 0020	HOW LONG LIVE ALONE					MD=7 OR GE	8		
	REF 0020	LOC	39	WIDTH	1	DK	1	COL	41
VAR 0021	PREFER LIVE ALONE					MD=7 OR GE	8		
	REF 0021	LOC	40	WIDTH	1	DK	1	COL	42

The codebook specifies the column in which each variable starts (LOC) and the number of columns it spans (WIDTH).<sup>20</sup> In this fragment of the codebook, only integer numeric variables appear. The missing data codes (MD) for each variable are also specified. The listing above provides the full codebook detail for variable 13, marital status, quoting the question posed by the interviewer, coding of the six possible responses and

20. The COL field should not be considered.

the frequency counts of each response.

One of the important notions about fixed format data file is that fields need not be separated: as we see above, where the single-column fields of variables 0019, 0020 and 0021 are stored as three successive integers. Stata must be instructed to interpret each of those digits as a separate variable. This is done with a *data dictionary*: a separate Stata file, with file extension `.dct`, specifying the necessary information to read a fixed format data file. The information in the codebook may be translated, line for line, into the Stata data dictionary. The Stata data dictionary need not be comprehensive. You might not want to read certain variables from the raw data file, so you would merely ignore those columns. This might be particularly important when working with Stata/IC and its limit of 2,047 variables. Many survey datasets contain many more than 2,000 variables. By judiciously specifying only the subset of variables that are of interest in your research, you may read such a text file using Stata/IC.

Stata supports two different formats of data dictionaries. The simpler format, used by `infix` ([D] `infix`), only requires that the starting and ending columns of each variable are given along with any needed data type information. To illustrate, we specify the information needed to read a subset of fields in this codebook into Stata variables, using the description of the data dictionary in `infix`:

```
. clear
. infix using 09289-infix
infix dictionary using 09289-0001-Data.raw {
* dictionary to read extract of ICPSR study 9289
  int v1      1-4
  int v2      5
  int v3      6-8
  int v4      9-12
  int v5      13-16
  int v6      17
  int v7      18-19
  int v8      20-21
  int v9      22
  int v10     23-25
  int v11     26
  int v12     27-28
  int v13     29
  int v14     30-31
  int v15     32
  int v16     33-34
  int v17     35
  int v18     36-37
  int v19     38
  int v20     39
  int v21     40
}
(2299 observations read)
```

Alternatively, we could set up a dictionary file for the fixed format version of `infile` ([D] `infile`). This is the more powerful option, as it allows us to attach variable labels and specify value labels. However, rather than specifying the column range of each field

that you want to read, you must indicate where it starts and its field width, given as the `%infmt` for that variable. With a codebook like that displayed above, we have the field widths available. We could also calculate the field widths from the starting and ending column numbers. We must not only specify which are string variables, but must give their data storage type. The storage type could differ from the `%infmt` for that variable. You might read a six-character code into a ten-character field knowing that other data use the latter width for that variable.

```
. clear
. infile using 09289-0001-Data
infile dictionary using 09289-0001-Data.raw {
_line(1)
_line(1)
_column(1)    int    V1                %4f    "ICPSR STUDY NUMBER-9289"
_column(5)    int    V2                :V2    %1f    "ICPSR EDITION NUMBER-2"
_column(6)    int    V3                %3f    "ICPSR PART NUMBER-001"
_column(9)    int    V4                %4f    "ICPSR ID"
_column(13)   int    V5                %4f    "ORIGINAL ID"
_column(17)   int    V6                :V6    %1f    "PROXY"
_column(18)   int    V7                :V7    %2f    "TIME BEGUN-HOUR"
_column(20)   int    V8                :V8    %2f    "TIME BEGUN-MINUTE"
_column(22)   int    V9                :V9    %1f    "TIME BEGUN-AM-PM"
_column(23)   int    V10               :V10   %3f    "AGE"
_column(26)   int    V11               :V11   %1f    "HISPANIC GROUP"
_column(27)   int    V12               :V12   %2f    "HISPANIC GROUP-OTHER"
_column(29)   int    V13               :V13   %1f    "MARITAL STATUS"
_column(30)   int    V14               :V14   %2f    "MARITAL STATUS-YEARS"
_column(32)   int    V15               :V15   %1f    "RESIDENCE TYPE"
_column(33)   int    V16               :V16   %2f    "RESIDENCE TYPE-OTHER"
_column(35)   int    V17               :V17   %1f    "OWN-RENT"
_column(36)   int    V18               :V18   %2f    "OWN-RENT-OTHER"
_column(38)   int    V19               :V19   %1f    "LIVE ALONE"
_column(39)   int    V20               :V20   %1f    "HOW LONG LIVE ALONE"
_column(40)   int    V21               :V21   %1f    "PREFER LIVE ALONE"
}
(2299 observations read)
```

The `_column()` directives in this dictionary are used where dictionary fields are not adjacent. Indeed, you could skip back and forth along the input record since the columns read need not be in ascending order. But then we could achieve the same thing with the `[R] order` command after data input. We are able to define variable labels using `infile`. In both of the examples above, the dictionary file specifies the name of the data file, which need not be the same as that of the dictionary file. For instance, `highway.dct` could read `highway.raw`, and if that were the case, the latter filename need not be specified. But we might want to employ the same dictionary to read more than one `.raw` file. To do so, leave the filename out of the dictionary file, and use the `using` option to specify the name of the `.raw` file. After loading the data, we may `describe` its contents:

```
. describe
Contains data
obs:          2,299
```

```
vars:          21
size:        105,754 (99.9% of memory free)
```

---

variable name	storage type	display format	value label	variable label
V1	int	%8.0g		ICPSR STUDY NUMBER-9289
V2	int	%8.0g	V2	ICPSR EDITION NUMBER-2
V3	int	%8.0g		ICPSR PART NUMBER-001
V4	int	%8.0g		ICPSR ID
V5	int	%8.0g		ORIGINAL ID
V6	int	%8.0g	V6	PROXY
V7	int	%8.0g	V7	TIME BEGUN-HOUR
V8	int	%8.0g	V8	TIME BEGUN-MINUTE
V9	int	%8.0g	V9	TIME BEGUN-AM-PM
V10	int	%8.0g	V10	AGE
V11	int	%8.0g	V11	HISPANIC GROUP
V12	int	%8.0g	V12	HISPANIC GROUP-OTHER
V13	int	%8.0g	V13	MARITAL STATUS
V14	int	%8.0g	V14	MARITAL STATUS-YEARS
V15	int	%8.0g	V15	RESIDENCE TYPE
V16	int	%8.0g	V16	RESIDENCE TYPE-OTHER
V17	int	%8.0g	V17	OWN-RENT
V18	int	%8.0g	V18	OWN-RENT-OTHER
V19	int	%8.0g	V19	LIVE ALONE
V20	int	%8.0g	V20	HOW LONG LIVE ALONE
V21	int	%8.0g	V21	PREFER LIVE ALONE

---

Sorted by:

Note: dataset has changed since last saved

The dictionary indicates that value labels are associated with the variables, but does not define those labels. Commands such as

```
label define V13      1 "MARRIED" 2 "WIDOWED" 3 "DIVORCED" 4 "SEPARATED" ///
                    5 "NOT MAR COHABITG" 6 "NEVER MARRIED"
```

must be given to create those labels.

One other advantage of the more elaborate `infile` data dictionary format should be noted. Many large survey datasets contain a number of variables that are real or floating-point values, such as a wage rate in dollars and cents or a percentage interest rate such as 6.125%. To save space, the decimal points are excluded from the text file and the codebook indicates how many decimal digits are included in the field. You could read these data as integer values and perform the appropriate division in Stata, but a simpler solution would be to build this information into the data dictionary. By specifying that a variable has an `infmt` of, for example, `%6.2f`, a value such as 123456 may be read properly as daily sales of \$1,234.56.

Stata's data dictionary syntax can handle many more complicated text datasets, including those with multiple records per observation, or those with header records that are to be ignored. See [D] `infile (fixed format)` for full details.

## 2.7.2 Importing data from other package formats

The previous section discussed how foreign data files could be brought into Stata. In many cases, the foreign data are already in the format of some other statistical package or application. For instance, a number of economic and financial data providers make SAS-formatted datasets readily available, while socio-economic datasets are often provided in SPSS format. The most straightforward and inexpensive way to deal with these package formats involves a third-party application: Stat/Transfer, a product of Circle Systems, Inc. It is not the only third-party application to provide such functionality: DBMS/Copy is often mentioned in this context. However, Stat/Transfer has the advantage of a co-marketing relationship with StataCorp, and a copy of Stat/Transfer may be acquired at an advantageous price with your Stata order.

The alternative to Stat/Transfer usually involves owning (or having access to) a working copy of the other statistical package, and having enough familiarity with the syntax of that package to understand how a dataset may be exported from its own proprietary format to ASCII format.<sup>21</sup> Even for those researchers who have that familiarity and copies of another package, this is a rather cumbersome solution, since (like Stata) packages such as SAS and SPSS have their own conventions for missing data formats, value labels, data types, and the like. Although the raw data may be readily exported to ASCII format, these attributes of the data will have to be recreated in Stata. For a large survey dataset with many hundred (or several thousand!) variables, that is unpalatable. A transformation utility like Stat/Transfer performs all of those housekeeping chores, ensuring that any attributes attached to the data (extended missing value codes, value labels, etc.) are placed in the Stata-format file. Of course, the mapping between packages is not always one-to-one. In Stata, a value label stands alone and may be attached to any variable or set of variables, whereas in other packages it is generally an attribute of a variable and must be duplicated for similar variables.

A very important distinction between Stata on the one hand and SAS and SPSS on the other is Stata's flexible set of data types. Stata, like the C language in which its core code is written, offers five numeric data types ([R] **data types**): integer types `byte`, `int`, `long` and floating-point types `float`, `double`, in addition to string types `str1-str244`. Most other packages do not have this broad array of data types, and resort to storing all numeric data in a single data type: e.g., "Raw data come in many different forms, but SAS simplifies this. In SAS there are just two data types: numeric and character." (Delwiche and Slaughter (1998), p. 4). This simplicity bears a sizable cost, since an indicator variable only requires a single byte of storage, whereas a double-precision floating-point variable requires eight bytes to hold up to 15 decimal digits of accuracy. Stata allows the user to specify the data type based on the contents of each variable, which can result in considerable savings in terms of both disk space and execution time when reading or writing those variables to disk. Stat/Transfer can be instructed to optimize a target Stata-format file in the transfer process, or you may use Stata's [R] **compress** statement to automatically perform that optimization. In any

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21. If SAS datasets are available in the SAS Transport (.xpt) format, they may be read by Stata's `fdause` command.

case, you should always take advantage of this optimization, since it will reduce the size of files and require less of your computer's memory to work with them.

A very useful feature of Stat/Transfer is the ability to generate a subset of a large file while transferring it from SAS or SPSS format. We spoke above of the possibility of reading only certain variables from a text file to avoid Stata/IC's limitation of 2,047 variables. You can always Stat/Transfer a sizable survey data file from SAS to Stata format, but if there are more than 2,047 variables in the file, the target file must be specified as a Stata/SE file. If you do not have access to Stata/SE, that will be problematic. The solution: use Stat/Transfer's ability to read a list of variables that you would like to keep (or a list of variables to drop), which will generate a subset file on the fly. Since Stat/Transfer can generate a machine-readable list of variable names, that list may be edited to produce the keep-list or drop-list.

Although we have spoken of SAS and SPSS, Stat/Transfer is capable of exchanging datasets with a wide variety of additional packages, including GAUSS, Excel, MATLAB, and others; see <http://stattransfer.com> for details. Versions of Stat/Transfer for Windows, Mac OS X and Linux/Unix are available.

We must also mention an alternative solution for data transfer between databases supporting some flavor of SQL, Structured Query Language. Stata can perform ODBC (Open Data Base Connectivity) operations with databases accessible via that protocol ([D] `odbc` for details). Since most SQL databases as well as non-SQL data structures such as Excel and Microsoft Access support ODBC, this is often suggested as a workable solution to dealing with foreign data. It does require that the computer system on which you are running Stata is equipped with ODBC drivers. These are installed by default on Windows systems with Microsoft Office, but may require the purchase of a third-party product for Mac OS X or Linux systems. If the necessary database connectivity is available, Stata's `odbc` is a full-featured solution. It allows for both the query of external databases and the insertion or update of records in those databases.

## 2.8 Guidelines for Stata do-file programming style

As you move away from interactive use of Stata and make greater use of do-files and ado-files in your research, the style of the contents of those files becomes more important. One of the reasons for using do-files is the audit trail that they provide. Are your do-files readable and comprehensible—not only today, but after several months? To highlight the importance of good programming style practices, we present here an edited excerpt from Nicholas J. Cox's excellent essay on "Suggestions on Stata programming style"<sup>22</sup> (Cox 2005f). The remainder of this section is quoted from that essay.

Programming in Stata, like programming in any other computer language, is partly a matter of syntax, as Stata has rules that must be obeyed. It is also partly a matter of style. Good style includes, but is not limited to, writing programs that are, above all else, clear. They are clear to the programmer, who may revisit them repeatedly,

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22. I am grateful to Nick Cox for permission to reproduce his excellent suggestions.

and they are clear to other programmers, who may wish to understand them, to debug them, to extend them, to speed them up, to imitate them, or to borrow from them.

People who program a great deal know this: setting rules for yourself and then obeying them ultimately yields better programs and saves time. They also know that programmers may differ in style and even argue passionately about many matters of style, both large and small. In this morass of varying standards and tastes, I suggest one overriding rule: Set and obey programming style rules for yourself. Moreover, obey each of the rules I suggest unless you can make a case that your own rule is as good or better.

Enough pious generalities: The devil in programming is in the details. Many of these details reflect longstanding and general advice (e.g., Kernighan and Plauger 1978).

### 2.8.1 Basic guidelines for do-file writers

1. Use natural names for logical constants or variables. Thus `local OK` should be 1 if true and 0 if false, permitting idioms such as `if 'OK'`. (But beware such logicals' taking on missing values.)
2. Type expressions so they are readable. Some possible rules are as follows:
  - a. Put spaces around each binary operator except `^` (`gen z = x + y` is clear, but `x ^ 2` looks odder than `x^2`).
  - b. `*` and `/` allow different choices. `num / den` is arguably clearer than `num/den`, but readers might well prefer `2/3` to `2 / 3`. Overall readability is paramount; compare, for example,
 

```
hours + minutes / 60 + seconds / 3600
```

 with
 

```
hours + minutes/60 + seconds/3600
```
  - c. Put a space after each comma in a function, etc.
  - d. Use parentheses for readability.

Note, however, that such a spaced-out style may make it difficult to fit expressions on one line, another desideratum.

3. Adopt a consistent style for flow control. Stata has `if`, `while`, `foreach`, and `forvalues` structures that resemble those in many mainstream programming languages. Programmers in those languages often argue passionately about the best layout. Choose one such layout for yourself. Here is one set of rules:
  - a. Tab lines consistently after `if` or `else` or `while` or `foreach` or `forvalues` (the StataCorp convention is that a tab is 8 spaces and is greatly preferable if Stata is to show your programs properly).
  - b. Put a space before braces.
  - c. Align the `i` of `if` and the `e` of `else`, and align closing braces `}` with the `i`, or the `e`, or the `w` of `while`, or the `f` of `foreach` or `forvalues`:

```

if ... {
    ...
}
else {
    ...
}
while ... {
    ...
}
foreach ... {
    ...
}

```

In Stata 8 and later, putting the opening and closing braces on lines above and below the body of each construct is compulsory (with the exceptions that the whole of an `if` construct or the whole of an `else` construct may legally be placed on one line). For earlier releases, it is strongly advised.

4. Write within 80 columns (72 are even better). The awkwardness of viewing (and understanding) long lines outweighs the awkwardness of splitting commands into two or more physical lines.
5. Use `#delimit ;` sparingly (Stata is not C). To deal with long lines, use `///` and continue on the next line of your do-file. You may use the triple-slash continuation on any number of consecutive lines of text.
6. Use blank lines to separate distinct blocks of code.
7. Consider putting `quietly` on a block of statements rather than on each or many of them. An alternative in some cases is to use `capture`, which eats what output there might have been and any errors that might occur, which is sometimes the ideal combination.
8. You can express logical negation by either `!` or `~`. Choose one and stick with it. StataCorp has changed recently from preferring `~` to preferring `!`.
9. Define constants to machine precision. Thus use `_pi` or `c(pi)` rather than some approximation, such as 3.14159, or use `-digamma(1)` for the Euler–Mascheroni constant  $\gamma$  rather than 0.57721. Cruder approximations may give results adequate for your purposes, but that does not mean that you should eschew wired-in features.
10. Avoid “magic numbers”. Use a macro or a scalar to hold a number whose meaning is obvious only to the programmer, and add a comment indicating what that number represents.

## 2.8.2 Enhancing speed and efficiency

Here is a list of basic ways to increase speed and efficiency of your code:

1. Test for fatal conditions as early as possible. Do no unnecessary work before checking that a vital condition has been satisfied.
2. Use `summarize`, `meanonly` for speed when its returned results are sufficient (see Cox 2007e). Also consider whether a `quietly count` fits the purpose better.
3. `foreach` and `forvalues` are cleaner and faster than most `while` loops.
4. Try to avoid looping over observations, which is very slow. Fortunately, it can usually be avoided.
5. Avoid using a variable to hold a constant. A macro or a scalar is usually all that is needed. One clear exception is that some graphical effects depend on a variable being used to store a constant.

## 2.9 How to seek help for Stata programming

Programming in any language can be a frustrating experience. In this section, I discuss a number of resources that you may find helpful in solving a programming problem, whether it arises as you scratch your head wondering “how can I get Stata to do that?” or after you have coded a trial solution. A do-file or ado-file program can be syntactically correct but not produce the desired results, or correct answers, and that is the more insidious problem: a program that works properly most of the time, but may fail under special conditions.

As obvious as it may seem, the most useful resources for Stata programmers are the on-line help and excellent printed documentation. The on-line help contains a great deal of the information in the manuals, but there is no substitute for the manuals in many cases. You should ensure that you have ready access to the latest version of Stata’s manuals. That said, recall that many of Stata’s commands are enhanced, corrected or even introduced between major versions of Stata, and the only documentation for new features or new commands appears in the on-line help. The `findit` ([R] `search`) command is often most useful, as it looks for the specified keyword(s) in the on-line help, FAQs on the Stata website, *Stata Technical Bulletin* and *Stata Journal* articles and the SSC Archive.<sup>23</sup> A judicious choice of keywords for `findit` will often prove very helpful.

What other resources are available? If you believe that Stata is actually not producing the results it should according to the documentation for a command, you can contact Stata technical support, following the guidelines at <http://www.stata.com/support/tech-support>. Like any large, complex software system, Stata has bugs. Thankfully, most bugs in official Stata are short-lived. Stata’s `update` ([R] `update`) capability makes it possible for Stata’s developers to provide corrected code within a few days of a bug’s diagnosis—but only if you keep your official Stata up to date! Before producing a trouble report for tech support, ensure that your Stata executable and ado-files are fully up to date by

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23. The `search` ([R] `search`) command places output in the Results window and scans all of these sources except the SSC Archive and other user sites. `search...`, `all`, a synonym for `findit`, will access all of the sites mentioned.

using `update query`. Even if you are using an older version of Stata, you may not have the last release of that older version installed. Many reported bugs have already been corrected in the latest downloadable routines.

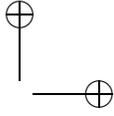
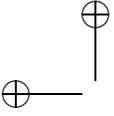
This caveat also applies, even more emphatically, to the user-written Stata routines that you may have downloaded from the *Stata Journal*, SSC Archive or individual users' websites. Although a good deal of user-written code may rival official Stata code in terms of reliability, it stands to reason that user-programmers (such as myself) are not as uniformly competent and careful as professional software developers. Thankfully, the `adoupdate` ([R] `adoupdate`) command allows you to check whether user-written code on your machine is up to date. Most user-programmers reliably respond to any reports of bugs in their code and post corrected versions on the SSC Archive or their own websites. Before reporting a bug in a user-written routine, ensure that you have the latest version.

Many users' programming problems are solved expeditiously by a posting on Statalist. Participants in this active discussion list can often suggest a solution to a well-posed programming problem, or assist in the diagnosis of your `do`-file or `ado`-file. To post to Statalist, you must be a member of the list, and to get helpful comments you should read and heed the Statalist FAQ (<http://www.stata.com/support/statalist/faq>). A posting that states "The `xyz` command doesn't work" will not attract much attention. If you want Statalisters to help, you should pose your problem in well-defined terms that allow list participants to understand what you are doing (or not doing) and what you are trying to do. You should not send attachments nor excessively lengthy output to Statalist, and should post in ASCII text mail format. Attachments, lengthy messages and non-ASCII messages may be discarded by the managing software. A number of other important admonitions appear in the Statalist FAQ. In summary, Statalisters can be very helpful in helping you solve your problems if you explain them clearly. This caveat also applies to another source of support: local "gurus", either colleagues or research support staff in your institution.

Last, I must mention Stata's own capabilities to diagnose your problem with a program you have written. Most of official Stata and user-written Stata routines are written in the interpreted *ado-file language*. When you give a Stata command, only the standard results or error messages usually appear. How can you track down an error in a `do`-file containing a loop construct (such as `forvalues` or `foreach`), or in an `ado`-file? By using `set trace on` ([P] `trace`). This command will instruct Stata to echo both the lines of code that it executes as well as their results (for instance, any substitutions of names or values into a command). By examining the results, which should be directed to a logfile, you may often determine where and why an error occurs. Coupled with judicious use of the `display` ([P] `display`) statement to print intermediate values, this can often speed the solution of a programming problem.<sup>24</sup>

---

24. You cannot `trace` the execution of a *built-in* Stata command. The `which` ([R] `which`) command will indicate whether a command is built-in or `ado`-file code.



## 3 Do-file programming: functions, macros, scalars and matrices

### 3.1 Introduction

This chapter discusses several elements of *do-file programming*: functions used to generate new variables, macros that store individual results and lists, scalars and matrices. Although functions will be familiar to all users of Stata, macros and scalars are often overlooked by interactive users. As nearly all Stata commands return results in the form of macros and scalars, familiarity with these concepts is very useful.

The first section of the chapter deals with several general details: the *varlist*, *numlist*, *if exp* and *in range* qualifiers, missing data handling and string to numeric conversion (and vice versa). Subsequent sections present functions for **generate** ([D] **generate**), functions for **egen** ([D] **egen**), computation with a *by varlist* :, and introduce macros, scalars and matrices.

#### 3.1.1 What you should learn from this chapter

- Understand the *varlist*, *numlist* and *if* and *in* qualifiers
- Know how to handle missing data and conversion of values to missing and *vice versa*
- Understand string to numeric conversion and *vice versa*
- Be familiar with functions for use with **generate**
- Understand how to recode discrete and continuous variables
- Be familiar with the capabilities of **egen** functions
- Know how to use *by*-groups effectively
- Understand the use of **local** and **global** macros
- Be familiar with extended macro functions and macro list functions
- Understand how to use numeric and string scalars
- Know how to use matrices to retrieve and store results

## 3.2 Some general programming details

In this section, we use the `census2c` dataset of U.S. state-level statistics to illustrate details of do-file programming:

```
. use census2c
(1980 Census data for NE and NC states)
. list, sep(0)
```

	state	region	pop	popurb	medage	marr	divr
1.	Connecticut	NE	3107.6	2449.8	32.00	26.0	13.5
2.	Illinois	N Cntrl	11426.5	9518.0	29.90	109.8	51.0
3.	Indiana	N Cntrl	5490.2	3525.3	29.20	57.9	40.0
4.	Iowa	N Cntrl	2913.8	1708.2	30.00	27.5	11.9
5.	Kansas	N Cntrl	2363.7	1575.9	30.10	24.8	13.4
6.	Maine	NE	1124.7	534.1	30.40	12.0	6.2
7.	Massachusetts	NE	5737.0	4808.3	31.20	46.3	17.9
8.	Michigan	N Cntrl	9262.1	6551.6	28.80	86.9	45.0
9.	Minnesota	N Cntrl	4076.0	2725.2	29.20	37.6	15.4
10.	Missouri	N Cntrl	4916.7	3349.6	30.90	54.6	27.6
11.	Nebraska	N Cntrl	1569.8	987.9	29.70	14.2	6.4
12.	New Hampshire	NE	920.6	480.3	30.10	9.3	5.3
13.	New Jersey	NE	7364.8	6557.4	32.20	55.8	27.8
14.	New York	NE	17558.1	14858.1	31.90	144.5	62.0
15.	N. Dakota	N Cntrl	652.7	318.3	28.30	6.1	2.1
16.	Ohio	N Cntrl	10797.6	7918.3	29.90	99.8	58.8
17.	Pennsylvania	NE	11863.9	8220.9	32.10	93.7	34.9
18.	Rhode Island	NE	947.2	824.0	31.80	7.5	3.6
19.	S. Dakota	N Cntrl	690.8	320.8	28.90	8.8	2.8
20.	Vermont	NE	511.5	172.7	29.40	5.2	2.6
21.	Wisconsin	N Cntrl	4705.8	3020.7	29.40	41.1	17.5

The listing of this dataset, `census2c`, is arranged in tabular format, similar to a spreadsheet. The rows of the table are the *observations*, cases or records. The columns are the Stata *variables* or fields. We see that there are 21 rows, each corresponding to one US state in the North East or North Central regions, and seven columns, or *variables*: `state`, `region`, `pop`, `popurb`, `medage`, `marr`, `divr`. The variables `pop` and `popurb` represent each state's 1980 population and urbanized population in thousands. The variable `medage`, median age, is measured in years, while the variables `marr` and `divr` represent the number of marriages and divorces, respectively, in thousands.

The Stata variable names must be distinct and follow certain rules of syntax. For instance, they may not contain embedded spaces, nor hyphens (-), nor characters outside the sets A-Z, a-z, 0-9, \_ . In particular, full stop or period (.) cannot appear within a variable name. Variable names must start with a letter or an underscore. Most importantly, *case matters*: `STATE`, `State` and `state` are three different variables to Stata. The Stata convention, which I urge that you adopt, is to use *lower case* names by default for all variables to avoid confusion, and only use upper case for some special reason. You may always use variable labels to contain additional information.

### 3.2.1 The varlist

Many Stata commands accept a *varlist*: a list of one or more variables to be used. A *varlist* may contain the variable names, or you may use a wild card (\*) such as \*id in the *varlist*. The \* will stand in for an arbitrary set of characters. In the `census2c` dataset `pop*` will refer to `pop` and `popurb`:

```
. summarize pop*
+-----+-----+-----+-----+-----+
| Variable | Obs | Mean | Std. Dev. | Min | Max |
+-----+-----+-----+-----+-----+
| pop      | 21 | 5142.903 | 4675.152 | 511.456 | 17558.07 |
| popurb   | 21 | 3829.776 | 3851.458 | 172.735 | 14858.07 |
+-----+-----+-----+-----+-----+
```

A *varlist* may also contain a hyphenated list, such as `dose1-dose4`. That refers to all variables in the dataset between `dose1` and `dose4`, including those two, *in the order of the dataset*. The dataset order is that provided by `describe` ([D] **describe**), or that shown in the **Variables** window. It may be modified by the `order` ([D] **order**) command.

### 3.2.2 The numlist

Many Stata commands require use of a *numlist*. A list of numeric arguments can be provided in several ways. It may be spelled out explicitly, as `0.5 1.0 1.5`. It may involve a range of values, such as `1/4` or `-3/3`. These lists would include the integers between those limits. You could also specify `10 15 to 30`, which would count from 10 to 30 by 5s, or use a colon to say the same thing as `10 15:30`. You may count by steps, as `1(2)9`, which is a list of the first five odd integers, or `9(-2)1`, that same list in reverse order. Square brackets may be used in place of parentheses.

One thing that generally should not appear in a *numlist* is a comma. A comma in a *numlist* will usually cause a syntax error. Other programming languages' loop constructs often spell out a range with an expression such as `1,10`. In Stata, such an expression will involve a *numlist* of `1/10`. One of the primary uses of the *numlist* is the `forvalues` ([P] **forvalues**) statement, described in Section 7.3 (but note that not all valid *numlists* are acceptable in `forvalues`).

### 3.2.3 if exp and in range qualifiers

Stata commands operate on all of the observations in memory by default. Almost all Stata commands accept *qualifiers*: `if exp` and `in range` clauses that restrict the command to a subset of the observations. If we wanted to apply a transformation to a subset of the dataset, or wanted to `list` ([R] **list**) only certain observations, or `summarize` ([R] **summarize**) only those observations that met some criterion, we would use an `if exp` or an `in range` clause on the command.

In many problems, the desired subset of the data is not defined in terms of obser-

vation numbers (as specified with `in range`) but in terms of some logical condition. In that case, it is more useful to employ the `if exp` qualifier. We could, of course, use `if exp` to express an `in range` condition. But the most common use of `if exp` involves transformation of data or specification of a statistical procedure for a subset of data identified by `if exp` as a logical condition. To illustrate these qualifiers:

```
. list state pop in 1/5
```

	state	pop
1.	Connecticut	3107.6
2.	Illinois	11426.5
3.	Indiana	5490.2
4.	Iowa	2913.8
5.	Kansas	2363.7

```
. list state pop medage if medage >= 32
```

	state	pop	medage
1.	Connecticut	3107.6	32.00
13.	New Jersey	7364.8	32.20
17.	Pennsylvania	11863.9	32.10

### 3.2.4 Missing data handling

Stata possesses 27 numeric missing value codes: the system missing value `.` and 26 others from `.a` through `.z`. They are treated as large positive values, and sort in that order, so that plain `.` is the smallest missing value (see [U] **12.2.1 Missing values**). This allows qualifiers such as `if variable < .` to exclude all possible missing values.<sup>1</sup> To make your code as readable as possible, use the `missing()` function described below.

Stata's standard practice for missing data handling is to omit those observations from any computation. For `generate` ([D] **generate**) or `replace`, missing values are typically propagated so that any function of missing data is missing. In univariate statistical computations (such as [R] **summarize** computing a mean or standard deviation) only non-missing cases are considered. For multivariate statistical commands, Stata generally practices *casewise deletion*: an observation in which any variable is missing is deleted from the computation. The `missing(x1,x2,...,xn)` function ([R] **functions**) returns 1 if any of the arguments is missing, and 0 otherwise: that is, it provides the user with a casewise deletion indicator.

Several Stata commands handle missing data in non-standard ways. The functions

---

1. Pre-version 8 Stata user code often used qualifiers like `if variable != .` to rule out missing values. That is now dangerous practice, since that qualifier will only capture the `.` missing data code. If any of the additional codes are present in the data (for instance, by virtue of having used Stat/Transfer to convert a SPSS or SAS dataset to Stata format) they will only be handled properly when `if variable < .` or `if !missing(variable)` is employed.

`max()` and `min()` and the `egen` ([D] `egen`) row-wise functions (`rowmax()`, `rowmean()`, `rowmin()`, `rowstd()`, `rowtotal()`) all *ignore* missing values (see Section 3.4). For example, `rowmean(x1,x2,x3)` will compute the mean of three, two, or one of the variables, returning missing only if all three variables' values are missing for that observation. The `egen` functions `rownonmiss()` and `rowmiss()` return, respectively, the number of non-missing and missing elements in their *varlists*. Although `correlate` ([R] `correlate`) *varlist* uses casewise deletion to remove any observation containing missing values in any variable of the *varlist* from the computation of the correlation matrix, the alternative command `pwcorr` computes pair-wise correlations using all available data for each pair of variables.

We have discussed missing values in numeric variables, but Stata also provides for missing values in string variables. The empty or null string ("") is taken as missing. There is an important difference to Stata between a string variable containing one or more spaces and a string variable containing no spaces (although they will appear identical to the naked eye). That suggests that you should not include one or more spaces as a possible value of a string variable; take care if you do.

#### Recoding missing values: the `mvdecode` and `mvencode` commands

When importing data from another statistical package, or a spreadsheet or database, differing notions of missing data codes may hinder the proper rendition of the data within Stata. Likewise, if the data are to be used in another program that does not use the `.` notation for missing data codes, there may be a need to use an alternative representation of Stata's missing data. The `mvdecode` and `mvencode` commands (see [D] `mvencode`) may be useful in those circumstances. The `mvdecode` command permits you to recode various numeric values to missing, as would be appropriate when missing data have been represented as `-99`, `-999`, `0.001`, and so on. Stata's full set of 27 numeric missing data codes may be used, so that `-9` may be mapped to `.a`, `-99` to `.b`, etc. The `mvencode` command provides the inverse function, allowing Stata's missing values to be revised to numeric form. Like `mvdecode`, `mvencode` can map each of the 27 numeric missing data codes to a different numeric value.

Many of the thorny details involved with the reliable transfer of missing data values between packages are handled very competently by Stat/Transfer. As this third-party application (remarketed by StataCorp) can also handle the transfer of variable and value labels between major statistical packages and create subsets of files' contents (e.g., only selected variables are translated into the target format) it is well worth the cost for those researchers who frequently import or export datasets.

### 3.2.5 String to numeric conversion and vice versa

Stata has two major kinds of variables: string and numeric. Quite commonly, a variable imported from an external source will be misclassified as string when it should be considered as numeric. For instance, if the first value read by `insheet` ([D] `insheet`) is

NA, that variable will be classified as a string variable. Stata provides several methods for converting string variables to numeric. First, if the variable has merely been misclassified as string, you may apply the brute force approach of the `real()` function: e.g., `generate patid = real(patientid)`. This will create missing values for any observations that cannot be interpreted as numeric.

Second, a more subtle approach is given by the `destring` ([D] **destring**) command, which can transform variables in place (with the `replace` option), and may be used with a *varlist* to apply the same transformation to an entire set of variables with a single command. This is useful if there are a number of variables that may require conversion. However, `destring` should only be used for variables that have genuine numeric content, but happen to have been misclassified as string variables.

Third, if the variable truly has string content and you need a numeric equivalent, you may use the `encode` ([D] **encode**) command. You should not apply `encode` to a string variable that has purely numeric content (for instance, one which has been misclassified as a string variable) because `encode` will attempt to create a value label for each distinct value of the variable. As an example, we create a numeric equivalent of the `state` variable:

```
. encode state, generate(stateid)
. describe state stateid
```

variable name	storage type	display format	value label	variable label
state	str13	%-13s		State
stateid	long	%13.0g	stateid	State

```
. list state stateid in 1/5
```

	state	stateid
1.	Connecticut	Connecticut
2.	Illinois	Illinois
3.	Indiana	Indiana
4.	Iowa	Iowa
5.	Kansas	Kansas

Although `stateid` is numeric, it has automatically been given the value label of the values of `state`. To see the numeric values, use `list` ([R] **list**) with the `noheader` option.

### Numeric to string conversion

We may also need to generate the string equivalent of a numeric variable. In many cases, it is easier to parse the contents of string variables and extract substrings that may have some particular significance. Such transformations can be applied to integer numeric variables by means of integer division and remainders, but are generally more cumbersome and error-prone. It should also be noted that the limits to exact representation of numeric values such as integers with many digits are circumvented by

placing those values in string form. A thorough discussion of these issues is given in Cox (2002c).

We discussed three methods for string-to-numeric conversion. For each method, the inverse function or command is available: the `string()` function, `tostring` and `decode`. The `string()` function is quite useful in allowing a numeric display format ([D] **format**) to be used. This would allow, for instance, the creation of a variable with leading zeros, as are integral in some ID-number schemes. The `tostring` command provides a more comprehensive approach, as it contains various safeguards to prevent the loss of information and may be used with a particular display format. Like `destring`, `tostring` may be applied to a *varlist* to alter an entire set of variables.

A common task is the restoration of leading zeros in a variable that has been transferred from a spreadsheet. For instance, U.S. ZIP (postal) codes and Social Security numbers may start with zero. The `tostring` command is useful here. Say that we have a variable `zip`:

```
. tostring zip, format(%05.0f) generate(zipstring)
```

The variable `zipstring` will contain strings of five-digit numbers with leading zeros included, as specified by the `format` option.

As an example of `decode` use, say that you have the `stateid` numeric variable defined above (with its value label) in your dataset, but do not have the variable in string form. You can create the string variable `statename` using `decode`:

```
. decode stateid, generate(statename)
. list stateid statename in 1/5
```

	stateid	statename
1.	Connecticut	Connecticut
2.	Illinois	Illinois
3.	Indiana	Indiana
4.	Iowa	Iowa
5.	Kansas	Kansas

Note that to use `decode`, the numeric variable to be decoded must have a value label.

### Working with quoted strings

You may be aware that `display "this is a quoted string"` ([P] **display**) will display the contents of that quoted string. What happens, though, if your string itself contains quotation marks? Then you must resort to *compound double quotes*. A command such as

```
. display ' "This is a "quoted" string. '
```

will properly display the string, with the inner quotation marks intact. If ordinary double quotes are used, Stata will produce an error message. Compound double quotes may often be used advantageously when there is any possibility that the contents of string variables might include quotation marks.

### 3.3 Functions for the generate command

The fundamental commands for data transformation are **generate** ([D] **generate**) and **replace**. They function in the same way, but two rules govern their use. **generate** may only be used to create a *new* variable: one whose name is not currently in use. On the other hand, **replace** can only be used to revise the contents of an *existing* variable. Unlike other Stata commands whose names can be abbreviated, **replace** must be spelled out for safety's sake.

We illustrate the use of **generate** by creating a new variable in our dataset that measures the fraction of each state's population living in urban areas in 1980. We need only specify the appropriate formula and Stata will automatically apply that formula to every observation that is specified by the **generate** command, using the rules of algebra. For instance, if the formula would result in a division by zero for a given state, the result for that state would be flagged as missing. We generate the fraction, **urbanized**, and use the **summarize** ([R] **summarize**) command to display its descriptive statistics:

```
. generate urbanized = popurb / pop
. summarize urbanized
```

Variable	Obs	Mean	Std. Dev.	Min	Max
urbanized	21	.6667691	.1500842	.3377319	.8903645

We see that the average state in this part of the US is 66.7% urbanized, with that fraction ranging from 34% to 89%.

If the **urbanized** variable already existed, but we wanted to express it as a percentage rather than a decimal fraction, we must use **replace**:

```
. replace urbanized = 100 * urbanized
(21 real changes made)
. summarize urbanized
```

Variable	Obs	Mean	Std. Dev.	Min	Max
urbanized	21	66.67691	15.00843	33.77319	89.03645

Note that **replace** reports the number of changes it made. In this case, it changed all 21 observations.

The concern for efficiency of a do-file is first a concern for *human* efficiency. You should write the data transformations as a simple, succinct set of commands that may readily be audited and modified. You may find that there are several ways to create the

same variable using `generate` ([D] `generate`) and `replace`. It is usually best to stick with the simplest and clearest form of these statements.

A variety of useful functions are located in Stata's programming functions category (`help programming functions` or [R] `functions`). For instance, a number of `replace` statements might themselves be replaced by a single call to the `inlist()` or `inrange()` functions (see Cox 2006c). The former will allow the specification of a variable and a list of values, and returns 1 for each observation if the variable matches one of the elements of the list, 0 otherwise. The function may be applied to either numeric or string variables. For string variables, up to ten string values may be specified in the list. For example:

```
. generate byte newengland = inlist(state, "Connecticut", "Maine", ///
> "Massachusetts", "New Hampshire", "Rhode Island", "Vermont")
. sort medage
. list state medage pop if newengland, sep(0)
```

	state	medage	pop
6.	Vermont	29.40	511.5
13.	New Hampshire	30.10	920.6
14.	Maine	30.40	1124.7
16.	Massachusetts	31.20	5737.0
17.	Rhode Island	31.80	947.2
19.	Connecticut	32.00	3107.6

The `inrange()` function allows specification of a variable and an interval on the real line and returns 1 or 0 to indicate whether the variable's values fall within the interval (which may be open: i.e., one limit may be  $\pm\infty$ ). For example:

```
. list state medage pop if inrange(pop, 5000, 9999), sep(0)
```

	state	medage	pop
2.	Michigan	28.80	9262.1
4.	Indiana	29.20	5490.2
16.	Massachusetts	31.20	5737.0
21.	New Jersey	32.20	7364.8

A number of data transformations involve the use of *integer division*: that is, truncating the remainder. For instance, four-digit U.S. Standard Industrial Classification (SIC) codes 3211–3299 divided by 100 must all yield 32. This is accomplished with the `int()` function (defined in `help math functions`).<sup>2</sup> A common task involves extracting one or more digits from an integer code; for instance, the third and fourth digits of the codes above can be defined as

```
. generate digit34 = SIC - int( SIC / 100 ) * 100
```

<sup>2</sup> Also see the discussion of `floor()` and `ceil()` functions in Section 3.3.3.

or

```
. generate mod34 = mod(SIC,100)
```

where the second construct makes use of the modulo (`mod()`) function (see Cox (2007c)). The third digit alone could be extracted with

```
. generate digit3 = int((SIC - int(SIC / 100) * 100) / 10)
```

or

```
. generate mod3 = (mod(SIC, 100) - mod(SIC, 10)) / 10
```

or even

```
. generate sub3 = real(substr(string(SIC), 3, 1))
```

using the `string()` function to express `SIC` as a string, the `substr()` function to extract the desired piece of that string and the `real()` function to convert the extracted string into numeric form.

As discussed above in Section 2.4, you should realize the limitations of this method in dealing with very long integers such as U.S. Social Security numbers of nine digits or ID codes of ten or twelve digits. The functions `maxbyte()`, `maxint()` and `maxlong()` are useful here. An excellent discussion of these issues is given in Cox (2002c).

Last, we must mention one exceedingly useful function for `generate` ([D] `generate`): the `sum()` function, which produces cumulative or running sums. That capability is very useful in the context of time-series data, where it may be used to convert a flow or other rate variable into a stock or other amount variable. If we have an initial capital stock value and a net investment series, the `sum()` of investment plus the initial capital stock defines the capital stock at each point in time. Note that this function does not place the single sum of the series into the new variable. If that is what you want, use the `egen` ([D] `egen`) function `total()`.

### 3.3.1 Use of `if exp` with indicator variables

A key element of many empirical research projects is the *indicator variable*: a variable taking on values  $\{0,1\}$  to indicate whether a particular condition is satisfied. These are commonly known as *dummy variables* or *Boolean variables*. Creation of indicator (dummy) variables is best accomplished using a *Boolean condition*: an expression that evaluates to true or false for each observation. The `if exp` qualifier has an important role here as well. Using our dataset, it would be possible to generate indicator variables for small and large states with the following commands. As we note below, we must take care to handle potentially missing values using the `missing()` function.

```
. generate smallpop = 0
. replace smallpop = 1 if pop <= 5000 & !missing(pop)
(13 real changes made)
. generate largepop = 0
```

```
. replace largepop = 1 if pop > 5000 & !missing(pop)
(8 real changes made)
. list state pop smallpop largepop, sep(0)
```

	state	pop	smallpop	largepop
1.	Connecticut	3107.6	1	0
2.	Illinois	11426.5	0	1
3.	Indiana	5490.2	0	1
4.	Iowa	2913.8	1	0
5.	Kansas	2363.7	1	0
6.	Maine	1124.7	1	0
7.	Massachusetts	5737.0	0	1
8.	Michigan	9262.1	0	1
9.	Minnesota	4076.0	1	0
10.	Missouri	4916.7	1	0
11.	N. Dakota	652.7	1	0
12.	Nebraska	1569.8	1	0
13.	New Hampshire	920.6	1	0
14.	New Jersey	7364.8	0	1
15.	New York	17558.1	0	1
16.	Ohio	10797.6	0	1
17.	Pennsylvania	11863.9	0	1
18.	Rhode Island	947.2	1	0
19.	S. Dakota	690.8	1	0
20.	Vermont	511.5	1	0
21.	Wisconsin	4705.8	1	0

This combination of `generate` and `replace` is required to define both the 0 and 1 values. If you merely used `replace smallpop = 1 if pop <= 5000`, the variable `smallpop` would be set to *missing*, not zero, for all observations which did not satisfy the *if* condition. A simpler approach would merely use the Boolean conditions:

```
. generate smallpop = (pop <= 5000)
. generate largepop = (pop > 5000)
```

Although this latter approach is more succinct, it suffers from a potentially serious flaw: if any values of `pop` are missing ([U] **12.2.1 Missing values**), they will be coded as 1 in the variable `largepop` and 0 in the variable `smallpop` as all of Stata's missing value codes are represented as very large positive numbers. The solution requires an *if exp*: `if !missing(pop)` added to the `generate` statements.<sup>3</sup>

```
. generate smallpop = (pop <= 5000) if !missing(pop)
. generate largepop = (pop > 5000) if !missing(pop)
```

If the data may contain missing values, they should always be taken into account using *if exp* qualifiers. Even if the current data do not include missing values, it is good programming practice to allow for them.

3. We could also apply this condition as `if pop < 0`, taking advantage of the fact that all measurable values are less than the system missing value.

The `if exp` in the example above *must* be used as shown: placing the `!missing(pop)` inside the Boolean expression (e.g., `(pop > 5000 & !missing(pop))`) would mistakenly assign a value of 0 to `largepop` for missing values of `pop`. The `if exp` qualifier, on the other hand, will cause any missing values of `pop` to be properly reflected in `largepop`.<sup>4</sup>

### 3.3.2 The `cond()` function

You may often want to code a result variable as *a* if a condition is true and *b* if that condition is false. The `cond(x,a,b)` function provides this capability without requiring an `if exp` qualifier: *x* is the condition to be tested, *a* is the result when true and *b* is the result when false. If you are familiar with the C or perl programming languages, you will recognize the similarity to those languages' ternary conditional operator `x?a:b`.

Suppose that we want to separate states having a ratio of marriages to divorces (the net marriage rate) above and below 2.0. We define `netmarr2x` as taking on values 1 and 2 and attach value labels for ease of use. The variable may then be used in `tabstat` ([R] `tabstat`):

```
. generate netmarr2x = cond(marr/divr > 2.0, 1, 2)
. label define netmarr2xc 1 "marr > 2 divr" 2 "marr <= 2 divr"
. label values netmarr2x netmarr2xc
. tabstat pop medage, by(netmarr2x)
Summary statistics: mean
by categories of: netmarr2x
```

netmarr2x	pop	medage
marr > 2 divr	5792.196	30.38333
marr <= 2 divr	4277.178	30.08889
Total	5142.903	30.25714

We see that states with a high net marriage rate are larger and have slightly older populations.

It is possible to nest the `cond()` function: that is, its second and third arguments may be additional `cond()` functions. However, this syntax can lead to rather unwieldy constructs with many parentheses. For a more positive view, see Kantor and Cox (2005).

---

4. An even simpler approach takes advantage of the mutually exclusive and exhaustive nature of these two indicator variables: `generate largepop = 1 - smallpop`. If missing values are properly handled in defining `smallpop`, the algebraic `generate` statement will propagate them in `largepop`, as any function of missing data produces missing data.

### 3.3.3 Recoding discrete and continuous variables

Stata's `recode` ([D] **recode**) command creates a new variable based on the coding of an existing categorical variable. If data transformations involve a large number of very similar statements, they are not being written efficiently. It is perfectly feasible to write a large number of transformation statements such as

```
replace newcode = 5 if oldcode == 2
replace newcode = 8 if oldcode == 3
replace newcode = 12 if inlist(oldcode, 5, 6, 7)
...
```

It is not a very good idea to perform transformations this way, because the use of copy and paste steps to construct these very similar statements is very likely to lead to typing errors when constructing a sizable number of statements.

Stata's `recode` ([R] **recode**) command usually produces more efficient and readable code.<sup>5</sup> For instance,

```
recode oldcode (2 = 5) (3 = 8) (5/7 = 12), gen(newcode)
```

will perform the above transformation. The equal sign should be taken to indicate assignment: (*oldvalue(s)* → *newvalue*). Unlike the line by line approach above using `replace`, `recode` can be applied to an entire *varlist*. This is handy in many cases where a questionnaire-based dataset contains a number of similar questions with the same coding. Use the `pref()` option to define the variable name stub. Missing data codes may be handled, all non-specified values may be mapped to a single outcome, and value labels for the values of the newly created variables may be defined. In fact, [R] `recode` may work in place, modifying the existing variables rather than creating new ones. As its documentation suggests, that is probably not a good idea in case any further modifications to the mapping arise.

Several `recode` *functions* are also available. The `recode(x, x1, x2, x3, x4, . . . , xn)` function will code a continuous variable into intervals:  $x \leq x_1$ ,  $x_1 < x \leq x_2$ , and so on. The resulting values are set equal to the threshold values. For example:

```
. generate medagebrack = recode(medage, 29, 30, 31, 32, 33)
. tabulate medagebrack
```

medagebrack	Freq.	Percent	Cum.
29	3	14.29	14.29
30	8	38.10	52.38
31	4	19.05	71.43
32	4	19.05	90.48
33	2	9.52	100.00
Total	21	100.00	

5. In some cases, there is an algebraic expression that offers a one-line solution using `generate`.

The `floor()` and `ceil()` functions may also be used to generate an integer variable (see Cox (2003c)). The `floor` function always rounds down (to the floor), while the `ceil()` function always rounds up (to the ceiling). These functions may be used to implement top-coding or bottom-coding of values.

Formally, for a value  $x$ , the `floor( $x$ )` function returns the integer  $n$  such that  $n \leq x < n + 1$ , while `ceil( $x$ )` function returns the integer  $n$  such that  $n - 1 < x \leq n$ . For positive integers, `floor()` discards the decimal part. The function `int()`, on the other hand, returns the integer obtained by truncating  $x$  toward zero, so that `int(-3.14159) = -3`. The `round( $x$ )` function returns the closest integer to  $x$ .<sup>6</sup>

Alternatively, to categorize  $x$  into a group defined by threshold values, the `irecode( $x, x_1, x_2, x_3, x_4, \dots, x_n$ )` function will return the group number (where  $x \leq x_1 \rightarrow 0$ ,  $x_1 < x \leq x_2 \rightarrow 1$  and so on). To illustrate, we create four population size categories and present their descriptive statistics. Given that state populations in our sample ranged from about 0.5 million to 17.5 million in 1980, we split the distribution at 1, 4 and 8 million:

```
. generate size=irecode(pop, 1000, 4000, 8000, 20000)
. label define popsize 0 "<1m" 1 "1-4m" 2 "4-8m" 3 ">8m"
. label values size popsize
. tabstat pop, stat(mean min max) by(size)
```

Summary for variables: pop  
by categories of: size

size	mean	min	max
<1m	744.541	511.456	947.154
1-4m	2215.91	1124.66	3107.576
4-8m	5381.751	4075.97	7364.823
>8m	12181.64	9262.078	17558.07
Total	5142.903	511.456	17558.07

Rather than categorizing a continuous variable using threshold values, we may want to group observations based on *quantiles*: quartiles, quintiles, deciles, or any other percentiles of their empirical distribution. We can readily create groupings of that sort with `xtile` (see [R] `pctile`):

```
. xtile medagequart = medage, nq(4)
. tabstat medage, stat(n mean min max) by(medagequart)
Summary for variables: medage
by categories of: medagequart (4 quantiles of medage)
```

medagequart	N	mean	min	max
1	7	29.02857	28.3	29.4
2	4	29.875	29.7	30
3	5	30.54	30.1	31.2
4	5	32	31.8	32.2

6. The `round()` function also has a two-argument form; see `help functions` for details.

Total	21	30.25714	28.3	32.2
-------	----	----------	------	------

## 3.4 Functions for the `egen` command

While the functions available for use with `generate` ([D] `generate`) or `replace` are limited to those listed in [R] `functions` (or, given subsequent additions, by `help functions`) Stata's `egen` ([D] `egen`) command provides an open-ended list of capabilities. Just as Stata's command set may be extended by placing additional `.ado` and `.sthlp` files on the `adopath`, the functions which may be invoked from `egen` are those defined by `.ado`-files whose names start with `_g`, stored on the `adopath`. A number of those functions are part of official Stata, as documented by [D] `egen` (or, given subsequent additions, by `help egen`). But your copy of Stata may include additional `egen` functions: either those you have written yourself, or those downloaded from the SSC Archive ([R] `ssc`) or from another Stata user's `net from...` site. In this section, we first discuss a number of official Stata's functions, and then present several useful additions developed by the Stata user community.

Although the syntax of an `egen` ([D] `egen`) statement is very similar to that of `generate`, several differences should be noted. As only a subset of `egen` functions allow a `by varlist:` prefix or `by(varlist)` option, the documentation should be consulted to determine whether a particular function is *byable*, in Stata parlance. Similarly, the explicit use of `_n` and `_N`, often useful in `generate` and `replace` commands (see Section 3.5.1) is not compatible with `egen`. As there is no way to specify that a variable created with a non-byable `egen` function should use the logic of `replace`, it may be necessary to use a temporary variable as the `egen` result and a subsequent `replace` to combine those values over `by`-groups.

### Official `egen` functions

If you seek spreadsheet-like functionality in Stata's data transformations, you should become acquainted with the row-wise `egen` ([D] `egen`) functions. Like the equivalent spreadsheet functions, the row-wise functions support the calculation of sums, averages, standard deviations, extrema and counts across a number of Stata variables. Wildcards may be used: e.g., if you have state-level U.S. Census variables `pop1890`, `pop1900`, ..., `pop2000` you may use `egen nrCensus = rowmean(pop*)` to compute the average population of each state over those decennial censuses. As discussed in the treatment of missing values in Section 3.2.4, the row-wise functions operate in the presence of missing values. The mean will be computed for all 50 states, although several were not part of the U.S. in 1890.

The number of non-missing elements in the row-wise `varlist` may be computed with `rownonmiss()`, with `rowmiss()` as the complementary value. Other official row-wise

functions include `rowmax()`, `rowmin()`, `rowtotal()` and `rowstd()` (row standard deviation). The functions `rowfirst()` and `rowlast()` give the first (last) non-missing values in the *varlist*. You may find this useful if the variables refer to sequential items: for instance, wages earned per year over several years, with missing values when unemployed. `rowfirst()` would return the earliest wage observation, and `rowlast()` the most recent.

Official `egen` also provides a number of statistical functions which compute a statistic for specified observations of a variable and place that constant value in each observation of the new variable. Since these functions generally allow the use of `by varlist:`, they may be used to compute statistics for each *by-group* of the data, as discussed in Section 3.5. This facilitates computing statistics for each household for individual-level data or each industry for firm-level data. The `count()`, `mean()`, `min()`, `max()` and `total()`<sup>7,8</sup> functions are especially useful in this context. As an illustration, we `egen` the average population in each of the `size` groups defined above, and express each state's population as a percentage of the average population in that group. Size category 0 includes the smallest states in our sample.

```
. bysort size: egen avgpop = mean(pop)
. generate popratio = 100 * pop / avgpop
. format popratio %7.2f
. list state pop avgpop popratio if size == 0, sep(0)
```

	state	pop	avgpop	popratio
1.	Rhode Island	947.2	744.541	127.21
2.	Vermont	511.5	744.541	68.69
3.	N. Dakota	652.7	744.541	87.67
4.	S. Dakota	690.8	744.541	92.78
5.	New Hampshire	920.6	744.541	123.65

Other functions in this statistical category include `iqr()` (inter-quartile range), `kurt()` (kurtosis), `egen mad()` (median absolute deviation), `mdev()` (mean absolute deviation), `median()`, `mode()`, `pc()` (percent or proportion of total), `pctile()`, `p(n)` (*n*<sup>th</sup> percentile), `rank()`, `sd()` (standard deviation), `skew()` (skewness) and `std()` (*z*-score).

7. Before Stata version 9, the `egen sum()` function performed this task, but was often confused with `generate`'s `sum()` function. Hence it was renamed.

8. An important note regarding `egen`'s `total()` function: it treats missing values as zeros, so that the `total()` of a variable with all missing values is computed as zero rather than missing. You can change this behavior with this function's `missing` option.

**egen functions from the user community**

The most comprehensive collection of additional `egen` ([D] `egen`) functions is contained in Nicholas J. Cox's `egenmore` package, available with the `ssc` ([R] `ssc`) command.<sup>9</sup> The `egenmore` package is a collection of many varied routines by Cox and others (including the author). Some of these routines extend the functionality of official `egen` routines, while others provide capabilities lacking in official Stata. Although some of the routines require Stata version 8.2 or better, many will work with older versions of Stata.<sup>10</sup>

Several `egenmore` functions work with standard Stata dates, expressed in numeric form as discussed in Section 2.4.2. The `egen bom()` and `eom()` functions create date variables corresponding to the first day or last day of a given calendar month. They can be used to generate the offset for any number of months (e.g., the last day of the third month hence). With the `work` option, the first (last) non-weekend day of the month can be specified (although there is no support for holidays). Companion functions `bomd()` and `eomd()` provide similar functionality using date variables: that is, they may be used to find the first (last) day of a month in which their date-variable argument falls. This is useful if you wish to aggregate observations by the calendar month in which they occurred.

A number of `egenmore` functions extend `egen`'s statistical capabilities. The `corr()` function computes correlations (optionally covariances) between two variables, `gmean()` and `hmean()` compute geometric and harmonic means, `rndint()` computes random integers from a specified uniform distribution, `semean()` computes the standard error of the mean and `var()` the variance. The `filter()` function generalizes `egen`'s `ma()` function, which can only produce two-sided moving averages of an odd number of terms. In contrast, `filter()` can apply any linear filter to data which have been declared as time series data by `tsset` ([TS] `tsset`), including panel data, for which the filter is applied separately to each panel.<sup>11</sup> The companion function `ewma()` may be used to apply an exponentially-weighted moving average to time series data.<sup>12</sup>

A function that has proved useful in data management is the `record()` function, meant to evoke "setting a record." We may want to compute the highest wage earned to date by each employee, or the lowest stock price encountered to date. That value can be considered the record value, and may be computed with this function. If our data contain annual wage rates for a number of employees over several years,

```
. egen hiwage = record(wage), by(empid) order(year)
```

will compute for each employee (as specified with `by(empid)`) the highest wage earned

---

9. The package is labelled `egenmore` as it further extends `egenodd`, which appeared in the *Stata Technical Bulletin* (Cox (1999), Cox (2000)). Most of the `egenodd` functions now appear in official Stata, so they will not be further discussed here. I am grateful to Nicholas J. Cox for his thorough documentation of `egenmore` functionality in `help egenmore`.

10. Some of the `egenmore` routines provide limited date-and-time functionality for pre-Stata 10 users. As discussed in Section 2.4.2, Stata now offers extensive support for timestamp variables, offering up to millisecond precision.

11. Similar functionality is available from `tssmooth ma` ([TS] `tssmooth ma`).

12. Also see `tssmooth exponential` ([TS] `tssmooth exponential`).

to date, allowing ready evaluation of conditions under which wages have fallen due to a job change, et cetera. A number of other **egen** functions are available in **egenmore**, and a variety of other useful user-written functions are available in the SSC Archive.

In summary, a number of common data management tasks can be expeditiously handled by **egen** functions. The open-ended nature of this command implies that new functions often become available, either through ado-file updates to official Stata or through contributions from the user community. The latter will generally be advertised on Statalist, with past messages accessible in the Statalist archives, and recent contributions are highlighted in **ssc whatsnew**.

## 3.5 Computation for by-groups

One of Stata's most useful features is the ability to transform variables or compute statistics over **by-groups**. **by-groups** are defined with the **by varlist:** prefix, and are often useful in data transformations using **generate** ([R] **generate**), **replace** and **egen** ([D] **egen**). Using **by varlist:** with one or more categorical variables, a command will be repeated automatically for each value of the **by varlist:.** However, it also has its limitations: **by varlist:** can only execute a single command.<sup>13</sup>

### 3.5.1 Observation numbering: `_n` and `_N`

The observations in the dataset are numbered 1, 2, ..., 21 in the list above. When you refer to an observation, you may do so with its observation number. The highest observation number, corresponding to the total number of observations, is known as `_N`, while the current observation number is known as `_n`. Under some circumstances, the meanings of these two symbols will be altered. The observation numbers will change if a **sort** ([R] **sort**) command alters the order of the dataset in memory.

Under the control of a **by-group**, the meanings of `_n` and `_N` are altered. Those markers usually refer to the current observation and last defined observation in the dataset, respectively. Within a **by-group**, `_n` is the current observation of the group and `_N` is the last observation of the group. In this example, we **gsort** ([R] **gsort**) the state-level data by region and descending order of population. We then use **generate**'s running **sum()** function, **by region:**, to display the total population in each region that lives in the largest, two largest, three largest ... states:

```
. gsort region -pop
. by region: generate totpop = sum(pop)
. list region state pop totpop, sepby(region)
```

	region	state	pop	totpop
1.	NE	New York	17558.1	17558.07
2.	NE	Pennsylvania	11863.9	29421.97

13. Also see Section 7.2.1.

3.	NE	New Jersey	7364.8	36786.79
4.	NE	Massachusetts	5737.0	42523.83
5.	NE	Connecticut	3107.6	45631.4
6.	NE	Maine	1124.7	46756.06
7.	NE	Rhode Island	947.2	47703.22
8.	NE	New Hampshire	920.6	48623.83
9.	NE	Vermont	511.5	49135.28
<hr/>				
10.	N Cntrl	Illinois	11426.5	11426.52
11.	N Cntrl	Ohio	10797.6	22224.15
12.	N Cntrl	Michigan	9262.1	31486.23
13.	N Cntrl	Indiana	5490.2	36976.45
14.	N Cntrl	Missouri	4916.7	41893.14
15.	N Cntrl	Wisconsin	4705.8	46598.9
16.	N Cntrl	Minnesota	4076.0	50674.87
17.	N Cntrl	Iowa	2913.8	53588.68
18.	N Cntrl	Kansas	2363.7	55952.36
19.	N Cntrl	Nebraska	1569.8	57522.18
20.	N Cntrl	S. Dakota	690.8	58212.95
21.	N Cntrl	N. Dakota	652.7	58865.67

We may use `_n` and `_N` in this context. They will be equal for the last observation of each by-group:

```
. by region: list region totpop if _n == _N
```

```
-> region = NE
```

	region	totpop
9.	NE	49135.28

```
-> region = N Cntrl
```

	region	totpop
12.	N Cntrl	58865.67

The computation of total population by region, stored as a new variable, could also have been performed with `egen`'s `total()` function. We could calculate mean population (or any other statistic) over a `by varlist:` with more than one variable:

```
. bysort region popsize: egen meanpop2 = mean(pop)
. list region popsize state pop meanpop2
```

	region	popsize	state	pop	meanpop2
1.	NE	<= 5 million	Rhode Island	947.2	1322.291
2.	NE	<= 5 million	Vermont	511.5	1322.291
3.	NE	<= 5 million	Connecticut	3107.6	1322.291
4.	NE	<= 5 million	Maine	1124.7	1322.291

5.	NE	<= 5 million	New Hampshire	920.6	1322.291
6.	NE	> 5 million	Massachusetts	5737.0	10630.96
7.	NE	> 5 million	Pennsylvania	11863.9	10630.96
8.	NE	> 5 million	New York	17558.1	10630.96
9.	NE	> 5 million	New Jersey	7364.8	10630.96
10.	N Cntrl	<= 5 million	Nebraska	1569.8	2736.153
11.	N Cntrl	<= 5 million	Missouri	4916.7	2736.153
12.	N Cntrl	<= 5 million	S. Dakota	690.8	2736.153
13.	N Cntrl	<= 5 million	Kansas	2363.7	2736.153
14.	N Cntrl	<= 5 million	Minnesota	4076.0	2736.153
15.	N Cntrl	<= 5 million	N. Dakota	652.7	2736.153
16.	N Cntrl	<= 5 million	Iowa	2913.8	2736.153
17.	N Cntrl	<= 5 million	Wisconsin	4705.8	2736.153
18.	N Cntrl	> 5 million	Illinois	11426.5	9244.112
19.	N Cntrl	> 5 million	Ohio	10797.6	9244.112
20.	N Cntrl	> 5 million	Michigan	9262.1	9244.112
21.	N Cntrl	> 5 million	Indiana	5490.2	9244.112

We may now compare each state's population with the average population of states of its size class (large or small) in its region.

Although `egen`'s statistical functions can be very handy, creating variables with constant values or constant values over `by`-groups in a large dataset will consume a great deal of Stata's available memory. If the constant values are only needed for a subsequent transformation such as computing each state population's deviation from average size, and will not be used in later analyses, you should `drop` (`[D]` `drop`) those variables at the earliest opportunity. Alternatively, consider other Stata commands that can provide this functionality. Ben Jann's `center` command (`findit center`) can transform a variable into deviation from mean form and it works with `by`-groups.

Another important consideration is the interpreted nature of `egen` functions, which implies that they may be considerably slower than built-in functions or special-purpose commands. `egen` functions *can* be used to generate constant values for each element of a `by`-group: total household income or average industry output. If that is your objective—if you want to construct a dataset with one value per household or per industry—`egen` is a very inefficient tool. Stata's `collapse` (`[D]` `collapse`) command, as illustrated above, is especially tailored to perform that very function and will generate a single summary statistic for each `by`-group.

### 3.6 Local macros

One of the most important concepts for Stata do-file authors is the *local macro*. This entity does not have an exact equivalent in some statistical packages and matrix languages. If you are familiar with lower-level programming languages such as Fortran or C you may find Stata's terminology for various objects rather confusing. In those languages, you refer to a *variable* with statements such as `x = 2`. Although you might

have to declare `x` before its use—for instance, as `integer` or `float`—the notion of a variable in those languages refers to an entity which can be assigned a single value, either numeric or string. In contrast, the Stata *variable* refers to one column of the dataset which contains `_N` values, one per *observation*.

So what corresponds to a Fortran or C *variable* in Stata's command language? Either a Stata *macro* or a *scalar*, to be discussed below. But that correspondence is not one-to-one, since a Stata *macro* may contain multiple elements. Stata's local macro is a container which can hold either a single object—such as a number or variable name—or a set of objects. A local macro may contain any combination of alphanumeric characters and can hold more than 8,600 characters in all versions of Stata. The Stata macro is really an *alias* which has both a name and a value. When its name is *dereferenced*, it returns its value. That operation may be carried out at any time. Alternatively, the macro's value may be modified by an additional command.

A macro may be either *local* or *global*, which refers to its *scope*, defining where its name will be recognized. A *local macro* is created in a do-file or in an ado-file and ceases to exist when that do-file terminates, either normally or abnormally. A *global macro* exists for the duration of the Stata program or interactive session. There are some good reasons to use global macros, but like any global definition, they may have unintended consequences. We shall say more about global macros in Section 3.7.

The Stata command to define a local macro is `local` (see [P] **macro**). For example:

```
. local anxlevel None Mild Moderate Severe
. display "The defined levels of anxiety are: `anxlevel'"
The defined levels of anxiety are: None Mild Moderate Severe
```

Notice that the first `local` command *names* the macro—as `maxlevel`—and then defines its *value* to be the list of four anxiety codes. To work with the value of the macro we must *dereference* it. The expression ``anxlevel'` refers to the *value* of the macro. Notice that the macro's name is preceded by the *left single quote* character (`'`) and followed by the *right single quote* character (`'`).<sup>14</sup> Stata uses different opening and closing quote characters to signify the beginning and end of a *macroname* because, as we shall see, macro references may be nested, one inside the other. It is important to understand that if macros are nested, they are evaluated from the inside out: that is, `'pid`year''` will first replace `'year'` with its value, and then evaluate `'pidyear'`.<sup>15</sup> To dereference the macro, the correct punctuation is vital. In the example's `display` ([P] **display**) statements, we must wrap the dereferenced macro in double quotes since `display` expects a double-quoted string argument or the value of a scalar expression such as `display log(14)`.

In most cases the `local` statement is written without an equals sign (`=`). It is acceptable syntax to use an equals sign following the macro's name, but it is a very

14. These characters are found in different places on different languages' keyboards. The right single quote is commonly known as the apostrophe.

15. For a thorough discussion of these issues, see Cox (2002b).

bad idea to get in the habit of using it unless it is required. The equals sign causes the remainder of the expression to be *evaluated*, rather than merely aliased to the macro's name. This is a common cause of head-scratching, where a user will complain "my do-file worked when I had eight regressors, but not when I had nine...". Defining a macro with an equals sign will cause *evaluation* of the remainder of the command as a numeric expression or as a string expression. A string expression cannot contain more than 244 characters, so that a result longer than that will not be evaluated correctly.

When is it appropriate to use an equals sign in a `local` statement? Whenever you *must* evaluate the macro's value. In this example, we show a macro used as a counter which fails to do quite what we had in mind:<sup>16</sup>

```
. local count 0
. local anxlevel None Mild Moderate Severe
. foreach a of local anxlevel {
2.   local count 'count' + 1
3.   display "Anxiety level 'count' : 'a'"
4. }
Anxiety level 0 + 1 : None
Anxiety level 0 + 1 + 1 : Mild
Anxiety level 0 + 1 + 1 + 1 : Moderate
Anxiety level 0 + 1 + 1 + 1 + 1 : Severe
```

In this case, we *must* use the equals sign to request *evaluation* rather than *concatenation*:

```
. local count 0
. local anxlevel None Mild Moderate Severe
. foreach a of local anxlevel {
2.   local count = 'count' + 1
3.   display "Anxiety level 'count' : 'a'"
4. }
Anxiety level 1 : None
Anxiety level 2 : Mild
Anxiety level 3 : Moderate
Anxiety level 4 : Severe
```

The corrected example's `local` statement contains the name of the macro twice: without punctuation, which defines its name, and on the right-hand side of the equals sign with its current value dereferenced by `'count'`. It is crucial to understand why the statement is written this way. Here we are *redefining* the macro in the first instance and *referencing* its current value in the second.

In contrast to this example, there are instances where we want to construct a macro within a loop, repeatedly redefining its value, and *must* avoid the equals sign:

```
. local count 0
. local anxlevel None Mild Moderate Severe
. foreach a of local anxlevel {
2.   local count = 'count' + 1
```

16. The `foreach` command is presented in Section 7.4.

```

3.   local newlist "'newlist' 'count' 'a'"
4. }
. display "'newlist'"
1 None 2 Mild 3 Moderate 4 Severe

```

The `local newlist` statement introduces a new twist. It defines the local macro `newlist` as a string containing its own current contents, space, *value-of-count*, space, *value-of-a*. Notice that the `foreach` ([P] **foreach**) statement defines the local macro `a` with the value of each anxiety level in turn. The first time through the loop, `newlist` does not exist, so how may we refer to its current value? Easily: every Stata macro has an empty or *null* value unless it has explicitly been given a non-null value. Thus, it takes on the string " 1 None" the first time, and then the second time through concatenates that string with the new string " 2 Mild", and so on. Use of the equals sign would be inappropriate in the `local newlist` statement as it would cause truncation of `newlist` at 244 characters. This would not cause trouble in this example, but it would be a serious problem if we had a longer list.

We may also use macro evaluation to generate macro values “on the fly”. For instance, we could construct a loop (see Section 7.3) that generates new variable names as local macros. Say that we have variables `v11`, `v12`, . . . , `v15` which should be renamed to `x1971`, `x1972`, . . . , `x1975`. We could do so with macro evaluation:

```

. forvalues i = 11/15 {
.     rename v'i' = x'=1960 + 'i''
. }

```

In this code fragment, the macro `i` is evaluated and added to the constant 1960 before the outer macro is evaluated. The first time through the loop, `i = 11` and the new variable name will be `x1971`.

From these examples, we might conclude that Stata’s macros are useful in constructing lists, or as counters and loop indices. They are that, but they play a much larger role in Stata do-files and ado-files and in the return values of many Stata commands. Macros are one of the key elements of Stata’s programming language that allow you to avoid repetitive commands and the retyping of computed results. Macros allow you to change the performance of your do-file by merely altering the contents of a local macro. In this manner, your do-file can be made quite general, and that set of Stata commands may be reused or adapted for use in similar tasks with a minimum of effort.

## 3.7 Global macros

Global macros are distinguished from local macros by their manner of creation (with the `global` statement; see [P] **macro**) and their means of reference. We obtain the value of the global macro `george` as `$george` with the dollar sign taking the place of the punctuation surrounding the local macro’s name when it is dereferenced. Global macros are often used to store items parametric to a program, such as a character string

containing today's date that is to be embedded in all filenames created by the program, or the name of a default directory in which your data sets and do-files are to be accessed.

Unless there is an explicit need for a global macro—a symbol with *global scope*—it is usually preferable to use a local macro. It is easy to forget that a global symbol was defined in do-file *A*. By the time you run do-file *G* or *H* in that session of Stata, you may find that they do not behave as expected, since they now pick up the value of the global symbol. Such problems are quite difficult to debug. Authors of Fortran or C programs have always been encouraged to “keep definitions local unless they must be visible outside the module.” That is very good advice for Stata programmers as well.

### 3.8 Extended macro functions and macro list functions

Stata contains a versatile library of functions that may be applied to macros: the *extended macro functions* (`help extended_fcn`, or [P] **macro**). These functions allow you to easily retrieve and manipulate the contents of macros. For instance:

```
. local anxlevel None Mild Moderate Severe
. local wds: word count 'anxlevel'
. display "There are 'wds' anxiety levels:"
There are 4 anxiety levels:
. forvalues i = 1/'wds' {
2.     local wd: word 'i' of 'anxlevel'
3.     display "Level 'i' is 'wd'"
4. }
Level 1 is None
Level 2 is Mild
Level 3 is Moderate
Level 4 is Severe
```

In this example, we use the `word count` and `word #` of extended functions, both of which operate on strings. We do *not* enclose the macro's value (`'anxlevel'`) in double quotes, for it then would be considered a single word.<sup>17</sup> This do-file will work for any definition of the list in `local anxlevel` without the need to define a separate `count` macro.

A wide variety of extended macro functions (`help extended_fcn`) perform useful tasks such as extracting the variable label or value label from a variable, or determining its data type or display format; extracting the row or column names from a Stata matrix; or generating a list of the files in a particular directory that match a particular pattern (e.g., `*.dta`). The `subinstr()` function allows a particular pattern to be substituted in a macro, either the first time the pattern is encountered or in all instances.

Another very useful set of functions support the manipulation of *lists* held in local macros. These functions are described in `help macro lists` or [P] **macro lists**. They

17. In this context a word is a space-delimited token in the string. In the string `Stata was first released in 1985` there are six words, including “1985”.

may be used to identify the unique elements of a list, or the duplicate entries; to sort a list; and to combine lists with Boolean operators such as AND, OR. A set of handy list functions allow one list's contents to be subtracted from another, identifying the elements of list *A* that are not also found in list *B*. You can test lists for equality, defined for lists as containing the identical elements in the same order, or for weak equality, which does not consider ordering. Functions are available which produce the union or intersection of two lists and to `sort` the elements of a list in alphabetical order. The `uniq` list function returns the unique (distinct) elements of a list, while `dups` returns the duplicate elements. The `posof` function may be used to determine whether a particular entry exists in a list, and if so, in which position in the list. To consider the entire list, function `A in B` returns 1 if all elements in list *A* are found in *B*, 0 otherwise. An excellent discussion of many of these issues may be found in Cox (2003a).

### 3.8.1 System parameters, settings and constants: `creturn`

When using Stata macros, you may find the system parameters, settings, and constants available in `creturn` ([P] `creturn`) very useful. For instance, you may want to embed today's date in Stata output such as the title of a table or graph. The value `c(current_date)` will return that string, and `c(current_time)` will return the time. You may use `c()` return values to capture the current working directory (`c(pwd)`), the version of Stata that you are running (`c(stata_version)`), the name of the last file specified in [D] `use` (`c(filename)`) and the date and time it was last saved (`c(filedate)`).

A number of `creturn` values are constants: `c(pi)` is an accurate value of  $\pi$  (which may also be referenced as `_pi`), while `c(alpha)` (`c(ALPHA)`) returns a list of the lowercase (uppercase) letters of the alphabet. The list of month names may be retrieved in full or abbreviated (3-letter) form with `c(Months)` (`c(Mons)`), while the list of weekdays in full or abbreviated form is accessible in `c(Weekdays)` (`c(Wdays)`). These month and day lists are often useful when matching input data that may have been provided in that format. See Cox (2004c).

## 3.9 Scalars

In addition to Stata's variables and local and global macros, there are two additional entities related to every analysis command: *scalars* and *matrices*. Scalars, like macros, can hold either numeric or string values, but a scalar can hold only a single value.<sup>18</sup> Most analysis commands return one or more results as numeric scalars. For instance, `describe` ([D] `describe`) returns the scalars `r(N)` and `r(k)`, corresponding to the number of observations and variables in the dataset. A scalar is also much more useful for storing a single numeric result, such as the mean of a variable, rather than storing that value in a Stata variable containing `_N` copies of the same number. A scalar may be referred to in any subsequent Stata command by its name:

18. The length of a string scalar is limited to the length of a string variable (244 characters).

```
. scalar root2 = sqrt(2.0)
. generate double rootage = age * root2
```

The distinction between a macro and a scalar appears when it is referenced. The macro must be dereferenced to refer to its value, while the scalar is merely named.

There is one important distinction between macros and Stata's *scalars*: the length of a string scalar is limited to the length of a string variable (244 bytes: see [R] **limits**), whereas a macro's length is for most purposes unlimited.<sup>19</sup>

Stata's scalars are typically used in a numeric context. When a numeric quantity is stored in a macro it must be converted from its internal (binary) representation into a printable form. By storing the result of a computation—for instance, a variable's mean or standard deviation—in a scalar, no conversion of its value need take place. However, a scalar can only appear in an expression where a Stata variable or a numeric expression could be used. For instance, one cannot specify a scalar as part of an *in range* qualifier as its value will not be extracted. It may be used in an *if exp* qualifier as that contains a numeric expression. Most of Stata's statistical and estimation commands return various numeric results as scalars (see Section 5.3).

Stata is capable of working with scalars of the same name as Stata variables. As the manual suggests, Stata will not become confused, but you well may. So, you should avoid using the same names for both entities; see Kolev (2006). We discuss Stata's *matrices* below. Scalars and matrices share the same *namespace*, so that you cannot have both a scalar named `gamma` and a matrix named `gamma`.

Stata's scalars play a useful role in do-files. By defining scalars at the beginning of the do-file and referring to them throughout the code, you make the do-file parametric. This avoids the difficulties of changing various constants in the do-file's statements everywhere where they appear. You may often need to repeat a complex data transformation task for a different category. You may want to work with 18–24 year old subjects rather than 25–39 year old subjects. Your do-files contain the qualifiers for minimum and maximum age throughout the program. If you define those age limits as scalars at the program's outset, the do-file becomes much simpler to modify and maintain.

We illustrate using the `fem2` dataset. These data are a modified version of the `fem` dataset on 118 female psychiatric patients presented in Rabe-Hesketh and Everitt (2006), originally available in Hand et al. (1994).<sup>20</sup> The `anxiety` measure is on a scale from 1=none to 4=severe, while `iq` is the intelligence quotient score. We use scalars to define segments of the IQ range for which we want to analyze `anxiety`.

```
. use fem2, clear
. scalar lb1 = 80
. scalar ub1 = 88
```

19. A macro is limited to 165,200 characters in Stata/IC and over one million characters in Stata/SE and Stata/MP.

20. I am grateful to Sophia Rabe-Hesketh and Brian Everitt for permission to use these data.

```

. scalar lb2 = 89
. scalar ub2 = 97
. scalar lb3 = 98
. scalar ub3 = 109
. forvalues i = 1/3 {
2.     display _n "IQ " lb'i' " - " ub'i'
3.     tabulate anxiety if inrange(iq, lb'i', ub'i')
4. }

```

IQ 80 - 88

ANXIETY	Freq.	Percent	Cum.
1	3	12.00	12.00
2	13	52.00	64.00
3	7	28.00	92.00
4	2	8.00	100.00
Total	25	100.00	

IQ 89 - 97

ANXIETY	Freq.	Percent	Cum.
1	5	7.35	7.35
2	38	55.88	63.24
3	24	35.29	98.53
4	1	1.47	100.00
Total	68	100.00	

IQ 98 - 109

ANXIETY	Freq.	Percent	Cum.
2	9	75.00	75.00
3	2	16.67	91.67
4	1	8.33	100.00
Total	12	100.00	

In this example the macros for `lb` and `ub` are dereferenced “on the fly” in the `display` and `tabulate` commands. If we had a much more elaborate do-file in which we wanted to carry out a number of analyses for these three groups of patients based on IQ score, we need only refer to the scalars we have defined which delineate the groups.

## 3.10 Matrices

Stata has long provided a full-featured matrix language which supports a broad range of matrix operations on real matrices, as described in [P] **matrix**. Stata also provides a dedicated matrix language, Mata, which operates in a separate environment within Stata, as discussed in Chapter 13 below.

Stata’s estimation commands typically create both scalars and Stata matrices: in particular, the matrix `e(b)`, containing the set of estimated coefficients, and the matrix `e(V)`, containing the estimated variance-covariance matrix of the coefficients. These

matrices may be manipulated by Stata's [P] **matrix** commands, and their contents used in later commands. Like all Stata estimation commands, **regress** ([R] **regress**) produces matrices **e(b)** and **e(V)** as the row vector of estimated coefficients (a  $1 \times k$  matrix) and the estimated variance-covariance matrix of the coefficients (a  $k \times k$  symmetric matrix), respectively. You can examine those matrices with the **matrix list** command or copy them for use in your do-file with the **matrix** statement. The command **matrix beta = e(b)** will create a matrix **beta** in your program as a copy of the last estimation command's coefficient vector:

```
. generate age2 = age^2
. regress weight age age2
```

Source	SS	df	MS			
Model	135.170028	2	67.5850139	Number of obs =	107	
Residual	647.10605	104	6.22217356	F( 2, 104) =	10.86	
Total	782.276078	106	7.379963	Prob > F =	0.0001	
				R-squared =	0.1728	
				Adj R-squared =	0.1569	
				Root MSE =	2.4944	

weight	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
age	.1652777	1.0152	0.16	0.871	-1.847902	2.178458
age2	.0009098	.0136163	0.07	0.947	-.0260919	.0279115
_cons	-5.918914	18.6551	-0.32	0.752	-42.91268	31.07485

```
. matrix b = e(b)
. matrix V = e(V)
. matrix list b
b[1,3]
      age      age2      _cons
y1  .16527767  .00090982 -5.9189145
. matrix list V
symmetric V[3,3]
      age      age2      _cons
age  1.0306315
age2 -.01380654  .0001854
_cons -18.91199  .25270496  348.01273
```

When using Stata's traditional **matrix** commands, matrix size is limited. In Stata/IC, you cannot have more than 800 rows or 800 columns in a matrix.<sup>21</sup> This implies that many matrix tasks cannot be handled using traditional **matrix** commands in a straightforward manner. For instance, **mkmat** ([P] **matrix mkmat**) can create a Stata matrix from a *varlist* of variables, but the number of observations that may be used is limited to 800 in Stata/IC. Beyond resorting to Mata, there are two points that should be made. First, Stata contains specialized operators such as [P] **matrix accum** that can compute cross-product matrices from any number of observations. A regression of 10,000 observations on 5 variables (including constant) involves a  $5 \times 5$  cross-products ma-

21. The limit in Stata/SE and Stata/MP of 11,000 rows or columns is much larger, but sizable matrices use a great deal of computer memory. As discussed in Chapter 13, Mata provides a more efficient solution in terms of its *views*: **help mata st\_view()** for details.

trix, regardless of  $N$ . Variations on this command such as `matrix glsaccum`, `matrix vecaccum`, `matrix opaccum` generate other useful summarizations. In that sense, the limitation on matrix dimension is not binding.

The brute force approach is rarely appropriate when working with complex matrix expressions. For example, the seemingly unrelated regression (*SUR*) estimator implemented by the `sureg` command ([R] `sureg`) is presented in textbooks as a generalized least squares (*GLS*) estimator of the form

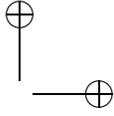
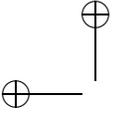
$$\hat{\beta} = (\mathbf{X}'\Omega^{-1}\mathbf{X})(\mathbf{X}'\Omega^{-1}\mathbf{y})$$

where  $\mathbf{X}$  is block-diagonal in the individual equations'  $X$  matrices. If there are  $G$  equations, each with  $T$  observations, the  $\Omega$  matrix is of order  $T \times G$  by  $T \times G$ . Given the algebra of partitioned matrices, every statistical package that performs *SUR* takes advantage of the fact that this expression can be rewritten as the product of a number of terms, one per equation in the system. In that expression, each term is no more than a single equation's regression. A huge matrix computation can be simplified as a loop over the individual equations. Although you might be tempted to copy the matrix expression straight out of the textbook or journal article into code, that will often be an infeasible approach in Stata's traditional matrix commands or in Mata, and indeed in *any* matrix language limited by the computer's available memory. Some cleverness is often necessary when implementing complicated matrix expressions to reduce the problem to a workable size.

For those Stata users who are writing do-files, Stata matrices are likely to be useful in two particular contexts: that of saved results as described above and as a way of organizing information for presentation. References to matrix elements appear in square brackets. As Stata does not have a vector data type, all Stata matrices have two subscripts and both subscripts must be given in any reference. A range of rows or a range of columns may be specified in an expression: see [P] `matrix` for details. Stata's traditional matrices are distinctive in that their elements may be addressed both conventionally by their row and column *numbers* (counting from 1, not 0) and by their row and column *names*.

Stata's matrices are often useful devices for housekeeping purposes such as the accumulation of results that are to be presented in tabular form. The `tabstat` ([R] `tabstat`) command may generate descriptive statistics for a set of `by`-groups. Likewise, `statsmat` (Cox and Baum, available using `ssc`) can be used to generate a matrix of descriptive statistics for a set of variables, or for a single variable over `by`-groups. Baum and Joao Pedro Azevedo's `outtable` can then be used to generate a  $\text{\LaTeX}$  table. An example of its use is given in Section 9.2. Michael Blasnik's `mat2txt` may be used to generate tab-delimited output. Stata matrices' row and column labels can be manipulated by `matrix rownames`, `matrix colnames` and several macro extended functions described in Section 3.8. This allows you to control the row and column headings on tabular output. Stata's traditional `matrix` operators make it possible to assemble a matrix from several submatrices. For instance, you may have one matrix for each country in a multi-country data set.

In summary, judicious use of Stata's traditional `matrix` commands ease the burden of many housekeeping tasks and make it feasible to update material in tabular form without retyping.



## 4 Cookbook: Do-file programming I

This first cookbook chapter presents a number of recipes for Stata do-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in a do-file.

### 4.1 Tabulating a logical condition across a set of variables

**The problem:** considering a number of related variables, you want to determine whether, for each observation, *all* variables satisfy a logical condition. Alternatively, you might want to know whether *any* satisfy that condition (for instance, taking on inappropriate values), or you might want to *count* how many of the variables satisfy the logical condition.<sup>1</sup>

This would seem to be a natural application of `egen` ([D] `egen`), as that command already contains a number of row-wise functions to perform computations across variables. For instance, the `anycount()` function counts the number of variables in its *varlist* whose values for each observation match those of an integer *numlist*, while the `rowmiss()` and `rownonmiss()` functions tabulate the number of missing and non-missing values for each observation, respectively. The three tasks above are all satisfied by `egen` functions from Nicholas Cox's `egenmore` package: `rall()`, `rany()` and `rcount()`, respectively. Why don't you just use those functions, then?

Two reasons come to mind. First, recall that `egen` functions are interpreted code. Unlike the built-in functions accessed by `generate`, the logic of an `egen` function must be interpreted each time it is called. For a large dataset, the time penalty can be significant. Second, to use an `egen` function, you must remember that there is such a function, and remember its name. In addition to Stata's official `egen` functions, documented in on-line help, there are many user-written `egen` functions available, but you must track them down.

For these reasons, current good programming practice suggests that you should avoid `egen` function calls in instances where the performance penalty might be an issue. This is particularly important within an ado-file program, but may apply to many do-files as well. In many cases, you can implement the logic of an `egen` function with a few lines of Stata commands.

---

1. This recipe relies heavily on Nicholas J. Cox's `egenmore` help file.

To use the `egenmore` function `rcount()`, we must define the logical condition to be tested using a specific syntax. For instance, imagine that we have a dataset of household observations, where variables `child1...child12` contain the current age of each child (or missing values for nonexistent offspring).<sup>2</sup> We could use `rcount()` to determine the number of school-age children:

```
. egen nschool = rcount(child1-child12), cond(@ > 5 & @ < 19)
```

where, as explained in `help egenmore`, the at sign (`@`) is a placeholder for each variable in the *varlist* in turn. Alternatively, we could compute `nschool` with a `foreach` loop:<sup>3</sup>

```
. generate nschool = 0
. foreach v of varlist child1-child12 {
.     replace nschool = nschool + inrange('v', 6, 18)
. }
```

The built-in `inrange()` function will execute more efficiently than the interpreted logic within `rcount()`. As a bonus, if we wanted to also compute an indicator variable signaling whether there are any school-age children in the household, we could do so within the same `foreach` loop:

```
. generate nschool = 0
. generate anyschool = 0
. foreach v of varlist child1-child12 {
.     replace nschool = nschool + inrange('v', 6, 18)
.     replace anyschool = max( anyschool, inrange('v', 6, 18))
. }
```

Note that in this case `anyschool` will remain at 0 for each observation unless one of the children's ages match the criteria specified in the `inrange` function. Once it is switched to 1, it will remain so.

An alternative (and more computationally efficient) way of writing this code takes advantage of the fact that `generate` is much faster than `replace`, as the latter command must keep track of the number of changes made in the variable.<sup>4</sup> Thus, we could write

```
. generate nschool = 0
. foreach v of varlist child1-child12 {
.     local nschool "'nschool' + inrange('v', 6, 18)"
. }
. generate byte nschool = `nschool'
. generate byte anyschool = nschool > 0
```

In this variation, the local macro is built up to include an `inrange()` clause for each of the possible 12 children. For a constructed dataset (`ex4.1.dta` of one million observations, the `egen` code runs in latter code runs in 3.81 seconds, while the comparable code employing `replace` and the `inrange()` function runs in 2.23 seconds.<sup>5</sup> By contrast, the last block of code, avoiding `replace`, runs in 0.78 seconds.

2. I assume that these variables are contiguous in the dataset (if not, we could use `order` to make them so).

3. The `foreach` command is presented in Section 7.4.

4. I am grateful to a StataCorp reviewer for this suggestion.

5. Note, though, that invoking `replace` twice in order to define `anyschool` as well requires 4.73 seconds!

In summary, you may often want to consider whether the convenience of an `egen` function is offset by its computational burden. Coding the logic in your `do-file` may be a more efficient approach.<sup>6</sup>

---

6. As I discuss in Chapter 13, Mata functions may also prove very useful in reducing the computational burden involved with tasks like these.

## 4.2 Computing summary statistics over groups

**The problem:** your dataset has a hierarchical nature, where observations represent individuals who are also identified by their household id code, or records of individual patient visits which can be aggregated over the patient id or over the clinic id. In the latter case, you can define groups of observations belonging to a particular patient, or to a particular clinic.

With this kind of hierarchical data structure, you may often want to compute summary statistics for the groups. This can be readily performed in Stata by `tabstat` ([R] `tabstat`), but that command will only display a table of summary measures. Alternatively, you could use `collapse` ([D] `collapse`) to generate a dataset of aggregated values for a variety of summary statistics, or `contract` ([D] `contract`) to generate a collapsed dataset of frequencies. However, you may find that these options do not fit the bill.

What if you want to juxtapose the summary statistics for each aggregate unit with the individual observations in order to compute one or more variables for each record? For instance, you might have repeated-measures data for a physician's patients measuring their height, weight and blood pressure at the time of each office visit. You might want to flag observations where their weight is above their median weight, or when their blood pressure is above the 75<sup>th</sup> percentile of their repeated measurements.

Computations such as these may be done with a judicious use of `by-groups` (see Section 3.5). For instance,

```
. by patientid: egen medwt = median(weight)
. by patientid: egen bp75 = pctlile(bp), p(75)
```

We have stressed that you should avoid using variables to store constant values (which would occur if you omitted the `by patientid:` prefix). But in these cases, we are storing a separate constant for each `patientid`. You may now compute indicators for weight, blood pressure and at-risk status, using the `byte` datatype for these binary variables:

```
. generate byte highwt = weight > medwt & !missing(weight, medwt)
. generate byte highbp = bp > bp75 & !missing(bp, bp75)
. generate byte atrisk = highwt & highbp
```

If you need to calculate a sum for each group (`patientid` in this case), you can use the `total()` function for `egen`. Alternatively, to improve computational efficiency, you could use

```
. by patientid: generate atriskvisits = sum(atrisk)
. by patientid: generate n_atrisk = atriskvisits if _n == _N
. gsort -n_atrisk
. list patientid n_atrisk if inrange(n_atrisk, 1, .)
```

This sequence of commands uses the `sum()` function from `generate`, which is a *running sum*. Its value when `_n == _N` is the total for that `patientid`. We store that value as

`n_atrisk` and sort it in descending order with `gsort ([D] gsort)`.<sup>7</sup> The `list` command then prints one record per `patientid` for those patients with at least one instance of `atrisk` in their repeated measures.

---

7. The `gsort` command is presented in Section 3.5.1.

### 4.3 Computing the extreme values of a sequence

**The problem:** you have hierarchical data such as observations of individual patient visits to a clinic. In the previous recipe, we described how summary statistics for each patient could be calculated. These include extrema: for instance, the highest weight ever recorded for each patient, or the lowest serum cholesterol reading. What you may need, however, is the *record* to date for those variables: the maximum (minimum) value observed so far in the sequence. This is a ‘record’ value in the context of setting a record: for instance, maximum points scored per game, or minimum time recorded for the 100-yard dash. How might you compute these values for hierarchical data?<sup>8</sup>

First, let us consider a single sequence (that is, data for a single patient in our example above). You might be tempted to think that this is a case where looping over observations will be essential—and you would be wrong! We exploit the fact that Stata’s `generate` and `replace` commands respect Stata’s sort order (see Newson (2004)). We need only record the first observation’s value and then use `replace` to generate the ‘record high’:

```
. sort visitdate
. generate maxwt = weight in 1
. replace maxwt = max(maxwt[_n - 1], weight) in 2/1
```

Unusually, you need not worry about missing values, as the `max()` function is smart enough to ignore them unless it is asked to compare missing with missing. If we want to calculate a similar measure for each `patientid` in the dataset, we use the same mechanism:

```
. sort patientid visitdate
. by patientid: generate minchol = serumchol if _n == 1
. by patientid: replace minchol = min(minchol[_n - 1], serumchol) if _n > 1
```

With repeated measures data, we cannot refer to observations 1,2, and so on as those are absolute references to the entire dataset. Recall that under the control of a `by`-group, the `_n` and `_N` values are redefined to refer to the observations in that `by`-group, allowing us to refer to `_n` in the `generate` command and the prior observation in that `by`-group with a `[_n - 1]` subscript.

---

<sup>8</sup> This recipe relies heavily on Nicholas J. Cox’ Stata FAQ, “How do I calculate the maximum or minimum seen so far in a sequence?” (<http://www.stata.com/support/faqs/data/sequence2.html>).

## 4.4 Computing the length of spells

**The problem:** you have ordered data (for instance, a time series of measurements) and you would like to examine *spells* in the data. These might be periods during which a qualitative condition is unchanged, as signaled by an indicator variable. As examples, consider the sequence of periods during which a patient's cholesterol remains above the recommended level, or a worker remains unemployed, or a released offender stays clear of the law. Alternatively, they might signal repeated values of a measured variable, such as the number of years that a given team has been ranked first in its league. Our concern with spells may involve identifying their existence and measuring their duration. Our discussion of these issues relies heavily on Cox (2007d). I am grateful to Nick Cox for his cogent exposition.

One solution to this problem involves using a ready-made Stata command, `tsspell`, written by Nicholas J. Cox. This command can handle any aspect of our investigation. It does require that the underlying data be defined as a Stata time series (for instance, with `tsset` (`[TS] tsset`). This makes it less than ideal if your data are ordered but not evenly spaced, such as patient visits to their physician which may be irregularly timed.<sup>9</sup> Another issue arises, though: that raised in Recipe 4.1 with respect to `egen`. The `tsspell` program is fairly complicated interpreted code, which may impose a computational penalty when applied to a very large dataset. You may only need one simple feature of the program for your analysis. Thus, you may want to consider analyzing spells in `do-file` code, perhaps much simpler than the invocation of `tsspell`. As in Recipe 4.1, you generally can avoid explicit looping over observations, and will want to do so whenever possible.

Assume that you have a variable denoting the ordering of the data (which might be a Stata date or date-and-time variable, but need not be) and that the data have been sorted on that variable. The variable of interest is `employer`, which takes on values `A,B,C...` or missing for periods of unemployment. You want to identify the beginning of each spell with an indicator variable. How do we know that a spell has begun? The condition

```
. generate byte beginspell = employer != employer[_n-1]
```

will suffice to define the start of each new spell (using the `byte` datatype to define this indicator variable). Of course, the data may be *left censored* in the sense that we do not start observing the employee's job history on her date of hire. But the fact that `employer[_n-1]` is missing for period 1 does not matter, as it will be captured as the start of the first spell. What about spells of unemployment? If they are coded as a missing value of `employer`, they will be considered spells as well.

First consider some fictitious data on an employee. She is first observed working for firm A in 1987, then is laid off in 1990. After a spell of unemployment, she is hired by firm B in 1992, and so on.

---

9. As Cox points out (Cox (2007d), p. 250) the ordered data may not have a time dimension at all, but may refer to spatial orientation.

```
. generate byte beginspell = employer != employer[_n-1]
. list, sepby(employer) noobs
```

year	employer	wage	begins~1
1987	A	8.25	1
1988	A	8.50	0
1989	A	8.75	0
1990		.	1
1991		.	0
1992	B	7.82	1
1993	B	7.98	0
1994	B	8.12	0
1995	B	8.40	0
1996	B	8.52	0
1997	C	9.00	1
1998	A	9.25	1
1999		.	1
2000		.	0
2001	D	10.18	1
2002	D	10.37	0
2003	E	11.00	1
2004	E	11.40	0
2005	E	11.80	0
2006		.	1

Notice that `beginspell` properly flags each change in employment status, including entry into unemployment. If we wanted to flag only spells of unemployment, we could do so with

```
. generate byte beginunemp = missing(employer) & ((employer ~= employer[_n-1]) | (_n == 1))
```

which would properly identify years in which unemployment spells commenced as 1990, 1999 and 2006.<sup>10</sup> The compound condition, including `(_n == 1)`, is required to prevent the first year as being considered as the start of a spell of unemployment if it is missing. This is once again the problem of left-censoring: if the employee was unemployed in 1987, she may have been unemployed in earlier years, but we do not observe that. We use parentheses to make it clear that Stata's AND and OR operators give us what we want. Extraneous parentheses are never harmful, and make it clear when you read the code at a later date what you meant to do.

With an indicator variable flagging the start of a spell, we can compute how many changes in employment status this employee has faced, as the count of that indicator

10. Recognize that these data are also *right-censored*, in that we observe the beginning of an unemployment spell in 2006, but do not know its duration.

variable provides that information. We can also use this notion to tag each spell as separate:

```
. list, sepby(employer) noobs
```

year	employer	wage	begins-1	beginu-p	spellnr
1987	A	8.25	1	0	1
1988	A	8.50	0	0	1
1989	A	8.75	0	0	1
1990	.	.	1	1	2
1991	.	.	0	0	2
1992	B	7.82	1	0	3
1993	B	7.98	0	0	3
1994	B	8.12	0	0	3
1995	B	8.40	0	0	3
1996	B	8.52	0	0	3
1997	C	9.00	1	0	4
1998	A	9.25	1	0	5
1999	.	.	1	1	6
2000	.	.	0	0	6
2001	D	10.18	1	0	7
2002	D	10.37	0	0	7
2003	E	11.00	1	0	8
2004	E	11.40	0	0	8
2005	E	11.80	0	0	8
2006	.	.	1	1	9

We have observed nine spells for this employee, the first and last of which are censored.

What if we now want to calculate the average wage paid by each employer?

```
. sort spellnr
. by spellnr: egen meanwage = mean(wage)
```

Or the duration of employment with each employer (length of each employment spell)?

```
. by spellnr: gen length = _N if !missing(employer)
```

Here we are taking advantage of the fact that the time variable is an evenly spaced time series. If we had unequally spaced data, we would want to use Stata's date functions to compute the duration of each spell.

This example may seem not all that useful as it refers to a single employee's employment history. However, all of the techniques we have illustrated work equally well when applied in the context of panel or longitudinal data as long as they can be placed on a time-series calendar. If we add an `id` variable to these data and `xtset id year`,

we may reproduce all of the results above by merely employing the `by id:` prefix. In the last three examples, we must sort by both `id` and `spell`: for example,

```
. sort id spellnr
. bysort id spellnr: egen meanwage = mean(wage)
```

is now required to compute the mean wage for each spell of each employee in a panel context.

A number of additional aspects of spells may be of interest. Returning to the single employee's data, we may want to flag only employment spells at least three years long. Using the `length` variable, we may generate such an indicator as:

```
. sort spellnr
. by spellnr: gen length = _N if !missing(employer)
(5 missing values generated)
. generate byte longspell = (length >= 3 & !missing(length))
. list year employer length longspell, sepby(employer) noobs
```

year	employer	length	longsp-1
1987	A	3	1
1988	A	3	1
1989	A	3	1
1990		.	0
1991		.	0
1992	B	5	1
1993	B	5	1
1994	B	5	1
1995	B	5	1
1996	B	5	1
1997	C	1	0
1998	A	1	0
1999		.	0
2000		.	0
2001	D	2	0
2002	D	2	0
2003	E	3	1
2004	E	3	1
2005	E	3	1
2006		.	0

For more detail on the handling of spells, see Cox (2007d).

## 4.5 Summarizing group characteristics over observations

**The problem:** your dataset has a hierarchical nature such as observations representing individuals who are also identified by their household id code, or group identifier. You would like to compute summary measures for each household (group) and attach them to the individual records.<sup>11</sup> Some fictitious data:

```
. list fam person female age, sepby(fam) noobs
```

fam	person	female	age
1	3	1	14
1	2	1	16
1	1	1	36
2	5	0	10
2	4	1	12
2	3	0	14
2	2	1	42
2	1	0	45
3	6	1	3
3	5	1	7
3	4	1	9
3	3	0	11
3	2	1	36
3	1	0	39

For simplicity, we have created data with no missing values. Some of the statements below would have to be “bulletproofed” if there was the possibility of missing values for some individuals.

For some calculations of interest, we have already addressed this issue in Recipe 4.2. We can readily calculate, for instance, the total household income for each family with the `egen total()` function with a `by:` prefix. We could do the same with a logical condition: for instance, how many adults (age at least 18) are there in each family?

```
. sort fam
. by fam: egen nadult = total(age >= 18)
```

How many siblings does each child have?

```
. by fam: egen nchild = total(age <= 17) if age <= 17
. generate sibs = nchild - 1
```

Note that the `if` clause `age <= 17` defines `nchild` only for children’s records. We can extend this logic to count the number of male children:

```
. by fam: egen nboys = total(age <= 17 & !female) if age <= 17
```

11. This recipe relies heavily on Nicholas J. Cox’ Stata FAQ, “How do I create variables summarizing for each individual properties of the other members of a group?” (<http://www.stata.com/support/faqs/data/members.html>).

or to count, for each child, how many brothers they have who are also children:

```
. by fam: egen nbros = total(age <= 17 & !female) if age <= 17
. replace nbros = nbros - (age <= 17 & !female)
```

where the subtraction in the `replace` statement states that you cannot be your own brother. Which children have older siblings who are also children?

```
. sort fam (age)
. by fam: generate byte older = (age <= 17 & age[_n+1] <= 17) * (age < age[_n+1])
```

How old is each child's oldest sibling (missing if the child is the oldest child)?

```
. by fam: egen oldestchild = max(age) if age<=17
. generate oldestsibling = cond(age < oldestchild & age <= 17, oldestchild, .)
```

```
. list fam female age nadult sibs nboys nbros older oldestsibling, sepby(fam) n
> oobs
```

fam	female	age	nadult	sibs	nboys	nbros	older	oldest-g
1	1	14	1	1	0	0	1	16
1	1	16	1	1	0	0	0	.
1	1	36	1	.	.	.	0	.
2	0	10	2	2	2	1	1	14
2	1	12	2	2	2	2	1	14
2	0	14	2	2	2	1	0	.
2	1	42	2	.	.	.	0	.
2	0	45	2	.	.	.	0	.
3	1	3	2	3	1	1	1	11
3	1	7	2	3	1	1	1	11
3	1	9	2	3	1	1	1	11
3	0	11	2	3	1	0	0	.
3	1	36	2	.	.	.	0	.
3	0	39	2	.	.	.	0	.

Many tricks of this sort can be used to evaluate group characteristics for each member of a group, and most of them allow us to avoid explicit looping over observations as one might in many programming languages. With judicious use of logical conditions and `by:` as a prefix or a `by()` option, you can write very efficient and succinct code to perform these tasks.

## 4.6 Using global macros to set up your environment

**The problem:** you are working on a large research project where the same datasets and Stata do-files may be accessed on several different computers: some Windows-based, some Linux-based. The do-files have references to datasets to be read and written which must be adjusted when the material is accessed from a different computer system.

Global macros (see Section 3.7) can be used to deal with these issues. Set up a master do-file for the project that defines the base directory to be accessed:

```
. global BASEDIR "c:/documents/project226"
. global SHAREDIR "c:/documents/datastore"
. global USER "gould"
. cd "$BASEDIR"
. do job1
```

on a Windows system, or

```
. global BASEDIR "/Users/baum/projects/226"
. global SHAREDIR "/Users/baum/research/data"
. global USER "cfb"
. cd "$BASEDIR"
. do job1
```

on a Linux or MacOS X machine. Note that in both file specifications I use the forward slash (/) rather than the backslash usually used in a Windows/DOS environment. Stata properly handles the slash for Windows, and by using the forward slash you avoid the difficulty that arises with the backslash's special meaning to Stata's interpreter.

With this logic, the master do-file, when executed, sets the system-specific directory to the value of the global macro `BASEDIR` and uses `cd ([D] cd)` to make that the current directory. The master do-file then calls do-file `job1.do`. Within that do-file, you may need to reference files that are outside of the project directory: for instance, files shared with other research projects. By defining the global macro `SHAREDIR`, your do-files may refer to files in that shared directory with syntax like

```
. use "$SHAREDIR/datafile1.dta"
```

The quotation marks in the `cd` and `use` statements will deal with the case where spaces may occur within the file specification. It is best to avoid spaces within directory names, but they are an unfortunate fact of life on many systems.

We may also want to embed additional information in a logfile produced by do-files of the research project: for instance, the identity of the user who ran the job. We can do that by placing statements such as

```
. display "Analysis run by $USER from $BASEDIR at $S_DATE $S_TIME"
```

in each do-file to be executed.

In summary, global macros may be very useful in establishing your Stata environment, particularly if you routinely work on more than one computer, or share files related to a research project with coworkers.

## 4.7 List manipulation with extended macro functions

**The problem:** You have a file containing four countries' GDP values, and you would like to regress each in turn on the other three countries' values. To enable this, you would like to be able to manipulate lists of items. The *macro list functions* described in Section 3.8 are available for this task.

We use the `gdp4cty` file, which is in Stata's *long format*,<sup>12</sup> in this example. The `levelsof` (`[D] levelsof`) command assembles a list of the `cty` values defined for `gdp`. That command displays the list and stores it in the local macro `gdplist`. We then apply `reshape wide` to place the data in the *wide format*, with a separate GDP variable for each country. A `foreach` loop builds up the macro `allcty` with those four variable names.

```
. use gdp4cty,clear
. keep cty gdp date
. levelsof cty, local(gdplist)
  "DE" "FR" "UK" "US"
. reshape wide gdp, i(date) j(cty) string
(note: j = DE FR UK US)
Data                                long  ->  wide
-----
Number of obs.                      400  ->   100
Number of variables                  3    ->    5
j variable (4 values)                cty  -> (dropped)
xij variables:
                                gdp  ->  gdpDE gdpFR ... gdpUS
-----

. describe
Contains data
  obs:                100
  vars:                 5
  size:              2,800 (99.9% of memory free)
-----
variable name  storage  display  value  variable label
              type   format   label
-----
date          float   %tq
gdpDE        float   %9.0g
gdpFR        float   %9.0g
gdpUK        float   %9.0g
gdpUS        float   %9.0g
-----

Sorted by:  date
. foreach c of local gdplist {
2.         local allcty "'allcty' gdp'c'"
3. }
```

We may then use one of the macro list functions (`help macrolist`). The minus list function (`-`) gives us the first list with all elements of the second list removed.<sup>13</sup> In a

12. For a discussion of long format, wide format and the `reshape` command, see Section 5.5.

13. You may also find the `OR` (`|`), `AND` list function (`&`) and `list sort` functions very useful.

`foreach` loop over countries, we produce the macro `allbut` as the other three variable names, and use that in the `regress` command.

```
. foreach c of local allcty {
2.     local allbut: list allcty - c
3.     qui regress 'c' 'allbut' date
4.     display _newline "Dependent variable 'c':"
5.     mat list e(b)
6. }
```

Dependent variable gdpDE:

e(b) [1,5]	gdpFR	gdpUK	gdpUS	date	_cons
y1	.0605496	.10816974	.09276896	-.82440282	445.32199

Dependent variable gdpFR:

e(b) [1,5]	gdpDE	gdpUK	gdpUS	date	_cons
y1	.05673715	-.16807133	-.08535245	-1.474414	678.2173

Dependent variable gdpUK:

e(b) [1,5]	gdpDE	gdpFR	gdpUS	date	_cons
y1	.08791943	-.14578622	-.17140193	-.37449064	621.80752

Dependent variable gdpUS:

e(b) [1,5]	gdpDE	gdpFR	gdpUK	date	_cons
y1	.06297068	-.06182947	-.14314374	-.0741045	622.66212

## 4.8 Using `creturn` values to document your work

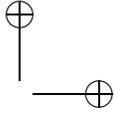
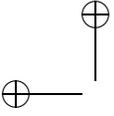
**The problem:** you would like to document aspects of the environment in the logfile produced by your do-file. The items you need to capture are available in the set of `creturn` ([P] `creturn`) values. For instance, you might include these lines in your do-file:

```
. local date `c(current_date)`
. local time `c(current_time)`
. local vers `c(stata_version)`
. local mem `c(memory)`
. local flav = cond(`c(MP)`, "MP", cond(`c(SE)`, "SE", "IC"))
. local cwd `c(pwd)`
.
. display _newline "Run 'date' at 'time' on Stata/'flav' version 'vers', memory
> = 'mem' bytes"
Run 5 Sep 2008 at 21:49:58 on Stata/MP version 10.1, memory = 307200000 bytes
. display _newline "Current working directory: 'cwd'"
Current working directory: /Users/baum/doc/ITSP/dof.8824
```

If you had already loaded a dataset into memory, you could display additional characteristics of the data:

```
. sysuse auto, clear
(1978 Automobile Data)
. display _newline "Datafile: `c(filename)' (N=`c(N)', k=`c(k)') as of `c(file
> date)'"
Datafile: /Applications/Stata/ado/base/a/auto.dta (N=74, k=12) as of 13 Apr 20
> 07 17:45
```

By embedding this information in the logfile, you can capture details of how and when the do-file was run which may be particularly useful in a shared environment: for instance, where several research assistants are performing various tasks to update the data.



# 5 Do-file programming: validation, results and data management

## 5.1 Introduction

This chapter discusses three topics: data validation, reusing computed results and commands for data management. Data validation tasks involve automating the process of ensuring that your data are sensible. We discuss the reuse of computed results to stress that you never need to copy values from Stata output and reenter them. That practice is error-prone and potentially irreproducible, whereas a do-file that automatically makes use of earlier computations is consistently reliable. Likewise, results of estimation can be automatically formatted for presentation in several formats, reducing the need for retyping and judgments about precision.

The last four sections of the chapter focus on reorganizing datasets. The `reshape` ([D] `reshape`) command allows an existing dataset to be altered in form, while the `append` ([D] `append`) and `merge` ([D] `merge`) commands serve to combine the dataset in memory with one or more external Stata-format files. A number of lesser-known but useful data management commands are also presented.

### 5.1.1 What you should learn from this chapter

- How to effectively validate data through scripted data checking
- How to access and reuse computed results in `return` and `ereturn` lists
- How to save and tabulate estimated results
- The mechanics of reorganizing datasets with `reshape`
- Procedures for combining data with `append` and `merge`

## 5.2 Data validation: the `assert`, `count` and `duplicates` commands

The first step in effective data management should always be *sanity checking*. Do all values of the raw data make sense? Are there any coding errors that are apparent in the range of data values? Are there values of numeric variables that should properly be coded as some sort of missing data, as discussed in Section 3.2.4? A recommended

practice for data management containing an audit trail involves the creation of a do-file that reads the raw data, applies a number of checks to ensure that data values are appropriate, and writes the initial Stata binary data file.<sup>1</sup> This data file should not be modified in later programs or interactive analysis. Each program that uses the file and creates additional variables, subsets or merges of the data should save the resulting modified file under a new name. Each step in the data validation and transformation process may then be documented and re-executed if the need arises. Even if the raw data are provided in Stata binary format from an official source, you should assume that coding errors may be present.

This methodology, involving the creation of an audit trail of all operations applied to the data, should begin right at the start of data management. Statalist postings often contain phrases such as “I did the original data transformations (or merges) in Excel, and now I need to...” Even if you are more familiar with a spreadsheet syntax than with the Stata commands needed to replicate that syntax, use of Stata is greatly preferable as its operations on the data can be precisely documented and replicated. Consider two research assistants starting with the same set of 12 spreadsheets, instructed to construct a single spreadsheet performing some complicated append or merge processes using copy and paste. What is the probability that the two research assistants will produce identical results? Many experienced researchers would agree that it is likely to be less than one.

The proposed solution: export the 12 spreadsheets to text format, and read them into Stata using a do-file that loops over the `.txt` or `.csv` files and applies the same transformations to each one and performing the appropriate `append` ([D] **append**) or `merge` ([D] **merge**) operations. That do-file, once properly constructed, will produce a reproducible result. The do-file can be easily modified to perform a similar task such as handling twelve spreadsheets containing cost elements rather than revenues. Comments should be added to the do-file documenting its purpose, dates of creation/modification, and creator/modifier. You may either place an asterisk (\*) or double forward slash (//) at the beginning of each comment line, or use the block comment syntax (/\* to begin a comment, \*/ to end it) to add several lines of comments to a do-file. Although it will take some time to learn how to use Stata’s programming features to set up such a systematic process of data management, it will prove invaluable in any context when questions arise about the data or when a modified version of the original data appears.

The data checks recommended above start with the elementary use of `describe` ([D] **describe**) and `summarize` ([R] **summarize**) which provide some very useful information about the data that have been imported (typically using `insheet` ([D] **insheet**), `infile` ([D] **infile**) or `infix` ([D] **infix**)). Let us consider a version of the `census2a` dataset that has been altered to illustrate data validation:

```
. use census2b, clear
  (Version of census2a for data validation purposes)
. describe
Contains data from census2b.dta
```

---

1. An intriguing extension of this notion, `ckvar`, is described in Rising (2007).

```

obs:          50                               Version of census2a for data vali
> dation
vars:         5                               purposes
size:        2,050 (99.9% of memory free)      23 Sep 2004 15:49

```

---

variable name	storage type	display format	value label	variable label
state	str14	%14s		
region	str7	%9s		
pop	float	%9.0g		
medage	float	%9.0g		
drate	float	%9.0g		

---

Sorted by:

The log displays the data types of the five variables. The first two are string variables (of maximum length 14 and 7 characters, respectively) while the other three are `float` variables. In this case, all data types appear to be appropriate.

Let us now consider descriptive statistics for the numeric variables in these data:

```

. summarize pop-drate

```

Variable	Obs	Mean	Std. Dev.	Min	Max
pop	49	4392737	4832522	-9	2.37e+07
medage	50	35.32	41.25901	24.2	321
drate	50	104.3	145.2496	40	1107

Several anomalies are revealed for the numeric variables. Population data appear to be missing for one state, which is unlikely for properly organized census data. Furthermore, population takes on a negative value for at least one state, indicating some coding errors. We use the knowledge that the values of U.S. states' populations in recent decades should be greater than several hundred thousand but no more than about 30 million. In your own research projects, you will have similar subject-matter knowledge that helps you define sensible ranges of values.

For instance, a median age value of 321 would suggest that Ponce de Leon is alive and well. As the `drate` (death rate) variable has a mean of 104 per 100,000, a value of ten times that amount suggests a coding error.

You may also find the `codebook` (`[D] codebook`) command very useful in displaying information about each variable and highlighting any unusual values:

```

. codebook

```

---

```

state (unlabeled)

```

---

```

type: string (str14), but longest is str13
unique values: 49 missing "": 0/50
examples: "Georgia"

```

```

        "Maryland"
        "Nevada"
        "S. Carolina"
    warning: variable has embedded blanks
-----
region                                     (unlabeled)
-----
        type: string (str7)
    unique values: 4                        missing "": 2/50
    tabulation:  Freq.  Value
                  2     ""
                  12    "N Cntrl"
                  9     "NE"
                  16    "South"
                  11    "West"
    warning: variable has embedded blanks
-----
pop                                         (unlabeled)
-----
        type: numeric (float)
        range: [-9,23667902]                units: 1
    unique values: 49                       missing .: 1/50
        mean: 4.4e+06
        std. dev: 4.8e+06
    percentiles:      10%      25%      50%      75%      90%
                    511456   947154   3.0e+06   5.3e+06   1.1e+07
-----
medage                                       (unlabeled)
-----
        type: numeric (float)
        range: [24.2,321]                   units: .1
    unique values: 37                       missing .: 0/50
        mean: 35.32
        std. dev: 41.259
    percentiles:      10%      25%      50%      75%      90%
                    27.5     28.7     29.75    30.2     31.85
-----
drate                                       (unlabeled)
-----
        type: numeric (float)
        range: [40,1107]                    units: 1
    unique values: 30                       missing .: 0/50
        mean: 104.3
        std. dev: 145.25
    percentiles:      10%      25%      50%      75%      90%
                    68.5     79      85.5     93      98

```

Rather than just using the Data Editor to visually scan for the problems sprinkled through this small illustrative dataset, we are interested in data validation techniques that can be applied to datasets with thousands of observations. We use `assert` ([D] `as-`

`sert`) to apply sanity checks for these three variables, and in the event of failure, we list the offending observations. If all checks are passed, this do-file should run without error:

```
use census2b, clear
                                // check pop
list if ~inrange(pop, 300000, 3e7)
assert inrange(pop, 300000, 3e7)
                                // check medage
list if ~inrange(medage, 20, 50)
assert inrange(medage, 20, 50)
                                // check drate
list if ~inrange(drate, 10, 104+145)
assert inrange(drate, 10, 104+145)
```

The first `list` ([D] `list`) command considers that population should be at least 300,000 and that it should be less than 30 million ( $3.0 \times 10^7$ ), and lists the observations (if any) that fall outside that range by using the unary *not* operator (`~`) and the `inrange()` function. By reversing the logical conditions in the `list` command, we construct the assertion that all cases have valid and non-missing (`< .`) values for `pop`. Likewise, we [D] `assert` that each state's median age should be between 20 and 50 years. Finally, we assert that the death rate should be at least 10 per 100,000 and less than approximately  $\hat{\mu} + \hat{\sigma}$  from that variable's descriptive statistics. Let us run the data validation do-file:

```
. use census2b, clear
(Version of census2a for data validation purposes)
.                                // check pop
. list if !inrange(pop, 300000, 3e7)
```

	state	region	pop	medage	drate
4.	Arkansas	South	-9	30.6	99
10.	Georgia	South	.	28.7	81
15.	Iowa	N Cntrl	0	30	90

```
. assert inrange(pop, 300000, 3e7)
3 contradictions in 50 observations
assertion is false
r(9);
end of do-file
r(9);
```

As we would expect, the do-file fails to run to completion since the first `assert` ([D] `assert`) locates three erroneous values of `pop`. We should now correct these entries and rerun the do-file until it executes without error. In these data, the numeric variables are continuous. In a dataset with categorical variables, you could use the `inlist()` function to validate that one of a set of particular integer values was present in each categorical variable.

This little example could be expanded to a very lengthy do-file (or a set of nested do-files) that checked each of several hundred variables. The same logic could be employed:

the do-file should exit without error if all assertions are satisfied. No news is good news.

You can use `tabulate` ([R] `tabulate oneway`) to check the values of string variables in our dataset. In the `census2b` dataset, we will want to use `region` as an identifier variable in later analysis, expecting that each state is classified in one of four U.S. regions.

```
. use census2b, clear
(Version of census2a for data validation purposes)
. list state if region == ""
```

	state
2.	Alaska
11.	Hawaii

```
. tabulate region
```

region	Freq.	Percent	Cum.
N Cntrl	12	25.00	25.00
NE	9	18.75	43.75
South	16	33.33	77.08
West	11	22.92	100.00
Total	48	100.00	

```
. assert !missing(region)
2 contradictions in 50 observations
assertion is false
r(9);
end of do-file
r(9);
```

The tabulation reveals that only 48 states have `region` defined. The assertion that we should have no missing values of `region` fails, and a list of values where the variable equals string missing (the null string) identifies Alaska and Hawaii as the misclassified entries.

Validating data with `tabulate` ([R] `tabulate twoway`) may be used to good advantage by generating cross-tabulations. Consider, for instance, a dataset of medical questionnaire respondents in which we construct a two-way table of `gender` and `NCPregnancy`, the number of completed pregnancies. Not only should the latter variable have a lower bound of zero and a sensible upper bound, its crosstabulation with `gender=="Male"` should yield zero values unless some females have been misclassified as males. We could check this with

```
. assert NCPregnancy = 0 if gender == "Male"
```

You can use `duplicates` ([D] `duplicates`) to check variables that should take on distinct values. This command can handle much more complex cases in which a combination of variables must be unique (or a so-called *primary key* in database terminology),<sup>2</sup>

2. As an example: U.S. Senators' surnames may not be unique, but the combination of surname and

but we will apply it to the single variable `state`:

```
. use census2b, clear
(Version of census2a for data validation purposes)

.
. duplicates list state
Duplicates in terms of state
```

obs:	state
16	Kansas
17	Kansas

```
. duplicates report state
Duplicates in terms of state
```

copies	observations	surplus
1	48	0
2	2	1

```
. assert r(unique_value) == r(N)
assertion is false
r(9);
end of do-file
r(9);
```

The return item `r(unique_value)` is set equal to the number of unique observations found. If that value falls short of the number of observations, `r(N)`, duplicates exist. The identification of duplicates in this supposedly unique identifier implies that the dataset must be corrected before its further use. The `duplicates` command could also be applied to numeric variables to detect the same condition.

In summary, a number of sound data management principles can improve the quality of analysis conducted with Stata. You should bring the data into Stata for manipulation as early in the process as possible. You should construct a well-documented do-file to validate the data, ensuring that variables that should be complete are complete, that unique identifiers are such, and that only sensible values are present in every variable. That do-file will run to completion without error if and only if all sanity checks are passed. Last, the validated and, if necessary, corrected file should not be modified in later analysis. Subsequent data transformations or merges should create new files rather than overwriting the original contents of the validated file. Strict adherence to these principles, although time-consuming, will ultimately save a good deal of your time, and provide those responsible for the research with the assurance that the data have been generated in a reproducible and well-documented fashion.

---

state code almost surely will be unique.

### 5.3 Reusing computed results: the `return` and `ereturn` commands

Each of Stata's commands reports its results: sometimes `noisily`, as when a non-zero return code is accompanied by an error message (`help _rc`), but usually quite silently. You may not be aware of the breadth and usefulness of the results made available for further use by Stata commands. Using stored results can greatly simplify your work with Stata as a do-file may be constructed to use the results of a previous statement in a computation, title, graph label, or even in a conditional statement.

We must distinguish between *r-class* and *e-class* commands. Each Stata command belongs to a class which may be *r*, *e*, or less commonly *s*. This applies to both those commands which are *built-in* (such as `summarize` ([R] `summarize`)) and to the 80% of official Stata commands that are implemented in the ado-file language.<sup>3</sup> The *e-class* commands are *estimation* commands, which return `e(b)` and `e(V)`—the estimated parameter vector and its variance-covariance matrix, respectively—to the calling program as well as other information (`help ereturn`). Almost all other official Stata commands are *r-class* commands which return *results* to the calling program (`help return`). Let us deal first with the simpler case of *r-class* commands.

Virtually every Stata command, including those which you might not think of as generating results, places items in the *return list* which may be displayed by the command of the same name.<sup>4</sup> For instance, consider `describe` ([D] `describe`) applied to a dataset of United Nations peacekeeping missions:

```
. use un, clear
. describe
Contains data from un.dta
  obs:          58
  vars:         15          13 Jun 2006 10:52
  size:         4,118 (99.9% of memory free)
```

---

variable name	storage type	display format	value label	variable label
name	str10	%10s		
mistype	float	%9.0g		
contype	float	%9.0g		
sevviol	float	%9.0g		
area	float	%9.0g		
loctype	float	%9.0g		
addloc	float	%9.0g		
borders	float	%9.0g		
primact	float	%9.0g		
spinv	float	%9.0g		
duration	float	%9.0g		
troop	float	%9.0g		

3. If this distinction interests you, `which` ([P] `which`) will report that a command is either built-in (i.e., compiled C or Mata code) or located in a particular ado-file on your hard disk. If it is stored in an ado-file, the `viewsource` ([P] `viewsource`) command may be used to view its code.

4. Significant exceptions: `generate` ([D] `generate`), `replace` and `egen` ([D] `egen`).

```

expnd          float   %9.0g
deaths         float   %9.0g
completed      byte    %8.0g

```

---

```

Sorted by:  duration
. return list
scalars:
      r(changed) = 0
      r(widthmax) = 60000
      r(k_max) = 5000
      r(N_max) = 4266665
      r(width) = 63
      r(k) = 15
      r(N) = 58

. local sb: sortedby
. display "dataset sorted by : 'sb'"
dataset sorted by : duration

```

The return list for the `describe` command contains items of a single type: *scalars*, as described in Section 3.9. `r(N)` and `r(k)` contain the number of observations and variables present in the dataset in memory. `r(changed)` is an indicator variable that will be set to 1 as soon as a change is made to the contents of the data. We also demonstrate here how information about the dataset's *sort order* may be retrieved by one of the extended macro functions discussed in Section 3.8. Any of the scalars defined in the return list may be used in a following statement without displaying the return list. A subsequent r-class command will replace the contents of the return list with its return values, so that if you want to use any of these items, you should save them to local macros or named scalars. For a more practical example, consider [R] **summarize**:

```

. summarize troop, detail

```

troop					
Percentiles			Smallest		
1%	2	2			
5%	28	15			
10%	50	28	Obs		49
25%	189	36	Sum of Wgt.		49
50%	1187		Mean		4270.102
			Std. Dev.		7624.842
			Largest		
75%	5522	18500			
90%	15522	19828	Variance		5.81e+07
95%	19828	25945	Skewness		2.943846
99%	39922	39922	Kurtosis		12.32439

```

. scalar iqr = r(p75) - r(p25)
. display "IQR = " iqr
IQR = 5333
. scalar semean = r(sd) / sqrt(r(N))
. display "Mean = " r(mean) " S.E. = " semean
Mean = 4270.102 S.E. = 1089.2632

```

The `detail` option displays the full range of results available—in this case, all in the form of scalars—after the `summarize` ([R] `summarize`) command. We compute the inter-quartile range (IQR) of the summarized variable and its standard error of mean as scalars and display those quantities. We often need the mean of a variable for further computations but do not wish to display the results of `summarize`. In this case, the `meanonly` option of `summarize` both suppresses output and the calculation of the variance or standard deviation of the series. The scalars `r(N)`, `r(mean)`, `r(min)` and `r(max)` are still available (see Cox 2007e).

When working with time series or panel data, it is often useful to know whether the data have been `xtset` ([XT] `xtset`), and if so, what variable is serving as the panel variable and (if defined) the calendar variable.<sup>5</sup> For example, consider this extract from the National Longitudinal Survey (NLS):

```
. use unionT, clear
(NLS Women 14-24 in 1968)

. xtset
    panel variable:  idcode (unbalanced)
    time variable:  year, 1970 to 1988, but with gaps
                   delta: 1 unit

. return list
scalars:
    r(tdelta) = 1
    r(tmax) = 1988
    r(tmin) = 1970
    r(imax) = 5159
    r(imin) = 1

macros:
    r(panelvar) : "idcode"
    r(timevar)  : "year"
    r(unit1)   : "."
    r(tsfmt)   : "%8.0g"
    r(tdeltas) : "1 unit"
    r(tmaxs)   : "1988"
    r(tmins)   : "1970"
    r(balanced) : "unbalanced"
```

In this example, we may note that the returned scalars include the first and last time periods in this panel data set (the years 1970 and 1988) and the range of the `idcode` variable, which is designated as `r(panelvar)`. The macros also include the time series calendar variable `r(timevar)` and the range of that variable in a form that can be readily manipulated: for instance, for graph titles. The value `r(tdelta)` indicates that the interval between time measurements is one time unit, or one year (see `r(tdeltas)`). The designation of the dataset as *unbalanced* implies that there are differing numbers of time-series observations available for different units (individuals).

A number of statistical commands are *r-class* as they do not estimate a model. The `correlate` command ([R] `correlate`) will return one estimated correlation coefficient

5. Panel data need not refer to time series for each individual; see [XT] `xtset`. The `tsset` ([TS] `tsset`) command may also be used to declare data as a time series of cross-sections.

regardless of the number of variables in the command's *varlist*: the correlation of the first two variables. However, the command also returns the full correlation matrix as matrix `r(C)`, which may be copied for further use. The `ttest` ([R] `ttest`) command is also r-class, and we may access its return list to retrieve all of the quantities it computes:

```
. ttest age, by(union)
Two-sample t test with equal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
0	20389	30.32302	.0456294	6.515427	30.23358	30.41245
1	5811	30.81535	.0837133	6.381461	30.65124	30.97946
combined	26200	30.43221	.0400895	6.489056	30.35364	30.51079
diff		-.4923329	.0964498		-.6813797	-.3032861

```

diff = mean(0) - mean(1)
Ho: diff = 0
Ha: diff < 0
Pr(T < t) = 0.0000

t = -5.1046
degrees of freedom = 26198
Ha: diff != 0
Pr(|T| > |t|) = 0.0000
Ha: diff > 0
Pr(T > t) = 1.0000

. return list
scalars:
r(sd) = 6.489056317184585
r(sd_2) = 6.381460760617624
r(sd_1) = 6.515426706403353
r(se) = .0964497730823021
r(p_u) = .9999998330518228
r(p_1) = 1.66948177204e-07
r(p) = 3.33896354408e-07
r(t) = -5.10455202650672
r(df_t) = 26198
r(mu_2) = 30.81535019790053
r(N_2) = 5811
r(mu_1) = 30.32301731325715
r(N_1) = 20389
```

The return list contains scalars representing each of the displayed values from `ttest` except the total number of observations (which can be computed as `r(N_1) + r(N_2)`), the standard errors of the group means and the confidence interval limits.

### 5.3.1 The ereturn list command

An even broader array of information is provided after any e-class (*estimation*) command as displayed by `ereturn list` ([P] `ereturn`). Most e-class commands return four types of Stata objects: scalars such as `e(N)`, summarizing the estimation process; macros, providing such information as the name of the response variable (`e(depvar)`) and the estimation method (`e(model)`); matrices `e(b)`, `e(V)` as described above; and a Stata *pseudo-variable*, `e(sample)`.<sup>6</sup> For example, consider a simple regression on the United

6. Although [U] **18.10.2 Saving results in e()** and the `ereturn list` output describe `e(sample)` as a function, it is perhaps better considered a variable, albeit one that does not appear in the dataset.

Nations peacekeeping dataset:

```
. use un, clear
. regress deaths duration troop
```

Source	SS	df	MS			
Model	103376.04	2	51688.0199	Number of obs =	42	
Residual	60815.7935	39	1559.37932	F( 2, 39) =	33.15	
Total	164191.833	41	4004.67886	Prob > F =	0.0000	
				R-squared =	0.6296	
				Adj R-squared =	0.6106	
				Root MSE =	39.489	

```

. ereturn list
scalars:
      e(N) = 42
      e(df_m) = 2
      e(df_r) = 39
      e(F) = 33.1465341558571
      e(r2) = .6296052472842496
      e(rmse) = 39.48897720443585
      e(mss) = 103376.0398278876
      e(rss) = 60815.7935054457
      e(r2_a) = .6106106445808778
      e(ll) = -212.4320571229659
      e(ll_0) = -233.2889619227027

macros:
      e(cmdline) : "regress deaths duration troop"
      e(title) : "Linear regression"
      e(vce) : "ols"
      e(depvar) : "deaths"
      e(cmd) : "regress"
      e(properties) : "b V"
      e(predict) : "regres_p"
      e(model) : "ols"
      e(estat_cmd) : "regress_estat"

matrices:
      e(b) : 1 x 3
      e(V) : 3 x 3

functions:
      e(sample)

```

Two particularly useful scalars on this list are `e(df_m)`, `e(df_r)`: the *model* and *residual* degrees of freedom, respectively: the numerator and denominator degrees of freedom for `e(F)`. The `e(rmse)` allows retrieval of the Root MSE of the equation. Two of the scalars do not appear in the printed output: `e(ll)`, `e(ll_0)`, the likelihood function evaluated

for the estimated model and for the null model, respectively.<sup>7,8</sup> Although the name of the response variable is available in macro `e(depvar)`, the names of the regressors are not shown here. They may be retrieved from the matrix `e(b)`, as illustrated in the example. As the estimated parameters are returned in a  $1 \times k$  row vector, the variable names are column names of that matrix:

```
. local regressors: colnames e(b)
. display "Regressors: 'regressors'"
Regressors: duration troop _cons
```

Another result displayed above should be noted: `e(sample)`, listed as a **function** rather than a **scalar**, **macro** or **matrix**. The `e(sample)` pseudo-variable returns 1 if an observation was included in the estimation sample and 0 otherwise. The `regress` ([R] `regress`) command honors any `if exp` and `in range` qualifiers and then practices casewise deletion to remove any observations with missing values across the set  $\{y, X\}$ . Thus, the observations actually used in generating the regression estimates may be fewer than those specified in the `regress` command. A subsequent command such as `summarize varlist if exp` (or `in range`) will not necessarily provide the descriptive statistics of the observations on  $X$  that entered the regression unless all regressors and the  $y$  variable are in the `varlist`. But the set of observations actually used in estimation can easily be determined with the qualifier `if e(sample)`:

```
. summarize regressors if e(sample)
```

will yield the appropriate summary statistics from the regression sample. It may be retained for later use by placing it in a new variable:

```
. generate byte reg1sample = e(sample)
```

where we use the `byte` data type to save memory as `e(sample)` is an indicator  $\{0,1\}$  variable.

The `estat` ([R] `estat`) command may be used to display a number of items after any estimation command. Some of those items (`ic`, `summarize`, and `vce`) are common to all estimation commands, while others depend upon the specific estimation command which precedes `estat`. For our estimated regression model,

```
. estat summarize
Estimation sample regress          Number of obs =      42
```

Variable	Mean	Std. Dev.	Min	Max
deaths	34.16667	63.28253	0	234
duration	90.04762	152.8856	2	641
troop	4785.5	8116.061	2	39922

7. In this case of ordinary least squares (*OLS*) regression with a constant term, the null model is that considered by the ANOVA  $F$  statistic: the intercept-only model with all slope coefficients constrained to zero.

8. These likelihood values may be displayed with the `estimates stats` command ([R] `estimates`) following estimation.

produces summary statistics, computed over the estimation sample, for the response variable and all regressors from the previous `regress` command.

In the following example, we employ the `matrix list` ([P] **matrix**) command to display the coefficient matrix generated by our regression: `e(b)`, the  $k$ -element row vector of estimated coefficients. Like all Stata matrices, this array bears row and column labels, so that an element may be addressed by either its row and column number<sup>9</sup> or its row and column names.

```
. matrix list e(b)
e(b) [1,3]
      duration      troop      _cons
y1    .13780304    .00591661   -6.5560927
```

The [R] `estat` command may be used to display the estimated variance-covariance (*VCE*) matrix by using `estat vce`.<sup>10</sup> This command provides a number of options to control the display of the matrix. To illustrate:

```
. estat vce
Covariance matrix of coefficients of regress model
      e(V) | duration      troop      _cons
-----+-----
duration | .00164817
troop    | 3.504e-06  5.849e-07
_cons   | -.16518387 -.00311436  66.906254
```

The diagonal elements of the *VCE* matrix are the squares of the estimated standard errors (`_se[]`) of the respective coefficients.

Many official Stata commands as well as many user-written routines make use of the information available from `ereturn list`. How can a command like `estat ovtest` ([R] **regress postestimation**) compute the necessary quantities after `regress`? Because it can retrieve all relevant information: the names of the regressors, dependent variable, and the net effect of all `if exp` and `in range` qualifiers (from `e(sample)`) from the results left behind as e-class scalars, macros, matrices or functions by the e-class command. Any do-file you write can perform the same magic if you use `ereturn list` to find the names of each quantity left behind for your use and store the results you need in local macros or scalars immediately after the e-class command. As noted above, retaining scalars as scalars is preferable to maintain full precision. You should not store scalar quantities in Stata variables unless there is good reason to do so.

The e-class commands may be followed by any of the `estimates` suite of commands described in the next section. Estimates may be saved in memory, combined in tabular form and saved to disk for use in a later session.

9. Stata matrices' rows and columns are numbered starting from 1.

10. Prior to version 9 of Stata, the `vce` command provided this functionality.

## 5.4 Storing, saving and using estimated results

The `estimates` ([R] `estimates`) suite of commands makes it easy to work with different sets of estimation results. You store a set of results in memory with the `estimates store name` command, which stores them under a name and, optionally, a descriptive title. Up to 300 sets of estimates may be stored in memory.<sup>11</sup> Stored estimates may be reviewed with `estimates replay namelist` where the *namelist* may refer to one or several sets of estimates in memory. Most usefully, estimates in memory may be combined in tabular form with `estimates table` or by user-written programs such as `estout` or `outreg2` (available from the SSC Archive). A set of estimates may also be permanently saved to a disk file by `estimates save filename`, and read from disk with `estimates use filename`. At that point you may review those prior estimates, tabulate them or even apply post-estimation commands such as `test` ([R] `test`) or `lincom` ([R] `lincom`) as long as they do not depend on the original dataset.

To organize several equations' estimates into a tabular form for scrutiny or publication you may use `estimates table`. You specify that a table is to be produced containing several sets of results. If you do not specify, `estimates table` assumes that you mean only the *active* set of results. To juxtapose several sets of estimates, you give their names in a *namelist* or specify all available sets with `*` or `_all`. Stata automatically handles alignment of the coefficients into the appropriate rows of a table. Options allow the addition of estimated standard errors (`se`), *t*-values (`t`), *p*-values (`p`) or significance stars (`star`). Each of these quantities may be given its own display `format` ([D] `format`) if the default is not appropriate, so that the coefficients, standard errors, *t*- and *p*-values need not be rounded by hand. Variable labels may be displayed in place of variable names with the `label` option. You may also choose to present coefficients in exponentiated form with the `eform` option. The order of coefficients in the table may be controlled by the `keep()` option rather than relying on the order in which they appear in the list of estimates' contents. Certain parameter estimates may be removed from the coefficient table with `drop()`. Any result left in `e()` (see [P] `ereturn`) may be added to the table with the `stats()` option, as well as several additional criteria such as the AIC and BIC model selection criteria.

Consider an example using several specifications from a model of air quality in a number of U.S. cities:

```
. use usairquality, clear
. quietly regress so2 temp manuf pop
. estimates store model1
. quietly regress so2 temp pop wind
. estimates store model2
. quietly regress so2 temp wind precip days
. estimates store model3
. quietly regress so2 temp manuf pop wind precip days
. estimates store model4
```

11. See `help limits`; the limit of 20 sets quoted in [R] `estimates` is outdated.

```
. estimates table model1 model2 model3 model4, stat(r2_a rmse) ///
> b(%7.3f) se(%6.3g) p(%4.3f)
```

Variable	model1	model2	model3	model4
temp	-0.587	-1.504	-1.854	-1.268
	.371	.43	.861	.621
	0.122	0.001	0.038	0.049
manuf	0.071			0.065
	.0161			.0157
	0.000			0.000
pop	-0.047	0.020		-0.039
	.0154	.0051		.0151
	0.004	0.000		0.014
wind		-2.858	-1.685	-3.181
		2.22	2.58	1.82
		0.206	0.518	0.089
precip			0.539	0.512
			.525	.363
			0.312	0.167
days			0.006	-0.052
			.236	.162
			0.980	0.750
_cons	58.196	128.501	128.862	111.728
	20.5	36.7	67.7	47.3
	0.007	0.001	0.065	0.024
r2_a	0.581	0.386	0.172	0.611
rmse	15.191	18.393	21.356	14.636

legend: b/se/p

After estimating and storing four different models of SO<sub>2</sub> (sulphur dioxide concentration) we use `estimates table` to present the coefficients, estimated standard errors and *p*-values in tabular form. The `stats` option adds summary statistics from the `e()` results.

```
. estimates table model4 model1 model3 model2, stat(r2_a rmse ll) ///
> b(%7.3g) star label title("Models of sulphur dioxide concentration")
Models of sulphur dioxide concentration
```

Variable	model4	model1	model3	model2
Mean temperature	-1.27*	-.587	-1.85*	-1.5**
Mfg. workers, 000	.0649***	.0712***		
Population	-.0393*	-.0466**		.0203***
Mean wind speed	-3.18		-1.69	-2.86
Mean precipitation	.512		.539	
Mean days quality=poor	-.0521		.006	
Constant	112*	58.2**	129	129**
r2_a	.611	.581	.172	.386
rmse	14.6	15.2	21.4	18.4
ll	-164	-168	-181	-175

legend: \* p<0.05; \*\* p<0.01; \*\*\* p<0.001

We chose to suppress the standard errors and display significance stars for the estimates while displaying variable labels rather than names with the `label` option. We add the log-likelihood value for each model with the `stats` option. The `estimates` commands may be used after any Stata estimation command, including multiple-equation commands.

We may also execute post-estimation commands on the stored estimates with `estimates for namelist`. In the four models above, let us test the hypothesis that the effect of mean temperature on SO<sub>2</sub> concentration is  $-1.6$ : a hypothetical value from other researchers' studies of this relationship.

```
. estimates for model1 model2 model3 model4: test temp = -1.6
```

---

```
Model model1
```

---

```
( 1) temp = -1.6
      F( 1, 37) = 7.45
      Prob > F = 0.0096
```

---

```
Model model2
```

---

```
( 1) temp = -1.6
      F( 1, 37) = 0.05
      Prob > F = 0.8236
```

---

```
Model model3
```

---

```
( 1) temp = -1.6
      F( 1, 36) = 0.09
      Prob > F = 0.7697
```

---

```
Model model4
```

---

```
( 1) temp = -1.6
      F( 1, 34) = 0.29
      Prob > F = 0.5964
```

We find that in only one case—that of `model1`—can the hypothesis be rejected by the data. It is important to note that we need not have the original data in memory to perform these tests. We can reproduce the results from `model1`:

```
. estimates replay model1
```

---

```
Model model1
```

---

Source	SS	df	MS	Number of obs =	41
Model	13499.2473	3	4499.7491	F( 3, 37) =	19.50
				Prob > F =	0.0000

Residual	8538.65513	37	230.774463		R-squared	=	0.6125
Total	22037.9024	40	550.947561		Adj R-squared	=	0.5811
					Root MSE	=	15.191

so2	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
temp	-.5871451	.3710077	-1.58	0.122	-1.338878	.1645878
manuf	.0712252	.0160601	4.43	0.000	.0386842	.1037661
pop	-.0466475	.0153719	-3.03	0.004	-.0777939	-.0155011
_cons	58.19593	20.48789	2.84	0.007	16.68352	99.70835

The four sets of estimates can also be documented with `estimates notes`<sup>12</sup> and saved to disk with `estimates save` for later use or exchange with another researcher:

```
. forvalues i = 1/4 {
2.     estimates restore model'i'
3.     estimates notes: from file 'c(filename)' saved 'c(filedate)'
4.     estimates save so2_model'i', replace
5. }
(results model1 are active now)
file so2_model1.ster saved
(results model2 are active now)
file so2_model2.ster saved
(results model3 are active now)
file so2_model3.ster saved
(results model4 are active now)
file so2_model4.ster saved
```

In a later Stata session (or after emailing these `.ster` files to another Stata user) we may retrieve any of these saved estimates and work with them. We `clear` and `estimates clear` to illustrate that neither data nor previously-stored estimates are needed.

```
. clear
. estimates clear
. estimates describe using so2_model3
Estimation results saved on 30jul2008 19:45, produced by
. regress so2 temp wind precip days
Notes:
1. from file usairquality.dta saved 30 Jun 2007 08:41
. estimates use so2_model3
. estimates store so2_model3
. estimates table *
```

Variable	so2_model3
temp	-1.8539796
wind	-1.6852669
precip	.5385879
days	.00600175
_cons	128.86154

12. See Section 3.8.1 regarding use of `c()` return values.

---

We must **store** the estimates to make them accessible to `estimates table`, although we could replay them with the original estimation command (`regress`) without taking that step. Note, however, that variable labels are not accessible without the original data in memory.

### 5.4.1 Generating publication-quality tables from stored estimates

Ben Jann's `estout` is a full-featured solution to preparing publication-quality tables in various output formats (Jann (2005), Jann (2007)). This routine, which he describes as a wrapper for `estimates table`, reformats stored estimates in a variety of formats, combines summary statistics from model estimation, and produces output in several formats such as Stata's SMCL for display in the Viewer, tab-delimited or comma-separated values (for word processors or spreadsheets),  $\text{\LaTeX}$ , rich text format (`rtf`) and HTML. A companion program in that package, `estadd`, allows the addition of user-specified statistics to the `e()` arrays accessible by `estimates`. A simplified version of `estout` is available as `esttab`, and the utility command `eststo` stores estimates without the need to name them. It may also be used as a prefix command (see Section 7.2). Complete documentation, including many examples of the use of the `estout` suite, is available at the website <http://repec.org/bocode/e/estout/>.

As an example:

```
. eststo: quietly regress so2 temp manuf pop
(est1 stored)

. eststo: quietly regress so2 temp pop wind
(est2 stored)

. eststo: quietly regress so2 temp wind precip days
(est3 stored)

. eststo: quietly regress so2 temp manuf pop wind precip days
(est4 stored)

. esttab using esttab_example.tex, ar2 label se nostar nodepvars brackets ///
> nomtitles title("Models of sulphur dioxide concentration") booktabs ///
> alignment(D{.}{.}{-1}) replace
(output written to esttab_example.tex)
```

producing a formatted  $\text{\LaTeX}$  table displayed as Table 5.1. These useful programs are available using [R] `ssc`, as is an alternative: Roy Wada's `outreg2`, which also has the facility to work with stored estimates. We illustrate the production of a  $\text{\LaTeX}$  table here, but these programs can equally well generate a rich text format (`rtf`) table or one in tab-delimited form which may be imported into standard office software.

Table 5.1: Models of sulphur dioxide concentration

	(1)	(2)	(3)	(4)
Mean temperature	-0.587 [0.371]	-1.504 [0.430]	-1.854 [0.861]	-1.268 [0.621]
Mfg. workers, 000	0.0712 [0.0161]			0.0649 [0.0157]
Population	-0.0466 [0.0154]	0.0203 [0.00514]		-0.0393 [0.0151]
Mean wind speed		-2.858 [2.219]	-1.685 [2.582]	-3.181 [1.815]
Mean precipitation			0.539 [0.525]	0.512 [0.363]
Mean days quality=poor			0.00600 [0.236]	-0.0521 [0.162]
Constant	58.20 [20.49]	128.5 [36.73]	128.9 [67.69]	111.7 [47.32]
Observations	41	41	41	41
Adjusted $R^2$	0.581	0.386	0.172	0.611

Standard errors in brackets

## 5.5 Reorganizing datasets with the reshape command

When data have more than one identifier per record, they may be organized in different ways. For instance, it is common to find on-line displays or downloadable spreadsheets of data for individual units—for instance, U.S. states—with the unit’s name labeling the row and the year labeling the column. If these data were brought into Stata in this form, they would be in the *wide form*, with the same measurement (population) for different years denoted as separate Stata variables:

```
. list, noobs
```

state	pop1990	pop1995	pop2000
CT	3291967	3324144	3411750
MA	6022639	6141445	6362076
RI	1005995	1017002	1050664

There are a number of Stata commands—such as `egen` ([D] `egen`) row-wise functions—which work effectively on data stored in the wide form. It may also be a useful form of data organization for producing graphs.

Alternatively, we can imagine stacking each year’s population figures from this display into one variable, `pop`. In this format, known in Stata as the *long form*, each datum is identified by two variables: the state name and the year to which it pertains:

```
. list, noobs sepby(state)
```

state	year	pop
CT	1990	3291967
CT	1995	3324144
CT	2000	3411750
MA	1990	6022639
MA	1995	6141445
MA	2000	6362076
RI	1990	1005995
RI	1995	1017002
RI	2000	1050664

This data structure is required for many of Stata’s statistical commands, such as the [XT] `xt` suite of panel data commands. As many knowledgeable Stata users have pointed out, the long form is also very useful for data management using `by`-groups and the computation of statistics at the individual level, often implemented with the `collapse` ([D] `collapse`) command.

Inevitably, you will acquire data (either raw data or Stata datasets) that are stored in either the wide or the long form and will find that translation to the other format is

necessary to carry out your analysis. The solution to this problem is Stata's `reshape` ([D] `reshape`) command, an immensely powerful tool for reformulating a dataset in memory without recourse to external files. In statistical packages lacking a data-reshape feature, common practice entails writing the data to one or more external text files and reading it back in. With the proper use of `reshape`, this is not necessary in Stata. But `reshape` requires, first of all, that the data to be reshaped are labelled in such a way that they can be handled by the mechanical rules that the command applies. In situations beyond the simple application of `reshape`, it may require some experimentation to construct the appropriate command syntax. This is all the more reason for enshrining that code in a do-file as some day you are likely to come upon a similar application for `reshape`.

In the remainder of this section, we work with several variations on a longitudinal (panel) dataset of U.S. school district characteristics. Let us consider the original form of this dataset:

```
. use mathpnl_long, clear
(modified mathpnl.dta from Wooldridge (2000))
. describe
Contains data from mathpnl_long.dta
  obs:      2,200                               modified mathpnl.dta from Wooldri
> dge (2000)
  vars:      7                                   28 Jun 2007 09:41
  size:      66,000 (99.9% of memory free)
```

variable name	storage type	display format	value label	variable label
distid	float	%9.0g		district identifier
expp	int	%9.0g		expenditure per pupil
revpp	int	%9.0g		revenue per pupil
avgsal	float	%9.0g		average teacher salary
math4score	float	%9.0g		% satisfactory, 4th grade math
math7score	float	%9.0g		% satisfactory, 7th grade math
year	int	%9.0g		year

```
Sorted by:  distid  year
```

We see that the dataset contains 2,200 observations, identified by the numeric `distid` school district identifier and `year`.

```
. xtset
      panel variable:  distid (strongly balanced)
      time variable:  year, 1992 to 1998
                delta:  2 units
. tabulate year
```

year	Freq.	Percent	Cum.
1992	550	25.00	25.00
1994	550	25.00	50.00
1996	550	25.00	75.00
1998	550	25.00	100.00

Total	2,200	100.00
-------	-------	--------

The dataset is in the *long form*, as `xtset` (`[XT] xtset`) shows, and is *strongly balanced*: that is, each of the 550 districts appears in the sample for each of the four years. The `delta: 2 units` qualifier indicates that the time series are biennial.

Imagine that we did not have this dataset available, but rather had its *wide-form* equivalent, perhaps acquired from a spreadsheet on school district expenditures. The wide-form dataset looks like:

```
. use mathpnl_wide, clear
(modified mathpnl.dta from Wooldridge (2000))
. describe
Contains data from mathpnl_wide.dta
  obs:                550                modified mathpnl.dta from Wooldri
> dge (2000)
  vars:                21                28 Jun 2007 09:41
  size:                41,800 (99.9% of memory free)
```

variable name	storage type	display format	value label	variable label
distid	float	%9.0g		district identifier
expp1992	int	%9.0g		1992 expp
revpp1992	int	%9.0g		1992 revpp
avgsal1992	float	%9.0g		1992 avgsal
math4score1992	float	%9.0g		1992 math4score
math7score1992	float	%9.0g		1992 math7score
expp1994	int	%9.0g		1994 expp
revpp1994	int	%9.0g		1994 revpp
avgsal1994	float	%9.0g		1994 avgsal
math4score1994	float	%9.0g		1994 math4score
math7score1994	float	%9.0g		1994 math7score
expp1996	int	%9.0g		1996 expp
revpp1996	int	%9.0g		1996 revpp
avgsal1996	float	%9.0g		1996 avgsal
math4score1996	float	%9.0g		1996 math4score
math7score1996	float	%9.0g		1996 math7score
expp1998	int	%9.0g		1998 expp
revpp1998	int	%9.0g		1998 revpp
avgsal1998	float	%9.0g		1998 avgsal
math4score1998	float	%9.0g		1998 math4score
math7score1998	float	%9.0g		1998 math7score

Sorted by: distid

We see that there are now 550 observations, one per school district, with separate variables containing the five measurements for each year. Those Stata variables are systematically named, which is a very important consideration. It means that we can readily use wildcards: for instance, `summarize expp*` to compute descriptive statistics for all expenditure-per-pupil variables. It also eases our task of reshaping the dataset. Let's say that you want to convert this wide-form dataset into its long-form equivalent.

The `reshape` command works with the notion of  $x_{i,j}$  data. Its syntax lists the variables to be stacked up, and specifies the  $i$  and  $j$  variables, where the  $i$  variable indexes the rows and the  $j$  variable indexes the columns in the existing form of the data.

```
. reshape long expp revpp avgsal math4score math7score, i(distid) j(year)
(note: j = 1992 1994 1996 1998)
Data                                wide  ->  long
-----
Number of obs.                      550  ->  2200
Number of variables                  21  ->   7
j variable (4 values)                ->  year
xij variables:
    expp1992 expp1994 ... expp1998  ->  expp
    revpp1992 revpp1994 ... revpp1998 ->  revpp
    avgsal1992 avgsal1994 ... avgsal1998 ->  avgsal
math4score1992 math4score1994 ... math4score1998->math4score
math7score1992 math7score1994 ... math7score1998->math7score
```

You use `reshape long` because the data are in the wide form and we want to place them in the long form. You provide the variable names to be stacked *without* their common suffixes: in this case, the `year` embedded in their wide-form variable name. The  $i$  variable is `distid` and the  $j$  variable is `year`: together, those variables uniquely identify each measurement. Stata's description of `reshape` speaks of  $i$  defining a unique observation and  $j$  defining a subobservation logically related to that observation. Any additional variables that do not vary over  $j$  are not specified in the `reshape` statement, as they will be automatically replicated for each  $j$ . After this command, you will have a dataset which is identical to the long-form dataset displayed above:

```
. describe
Contains data
obs:                2,200                               modified mathpnl.dta from Wooldri
> dge (2000)
vars:                7
size:                66,000 (99.9% of memory free)
-----
variable name      storage  display  value  variable label
                  type    format   label
-----
distid             float   %9.0g
year               int     %9.0g
expp               int     %9.0g
revpp              int     %9.0g
avgsal             float   %9.0g
math4score         float   %9.0g
math7score         float   %9.0g
-----
Sorted by:  distid year
Note:  dataset has changed since last saved
```

What if you wanted to reverse the process, and translate the data from the long to the wide form?

```
. reshape wide expp revpp avgsal math4score math7score, i(distid) j(year)
(note: j = 1992 1994 1996 1998)
Data
-----
Number of obs.          2200 ->    550
Number of variables      7 ->    21
j variable (4 values)   year -> (dropped)
xij variables:
                        expp -> expp1992 expp1994 ... expp1998
                        revpp -> revpp1992 revpp1994 ... revpp1998
> 8
                        avgsal -> avgsal1992 avgsal1994 ... avgsal
> 1998
> . math4score1998      math4score -> math4score1992 math4score1994 ..
> . math7score1998     math7score -> math7score1992 math7score1994 ..
-----
```

You can see that this command is identical to the first `reshape` command, with the exception that now you `reshape wide`, designating the target form. It reproduces the wide-form dataset described above.

This example highlights the importance of having appropriate variable names for `reshape`. If our wide-form dataset contained the variables `exp1992`, `Expen94`, `xpend_96` and `expstu1998` there would be no way to specify the common stub labeling the choices. However, one common case can be handled without the renaming of variables. Say that we have the variables `exp92pp`, `exp94pp`, `exp96pp`, `exp98pp`. The command

```
reshape long exp@pp, i(distid) j(year)
```

will deal with that case, with the `@` as a placeholder for the location of the `j` component of the variable name. In more difficult cases, where the repeated use of `rename ([D] rename)` may be tedious, `renvars` (Cox and Weesie (2001), Cox and Weesie (2005)) may be useful.

This discussion has only scratched the surface of `reshape`'s capabilities. There is no substitute for experimentation with this command after a careful perusal of `help reshape ([D] reshape)`, as it is one of the most complicated elements of Stata. See the following chapter and Nicholas Cox's Stata FAQ<sup>13</sup> for more guidance with `reshape` usage.

## 5.6 Combining datasets

You may be aware that Stata can only work with one dataset at a time. How, then, do you combine datasets in Stata? First of all, it is important to understand that at least one of the datasets to be combined must already have been saved in Stata format. Second, you should realize that each of Stata's commands for combining datasets provides

13. <http://www.stata.com/support/faqs/data/reshape3.html>

a certain functionality, which should not be confused with that of other commands. For instance, consider the `append ([D] append)` command with two stylized datasets:

$$\text{dataset1 : } \begin{pmatrix} id & var1 & var2 \\ 112 & \vdots & \vdots \\ 216 & \vdots & \vdots \\ 449 & \vdots & \vdots \end{pmatrix}$$

$$\text{dataset2 : } \begin{pmatrix} id & var1 & var2 \\ 126 & \vdots & \vdots \\ 309 & \vdots & \vdots \\ 421 & \vdots & \vdots \\ 604 & \vdots & \vdots \end{pmatrix}$$

These two datasets contain the same variables, as they must for `append` to sensibly combine them. If `dataset2` contained `idcode`, `Var1`, `Var2` the two datasets could not sensibly be appended without renaming the variables.<sup>14</sup> Appending these two datasets with common variable names creates a single dataset containing all of the observations:

$$\text{combined : } \begin{pmatrix} id & var1 & var2 \\ 112 & \vdots & \vdots \\ 216 & \vdots & \vdots \\ 449 & \vdots & \vdots \\ 126 & \vdots & \vdots \\ 309 & \vdots & \vdots \\ 421 & \vdots & \vdots \\ 604 & \vdots & \vdots \end{pmatrix}$$

The rule for `append`, then, is that if datasets are to be combined, they should share the same variable names and datatypes (string vs. numeric). In the above example, if `var1` in `dataset1` was a `float` while that variable in `dataset2` was a `string` variable, they could not be appended. It is permissible to append two datasets with differing variable names in the sense that `dataset2` could also contain an additional variable or variables (for example, `var3`, `var4`). The values of those variables in the observations coming from `dataset1` would then be set to missing.

<sup>14</sup> Recall that in Stata `var1` and `Var1` are two separate variables.

While `append` combines datasets by adding observations to the existing variables, the other key command, `merge` (`[D] merge`) combines variables for the existing observations. Consider these two stylized datasets:

$$\text{dataset1 : } \begin{pmatrix} id & var1 & var2 \\ 112 & \vdots & \vdots \\ 216 & \vdots & \vdots \\ 449 & \vdots & \vdots \end{pmatrix}$$

$$\text{dataset3 : } \begin{pmatrix} id & var22 & var44 & var46 \\ 112 & \vdots & \vdots & \vdots \\ 216 & \vdots & \vdots & \vdots \\ 449 & \vdots & \vdots & \vdots \end{pmatrix}$$

We may `merge` these datasets on the common *merge key*: in this case, the `id` variable:

$$\text{combined : } \begin{pmatrix} id & var1 & var2 & var22 & var44 & var46 \\ 112 & \vdots & \vdots & \vdots & \vdots & \vdots \\ 216 & \vdots & \vdots & \vdots & \vdots & \vdots \\ 449 & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$

The rule for `merge`, then, is that if datasets are to be combined on one or more *merge keys*, they each must have one or more variables with a common name and datatype (string vs. numeric). In the example above, each dataset must have a variable named `id`. That variable can be numeric or string, but that characteristic of the merge key variables must match across the datasets to be merged. Of course, we need not have exactly the same observations in each dataset: if `dataset3` contained observations with additional `id` values, those observations would be merged with missing values for `var1` and `var2`. As we shall see in Section 5.8, we have illustrated the simplest kind of merge: the *one-to-one merge*. Stata supports several other types of merges. But the key concept should be clear: the `merge` command combines datasets “horizontally”, adding variables’ values to existing observations. With these concepts in mind, let us consider these commands in the context of our prior example.

## 5.7 Combining datasets with the `append` command

Datafiles downloaded from their providers often contain a single period’s information, or data about a single entity. A research project may require that you download several separate datasets and combine them for statistical analysis. In the school district example above, imagine that we could only access separate datafiles for each of the four

years 1992, 1994, 1996 and 1998. Combining these datasets into a single dataset would be a task for `append` ([D] `append`). However, there are two caveats. First of all, it is possible that the individual datasets lack a year variable. It would, after all, be a constant value within the 1992 dataset. But if we append these datasets, we will lose the information of which observation pertains to which year. If individual datasets lack a dataset identifier, we must add one. That is as simple as `generate int year = 1992` and saving those data.<sup>15</sup> Second, as discussed above, we must ensure that the variable names across the individual datasets are identical. If necessary, `rename` ([D] `rename`) or `renvars` (Cox and Weesie (2001), Cox and Weesie (2005)) should be used to ensure that variable names match.

You may then use `append` to combine the four school district datasets:

```
. use mathpnl1992, clear
(modified mathpnl.dta from Wooldridge (2000))
. append using mathpnl1994
. append using mathpnl1996
. append using mathpnl1998
. label data ""
. save mathpnl_appended, replace
file mathpnl_appended.dta saved
. describe
Contains data from mathpnl_appended.dta
  obs:          2,200
  vars:          14                               30 Jul 2008 19:45
  size:        127,600 (99.9% of memory free)
```

variable name	storage type	display format	value label	variable label
distid	float	%9.0g		district identifier
lunch	float	%9.0g		% eligible for free lunch
enrol	float	%9.0g		school enrollment
expp	int	%9.0g		expenditure per pupil
revpp	int	%9.0g		revenue per pupil
avgsal	float	%9.0g		average teacher salary
drop	float	%9.0g		high school dropout rate, %
grad	float	%9.0g		high school grad. rate, %
math4score	float	%9.0g		% satisfactory, 4th grade math
math7score	float	%9.0g		% satisfactory, 7th grade math
year	int	%9.0g		year
staff	float	%9.0g		staff per 1000 students
cpi	float	%9.0g		consumer price index
rexpp	float	%9.0g		real spending per pupil, 1997\$

Sorted by:

The combined dataset contains all four years' data in the long form, with each ob-

15. The same caveat applies if individual datasets contain information for a single entity. For instance, if one file contains timeseries of Connecticut infant mortality data and a second contains that variable for Massachusetts, we must ensure that each file contains a state identifier variable of some sort before combining them.

ervation identified by `distid` and `year`, identical to the long-form dataset described above.

## 5.8 Combining datasets with the merge command

The long-form dataset we constructed above is very useful if you want to add aggregate-level information to individual records. For instance, imagine that you have downloaded a separate file identifying the state in which each school district appears:

```
. describe
Contains data from mathpnl_state.dta
obs:          550
vars:         2                               30 Jul 2008 19:45
size:         7,700 (99.9% of memory free)
```

variable name	storage type	display format	value label	variable label
<code>distid</code>	float	%9.0g		district identifier
<code>state</code>	int	%8.0g		State code

```
Sorted by: distid
```

Say you want to compute descriptive statistics and generate graphs for our school district data separately for certain states. With the aid of this auxiliary dataset, you can easily code each of the 550 districts' four timeseries observations with the appropriate state code:

```
. use mathpnl_long, clear
(modified mathpnl.dta from Wooldridge (2000))
. merge distid using mathpnl_state, sort uniuqsing
variable distid does not uniquely identify observations in the master data
. tab _merge
```

_merge	Freq.	Percent	Cum.
3	2,200	100.00	100.00
Total	2,200	100.00	

```
. assert _merge == 3
. drop _merge
. save mathpnl_longs, replace
file mathpnl_longs.dta saved
```

This use of `merge` ([D] `merge`) is known as a *one-to-many* match merge where the state code for each school district is added to the individual records of each of the district. The `distid` variable is the *merge key*. Unless both the *master file* (`mathpnlL.dta`) and the *using file* (`mathpnl_state.dta`) are sorted by the merge key, the `sort` option should be specified.

By default, `merge` creates a new variable `_merge`, which takes on integer values for each observation of 1 if that observation was only found in the master dataset, 2 if it was only found in the using dataset, or 3 if it was found in both datasets. In this case, we expect that `tab _merge` should reveal that all values equal 3, as it does. We also use the `uniquising` option to ensure that there are no duplicate values of the district id in the using file. That file should uniquely map each district to a single state code, so a duplicate value of `distid` must be a data entry error. If the same `distid` mistakenly appears on two records in the using file, asserting `uniquising` will cause `merge` to fail. Absent such errors, each of the district's observations (four in number, one for each year) will be mapped to a single state code.

This strategy will also work if you have a comprehensive list of school districts in the using file. Consider that the 550 school districts in `mathpnl_long.dta` are a random sample of U.S. school districts, and that the information you have located identifying districts by state lists *all* U.S. school districts. The one-to-many merge still works perfectly well. After the merge, `_merge` will indicate that each `distid` in the using file that did not match a `distid` in our sample now has `_merge=2`. Those observations in the merged file should be deleted (with `drop if _merge == 2`) before it is saved.

Alternatively, if `_merge` reveals that any observations have `_merge=1`, it indicates that some of our `distid` values are not being successfully matched in the using file. This probably indicates errors in one of the files and should be corrected. The `assert _merge == 3` in the commands above will ensure that the do-file aborts if there are unmatched records in the master file.<sup>16</sup>

In your particular application, you may find that `_merge` values of 1 or 2 are appropriate. The key notion is that you should always tabulate `_merge` and consider whether the results of the merge are sensible in the context of your work. It is an excellent idea to use the `uniquemaster`, `uniquising` or `unique` options on the `merge` command whenever those conditions should logically be satisfied in your data, and one of those options is required if the `sort` option is also used.

In comparison with a lengthy and complicated do-file using a set of `replace` statements, the `merge` technique is far better. By merely altering the contents of the using file we may correct any difficulties which appear in the one-to-many merge. Furthermore, if we had a number of school district-specific variables to be added to the individual observations these variables would all be handled with a single `merge` command. We might want to merge aggregate time series information instead. For example, if we wanted to compute real expenditures per pupil, we would match on the merge key `year` to incorporate a price deflator (varying by year, but not by school district) in the merged file. This technique proves exceedingly useful when working with individual data and panel data where we have aggregate information to be combined with the individual-level data.

16. The do-file will also abort if there are unmatched records in the using file, as described above. If this is not desired, you could validate the merge using `assert _merge >= 2`.

### 5.8.1 The dangers of many-to-many merges

In the previous subsection we discussed using `merge` ([D] `merge`) to attach aggregate characteristics to individual records using a *one-to-many* merge. There are very good reasons to employ a one-to-many merge, as we did above with school district-level characteristics, or its inverse: a many-to-one merge, which would essentially reverse the roles of the master and using datasets. The `merge` command may also be used to combine datasets using a *one-to-one* match merge, as we illustrated in Section 5.6. This would be appropriate if we had two or more datasets whose observations pertained to the same units: e.g., U.S. state population figures from the 1990 and 2000 Censuses. In that case, you would want to `assert _merge = 3` if you know that each dataset should contain the same observations, and should use the `unique` option on `merge`.

There is a great danger in stumbling into the alternative to the one-to-many or one-to-one merge: the *many-to-many* merge. This problem arises when there are multiple observations in both datasets for some values of the merge key variable(s). The result of match-merging two datasets which both have more than one value of the merge key variable(s) is unpredictable, as it depends on the sort order of the datasets. This leads to the seemingly illogical result that repeated execution of the same `do`-file will most likely result in a different number of cases in the result dataset without any error indication. There is no unique outcome for a many-to-many merge. When it is encountered it usually results from a coding error in one of the files. The `duplicates` ([D] `duplicates`) command (see Section 5.2) is very useful in tracking down such errors. To prevent such difficulties in employing [D] `merge`, you should specify either the `uniquemaster` or the `uniquusing` option in a match merge. If no `uniq...` option is used, observations may be matched inappropriately.

In a one-to-one match merge, the option `unique` should be used as it implies both `uniquemaster` and `uniquusing`, asserting that the merge key should be unique in both datasets.<sup>17</sup> Imagine that you have four separate school district datafiles, within which each variable is labeled with its year (e.g., `expp1992`, `revpp1992`). You would not want to `append` these datasets as their variable names differ. But you could generate a wide-form dataset from the individual datasets with `merge`:

```
. use mathpnl1992m, clear
. forvalues y=1994(2)1998 {
2.     merge distid using mathpnl'y'm, sort unique
3.     assert _merge == 3
4.     drop _merge
5. }
. save mathpnlm, replace
file mathpnlm.dta saved
```

We have used the `unique` option to specify that each of the four datasets in the merge contains unique values of `distid`.

---

17. Those familiar with relational data base management systems such as SQL will recognize that the concept of uniqueness refers to the merge key serving as a valid and unique *primary key* for the dataset.

## 5.9 Other data management commands

Stata provides a number of data management commands less commonly used than `append` ([D] **append**) and `merge` ([D] **merge**). In this section, we discuss the `fillin` ([D] **fillin**), `cross` ([D] **cross**), `stack` ([D] **stack**), `separate` ([D] **separate**), `joinby` ([D] **joinby**) and `xpose` ([D] **xpose**) commands.

### 5.9.1 The fillin command

We spoke earlier of a *balanced panel*: a longitudinal dataset in which there are  $N$  cross-sectional units, each with  $T$  time-series observations. Many panel datasets are *unbalanced*, with differing numbers of time-series observations available for different units. This does not create problems for Stata's panel data (`xt`) commands, but may cause difficulty if the data are to be exported to other software, particularly matrix languages that expect the dataset to contain  $N \times T$  observations. The `fillin` ([D] **fillin**) command deals with this issue by adding observations with missing data so that all interactions of its *varlist* exist, thus making a complete rectangularization of *varlist*.<sup>18</sup> See Cox (2005a) for more details.

The `fillin` command will work in any context, not only that of panel data. For instance, we might have a list of patients' ages and the average cholesterol level for male and female patients of that age. That dataset might not contain every combination of age and gender. If we want to rectangularize it, we specify `age gender` in the *varlist*.

### 5.9.2 The cross command

The `cross` command ([D] **cross**) forms every pairwise combination of the data in memory with the data in the using dataset. Imagine that you have a list of racial categories as the sole variable in memory: `race`, coded `White`, `Black`, `Asian`, `Hispanic`. The file `cancers.dta` contains a list of the 10 most common forms of cancer: `Lung`, `Colon`, `Breast`, `Cervical`, `Prostate`, etc. coded as the variable `cancertype`. If you perform

```
. cross using cancers
```

you will create a dataset with 40 observations in which each of the racial categories is matched with each of the cancer categories in turn. See Franklin (2006) for more details.

18. The `tsfill` command ([TS] **tsfill**) is a specialized version of `fillin`. When executed with its `full` option, a panel dataset will be *balanced* by the addition of missing observations as needed.

### 5.9.3 The stack command

The `stack` ([D] `stack`) command allows you to vertically stack the variables in its *varlist*.<sup>19</sup> For instance,

```
. stack x1 x2 x3 x4, into(z1 z2)
```

will create `z1` as the “stack” of `x1` and `x3`, and `z2` as the “stack” of `x2` and `x4`. Variables may be repeated in the *varlist* to juxtapose a single variable against others. For example,

```
. stack x1 x2 x1 x3 x1 x4, into(z1 z2)
```

will create two new variables, one containing three copies of `x1`, the other containing the stacked form of `x2`, `x3` and `x4`.

When might you use `stack`? It is often a useful tool when preparing data for graphics where some form of the `graph` ([G] `graph twoway scatter`) command expects a single variable. For example:

```
. use mathpnl_wide, clear
(modified mathpnl.dta from Wooldridge (2000))
. preserve
. stack expp1992 avgsal1992 expp1998 avgsal1998, into(expp sal) wide clear
. scatter expp1992 expp1998 sal, m(oh x) scheme(s2mono) ///
> title("School District Expenditures vs. Average Salaries") ///
> xtitle("Average salaries") ytitle("Expenditures") ///
> legend(position(5) ring(0) label(1 "1992") label( 2 "1998"))
. restore
```

Using the wide-form school district data, we employ `stack` to juxtapose expenditures per pupil in 1992 and 1998 with average teacher salaries in those two years and produce a scatterplot, as Figure 5.1 illustrates.

Note that `stack` clears the dataset in memory (automatically if its `clear` option is specified), retaining only those variables listed in the `into()` option unless the `wide` option is specified. With that option, the variables in the *varlist* are retained as well. In any case, a new variable `_stack` is created which identifies the groups. If you do not want to disrupt the dataset in memory, use `preserve` ([D] `preserve`) and `restore` ([D] `restore`) as illustrated above and described in Section 2.5.

### 5.9.4 The separate command

The `separate` ([D] `separate`) command can convert a single variable into several new variables, either on the basis of a true-or-false Boolean expression (for two groups only) or in terms of a *byvar*. In the latter case, the number of distinct values of the *byvar* (which may be of numeric or string type) will determine the number of new variables

19. In linear algebra, this is the `vec()` operation, available in Stata’s matrix language as the `vec()` function (`help matrix` and in Mata (`help mata vec()`)).

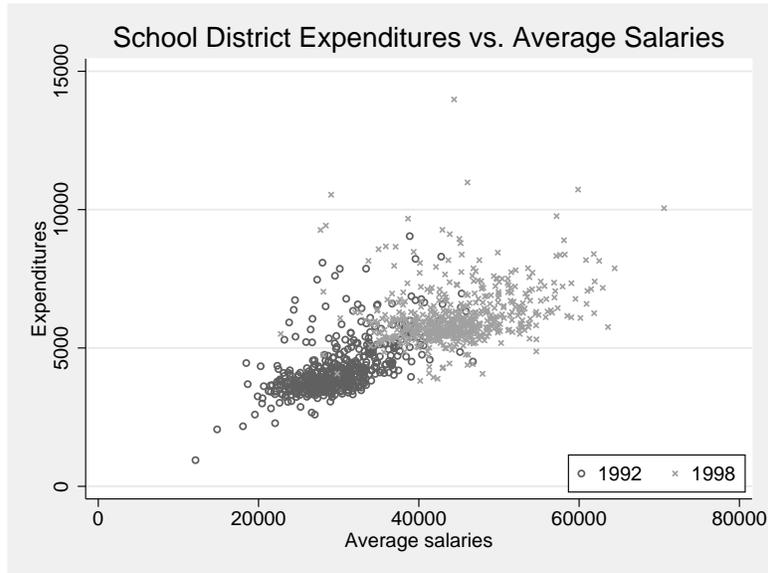


Figure 5.1: Superimposed scatter plots.

created.

As an example, consider the long-form school district dataset, and imagine that you want to create distinct expenditure-per-pupil variables for each year:

```
. use mathpnl_long, clear
(modified mathpnl.dta from Wooldridge (2000))
. separate expp, by(year) veryshortlabel
```

variable name	storage type	display format	value label	variable label
expp1992	int	%9.0g	1992	
expp1994	int	%9.0g	1994	
expp1996	int	%9.0g	1996	
expp1998	int	%9.0g	1998	

```
. summarize expp*
```

Variable	Obs	Mean	Std. Dev.	Min	Max
expp	2200	5205.833	1255.723	946	13982
expp1992	550	4181.165	933.6362	946	9041
expp1994	550	4752.56	993.0163	1147	10461
expp1996	550	5737.953	981.382	2729	10449
expp1998	550	6151.653	1028.371	3811	13982

We make use of the undocumented `veryshortlabel` option, which is a more austere variant of the `shortlabel` option. See Cox (2005e).

The `separate` command may also be very useful in creating variables that correspond to a qualitative identifier: for instance, different variables for each ethnic group's blood pressure measurements.

### 5.9.5 The `joinby` command

The `joinby` (`[D] joinby`) command creates a new dataset by forming all possible pairwise combinations of the two datasets, given a merge key. It is similar in that sense to `cross` which does not make use of a merge key. In many instances where a researcher considers `joinby`, they probably want to do a `merge` (`[D] merge`).<sup>20</sup>

One instance in which `joinby` might come in handy is that which would involve a many-to-many merge, as discussed in Section 5.8.1. Let's say that you have one dataset containing firms' subsidiaries, all identified by their `firmid` number. That is, many large multinational corporations consist of a number of component firms: in some cases, corresponding to the country in which they are incorporated. You have a second file which contains, for each `firmid`, a set of product codes. You want to construct a dataset in which each subsidiary is matched with each product sold by the parent firm. The variable `firmid` appears with duplicate entries in both datasets. If you use `joinby`:

```
. use subsidiaries, clear
. joinby firmid using products
```

you will create the desired data structure.

By default, if a value of `firmid` appears in one dataset but not the other, its observations will be dropped.<sup>21</sup> The merge key for `joinby` need not be a single variable. As in the example above, if both subsidiaries and product records are coded by country, you might use

```
. joinby firmid country using products
```

to produce a dataset that will contain subsidiary-product combinations for each country in which that product is sold.

### 5.9.6 The `xpose` command

Another Stata data management command is capable of making radical changes to the organization of the data: `xpose` (`[D] xpose`). This is the *transpose* command, which turns observations into variables and *vice versa*. This functionality is familiar to those who have used spreadsheets or matrix languages. It is rarely useful in Stata, as applying `xpose` will usually destroy the contents of string variables. If all variables in the dataset are numeric, this command may be useful. Rather than employing `xpose`, you should consider whether the raw data might be read in using the `byvariable` option of `infile`

20. Those familiar with relational data base management systems will recognize `joinby` as the SQL *outer join*, which is a technique to be avoided in most data base tasks.

21. The `unmatched` option reverses this behavior.

([D] **infile**). If there is truly a need to transpose the data, it was probably not created sensibly in the first place.

## 6 Cookbook: Do-file programming II

This cookbook chapter presents a number of recipes for Stata do-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in a do-file.

### 6.1 Efficiently defining group characteristics and subsets

**The problem:** say that your cross-sectional dataset contains a record for each patient who has been treated at one of several clinics. You want to associate each patient's clinic with an location code (for urban clinics, the Standard Metropolitan Statistical Area (SMSA) in which the clinic is located). The SMSA identifier is not on the patient's record but it is available to you. How do you get this associated information on each patient's record without manual editing? One quite cumbersome technique (perhaps familiar to users of other statistical packages) involves writing a long sequence of statements with `if exp` clauses. Thankfully, there is a better way.<sup>1</sup>

Let us presume that we have Stata dataset `patient` containing the individual's details as well as `clinicid`, the clinic ID. Assume that it can be dealt with as an integer. If it were a string code, that could easily be handled as well.

Create a text file, `clinics.raw`, containing two columns: the clinic ID (`clinicid`) and the SMSA FIPS code (`smsa`).<sup>2</sup> For instance,

```
12367 1120
12467 1120
12892 1120
13211 1200
14012 4560
... ..
23435 5400
29617 8000
32156 9240
```

where SMSA codes 1120, 1200, 4560, 5400, 8000 and 9240 refer to the Boston, Brockton, Lowell, New Bedford, Springfield-Chicopee-Holyoke and Worcester, MA SMSAs,

---

1. This recipe is adapted from my Stata FAQ "How do you define group characteristics in your data in order to create subsets?", <http://www.stata.com/support/faqs/data/characteristics.html>.

2. The FIPS (Federal Information Processing System) code is a four-digit integer assigned to each SMSA. See <http://www.census.gov/population/estimates/metro-city/60mfips.txt>

respectively.

Read the file into Stata with `infile clinicid smsa using clinics`, and save the file as Stata dataset `clinic_char`. Now use the patient file and give the commands

```
. merge clinicid using clinic_char, sort uniquising
. tab _merge
```

We use the `uniquising` option as discussed in Section 5.8 to ensure that the `clinic_char` dataset has a single record per clinic. After the merge is performed you should find that all patients now have an `smsa` variable defined. If there are missing values in `smsa`, list the `clinicids` for which that variable is missing and verify that they correspond to non-urban locations. When you are satisfied that the merge has worked properly, type

```
. drop _merge
```

You have performed a *one-to-many merge*, attaching the same SMSA identifier to all patients who have been treated at clinics in that SMSA. You may now use the `smsa` variable to attach SMSA-specific information to each patient record with `merge`.

Unlike an approach depending on a long list of conditional statements such as

```
. replace smsa=1120 if inlist(clinicid,12367,12467,12892,...)
```

this approach leads you to create a Stata dataset containing your clinic ID numbers so that you may easily see whether you have a particular code in your list. This approach would be especially useful if you revise the list for a new set of clinics.

### 6.1.1 Selecting a subset of observations using a complicated criterion

As Nicholas Cox has pointed out in a Stata FAQ,<sup>3</sup> this approach may also be fruitfully applied if you need to work with a subset of observations that satisfy a complicated criterion. This might be best defined in terms of an indicator variable that specifies the criterion (or its complement). The same approach may be used. Construct a file containing the identifiers that define the criterion (in the example above, the clinic IDs to be included in the analysis). Merge that file with your dataset and examine the `_merge` variable. That variable will take on values 1, 2 or 3, with a value of 3 indicating that the observation falls in the subset. You may then define the desired indicator:

```
. generate byte subset1 = _merge == 3
. drop _merge
. regress ... if subset1
```

Using this approach, any number of subsets may be easily constructed and maintained, avoiding the need for complicated conditional statements.

3. See <http://www.stata.com/support/faqs/data/selectid.html>

## 6.2 Applying reshape repeatedly

**The problem:** are your data the wrong shape?<sup>4</sup> That is, are they not organized in the structure that you need to conduct the analysis you have in mind? Data sources often provide the data in a structure quite suitable for presentation but very clumsy for statistical analysis. One of the key data management tools Stata provides is `reshape` ([D] `reshape`). If you need to modify the structure of your data, you should surely be familiar with `reshape` and its two functions: `reshape wide` and `reshape long`. In some cases, you may have to apply `reshape` twice to solve a particularly knotty data management problem.

As a first example, consider this question, posed on Statalist, by an individual who has a dataset in the wide form:

country	tradeflow	Yr1990	Yr1991
Armenia	imports	105	120
Armenia	exports	90	100
Bolivia	imports	200	230
Bolivia	exports	80	115
Colombia	imports	100	105
Colombia	exports	70	71

He would like to reshape the data into the long form:

country	year	imports	exports
Armenia	1990	105	90
Armenia	1991	120	100
Bolivia	1990	200	80
Bolivia	1991	230	115
Colombia	1990	100	70
Colombia	1991	105	71

We must exchange the roles of years and tradeflows in the original data to arrive at the desired structure, suitable for analysis as `xt` data. This can be handled by two successive applications of `reshape`:

```
. clear
. input str8 country str7 tradeflow Yr1990 Yr1991
      country tradeflow   Yr1990   Yr1991
1. Armenia imports 105 120
2. Armenia exports 90 100
3. Bolivia imports 200 230
4. Bolivia exports 80 115
5. Colombia imports 100 105
6. Colombia exports 70 71
```

4. This recipe is adapted from Stata Tip 45 (Baum and Cox (2007)). I am grateful to Nicholas J. Cox for his contributions to this Stata Tip.

```

7. end
. reshape long Yr , i(country tradeflow)
(note: j = 1990 1991)
Data                wide  ->  long
-----
Number of obs.      6    ->   12
Number of variables  4    ->   4
j variable (2 values)  ->  _j
xij variables:
                    Yr1990 Yr1991  ->  Yr
-----

```

This transformation swings the data into long form with each observation identified by `country`, `tradeflow` and the new variable `_j`, taking on the values of year. We now perform `reshape wide` to make imports and exports into separate variables:

```

. rename _j year
. reshape wide Yr, i(country year) j(tradeflow) string
(note: j = exports imports)
Data                long  ->  wide
-----
Number of obs.      12   ->   6
Number of variables  4    ->   4
j variable (2 values)  tradeflow -> (dropped)
xij variables:
                    Yr    ->  Yrexports Yrimports
-----

```

Transforming the data to wide form once again, the `i()` option contains `country` and `year` as those are the desired identifiers on each observation of the target dataset. We specify that `tradeflow` is the `j()` variable for `reshape`, indicating that it is a `string` variable. The data now have the desired structure. Although we have illustrated this double-reshape transformation with only a few countries, years and variables, the technique generalizes to any number of each.

As a second example of successive applications of `reshape`, consider the World Bank's *World Development Indicators* (WDI) dataset.<sup>5</sup> Their extract program generates a comma-separated-value (CSV) database extract, readable by Excel or Stata, but the structure of those data hinders analysis as panel data. For a recent year, the header line of the CSV file is:

```

"Series code","Country Code","Country Name","1960","1961","1962","1963",
"1964","1965","1966","1967","1968","1969","1970","1971","1972","1973",
"1974","1975","1976","1977","1978","1979","1980","1981","1982","1983",
"1984","1985","1986","1987","1988","1989","1990","1991","1992","1993",
"1994","1995","1996","1997","1998","1999","2000","2001","2002","2003","2004"

```

That is, each row of the CSV file contains a *variable* and *country* combination, with

5. <http://econ.worldbank.org>

the columns representing the elements of the timeseries.<sup>6</sup>

Our target dataset structure is that appropriate for panel-data modeling with the variables as columns and rows labeled by country and year. Two applications of `reshape` will again be needed to reach the target format. We first `insheet` ([D] `insheet`) the data and transform the trilateral country code into a numeric code with the country codes as labels:

```
. insheet using wdiex.raw,comma names
. encode countrycode, generate(cc)
. drop countrycode
```

We then must deal with the fact that the timeseries variables are named `var4-var48`, as the header line provided invalid Stata variable names (numeric values) for those columns. We use `rename` ([D] `rename`) to change `v4` to `d1960`, `v5` to `d1961` and so on, as described in Section 3.6. We use a technique for macro expansion, involving the equals sign, by which an algebraic expression may be evaluated within a macro. In this case, the target variable name contains the string 1960, 1961, ..., 2004:

```
. forvalues i=4/48 {
.   rename v'i' d'=1956+'i''
. }
```

We now are ready to carry out the first `reshape`. We want to identify the rows of the reshaped dataset by both `countrycode` (`cc`) and `seriescode`, the variable name. The `reshape long` will transform a fragment of the WDI dataset containing two series and four countries:

```
reshape long d, i(cc seriescode) j(year)
(note: j = 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 197
> 3 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988
> 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 20
> 04)
```

Data	wide	->	long
Number of obs.	7	->	315
Number of variables	48	->	5
j variable (45 values)		->	year
xij variables:	d1960 d1961 ... d2004	->	d

```
list in 1/15
```

	cc	seriesc-e	year	countryname	d
1.	AFG	adjnetsav	1960	Afghanistan	.
2.	AFG	adjnetsav	1961	Afghanistan	.
3.	AFG	adjnetsav	1962	Afghanistan	.
4.	AFG	adjnetsav	1963	Afghanistan	.
5.	AFG	adjnetsav	1964	Afghanistan	.
6.	AFG	adjnetsav	1965	Afghanistan	.

6. A variation occasionally encountered will resemble this structure, but with time periods in reverse chronological order. The solution below can be used to deal with that problem as well.

7.	AFG	adjnetsav	1966	Afghanistan	.
8.	AFG	adjnetsav	1967	Afghanistan	.
9.	AFG	adjnetsav	1968	Afghanistan	.
10.	AFG	adjnetsav	1969	Afghanistan	.
11.	AFG	adjnetsav	1970	Afghanistan	-2.97129
12.	AFG	adjnetsav	1971	Afghanistan	-5.54518
13.	AFG	adjnetsav	1972	Afghanistan	-2.40726
14.	AFG	adjnetsav	1973	Afghanistan	-.188281
15.	AFG	adjnetsav	1974	Afghanistan	1.39753

The rows of the data are now labeled by year but one problem remains: all variables for a given country are stacked vertically. To unstack the variables and put them in shape for `xtreg` (`[XT] xtreg`), we must carry out a second `reshape` which spreads the variables across the columns, specifying `cc` and `year` as the *i* variables and *j* as `seriescode`. As that variable has string content we use the `string` option.

```

reshape wide d, i(cc year) j(seriescode) string
(note: j = adjnetsav adjsavC02)
Data                long   ->   wide
-----
Number of obs.      315   ->   180
Number of variables    5   ->    5
j variable (2 values)  seriescode -> (dropped)
xij variables:
                    d   ->  dadjnetsav dadjsavC02
-----

order cc countryname
tsset cc year
      panel variable:  cc (strongly balanced)
      time variable:  year, 1960 to 2004

```

After this transformation, the data are now in shape for `xt` modeling, tabulation or graphics.

As illustrated here, the `reshape` command can transform even the most inconvenient data structure into the structure needed for your research. It may take more than one application of `reshape` to get there from here, but it can do the job.

## 6.3 Handling time-series data effectively

**The problem:** daily data are often generated by non-daily processes. For instance, the financial markets are closed on weekends and many holidays.<sup>7</sup> Stata’s time-series date schemes ([U] 24. Dealing with dates and times) allow for daily (and intra-daily) data, but gaps in time-series may be problematic. A model that employs lags or differences will lose multiple observations every time a gap appears, discarding many of the original data points. Analysis of “business-daily” data often proceeds by assuming that Monday follows Friday, and so on. At the same time, we usually want data to be placed on Stata’s time-series calendar so that useful tools such as the [G] `tsline` ([G] `tsline`) graph will work and label data points with readable dates.

In a 2006 Stata Users Group presentation in Boston, David Drukker spoke to this point. His solution: generate two date variables, one containing the actual calendar dates, another numbering successive available observations consecutively. The former variable (`caldate`) is `tsset` ([TS] `tsset`) when the calendar dates are to be used, while the latter (`seqdate`) is `tsset` when statistical analyses are to be performed.

To illustrate, I download daily data on the three-month US Treasury bill rate with Drukker’s `freduse` command (Drukker (2006)) and retain the August 2005–present data for analysis.<sup>8</sup>

```
. clear
. freduse DTB3
(14263 observations read)
. rename daten caldate
. tsset caldate
      time variable:  caldate, 04jan1954 to 03sep2008, but with gaps
      delta: 1 day
. keep if tin(1aug2005,)
(13455 observations deleted)
. label var caldate date
. tsline DTB3
```

These data do not contain observations for weekends and are missing for US holidays. You may not want to drop the observations containing missing data, though, as we may have complete data for other variables. For instance, exchange rate data are available every day. If there were no missing data in our series—only missing observations—you could use Drukker’s suggestion and `generate seqdate = _n`. As there are observations for which `DTB3` is missing, you must follow a more complex route:

```
. quietly generate byte notmiss = !missing(DTB3)
. quietly generate seqdate = cond(notmiss,sum(notmiss),.)
. tsset seqdate
```

---

7. This recipe is adapted from Stata Tip 40 (Baum (2007)). I am grateful to David M. Drukker for his contributions to this Stata Tip.

8. If you run this example, you will retrieve a longer time-series, and produce different output than shown below.

```

time variable: seqdate, 1 to 776
              delta: 1 unit

```

The variable `seqdate` is created as the sequential day number for every non-missing day and is itself missing when `DTB3` is missing. This allows us to use this variable in `tsset` and then employ time-series operators (see [U] 11.4 **varlists**) in `generate` or estimation commands such as `regress`. You may want to display the transformed data (or results from estimation, such as predicted values) on a time-series graph. You can view the data graphically with `tsline` ([G] **tsline**): To do this, you can just revert to the other `tsset` declaration:

```

. quietly generate dDTB3 = D.DTB3
. label var dDTB3 "Daily change in 3-mo Treasury rate"
. tsset caldate
    time variable: caldate, 01aug2005 to 03sep2008, but with gaps
    delta: 1 day
. tsline dDTB3, yline(0)

```

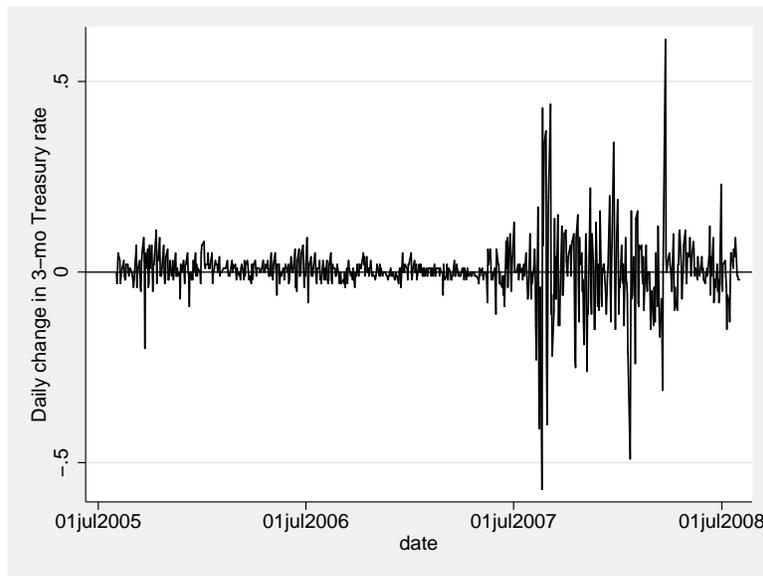


Figure 6.1: Change in Treasury bill rate.

If you retain both the `caldate` and `seqdate` variables in our saved dataset, you will always be able to view these data either on a time-series calendar or as a sequential series. In my research, I need to know how many calendar days separate each observed point (1 for Thursday–Friday but 3 for Friday–Monday) and then sum the `dDTB3` by month, weighting each observation by the square root of the days of separation:

```

. tsset seqdate
      time variable:  seqdate, 1 to 776
      delta: 1 unit
. quietly generate dcal = D.caldate if !missing(seqdate)
. quietly generate month = mofd(caldate) if !missing(seqdate)
. format %tm month
. sort month (seqdate)
. quietly by month: generate adjchange = sum(dDTB3/sqrt(dcal))
. quietly by month: generate sumchange = adjchange if _n==_N & !missing(month)
. list month sumchange if !missing(sumchange), sep(0) noobs

```

month	sumchange
2005m8	-.003812
2005m9	-.0810769
2005m10	.2424316
2005m11	-.063453
2005m12	.096188
2006m1	.2769615
2006m2	.099641
2006m3	.0142265
2006m4	.0938675
2006m5	.0350555
2006m6	.0327906
2006m7	.0304485
2006m8	-.083812
2006m9	-.123094
2006m10	.1338675
2006m11	-.0428446
2006m12	-.015
2007m1	.0523205
2007m2	.0023205
2007m3	-.1142265
2007m4	-.0973205
2007m5	-.2245855
2007m6	.012376
2007m7	.0089786
2007m8	-.9057735
2007m9	-.4818504
2007m10	-.0882864
2007m11	-.9123026
2007m12	-.029279
2008m1	-1.177312
2008m2	-.2422094
2008m3	-.6493376
2008m4	-.000718
2008m5	.377735
2008m6	-.1321539
2008m7	-.201188
2008m8	-.0783419
2008m9	-.02

## 6.4 reshape to perform row-wise computation

**The problem:** in the context of a panel (longitudinal) dataset, some attributes are stored in separate Stata variables. We want to perform some computations across those Stata variables.

In this example, taken from a question on Statalist, the user has a panel of elections identified by U.S. state and year with a set of variables listing names of candidates (given names only in this fictitious example):

```
. use cb5a, clear
. list
```

	state	year	cand1	cand2	cand3
1.	TX	2001	Tom	Dick	Harry
2.	TX	2005	Dick	Jane	Harry
3.	MA	2002	John	Jim	Jack
4.	MA	2003	Jim	Jill	Joan
5.	MA	2005	John	Jill	Jim

We want to compute the number of candidates who have stood for election in each state over the available years. Several candidates have stood more than once. This problem is solved by placing the data in Stata's *long* form with `reshape long`. The unique row identifier is constructed from the state and year variables with the `concat()` function from `egen` ([D] `egen`):

```
. egen rowid = concat(state year)
. reshape long cand, i(rowid) j(candnr)
(note: j = 1 2 3)
```

```
Data
```

---

	wide	->	long
Number of obs.	5	->	15
Number of variables	6	->	5
j variable (3 values)		->	candnr
xij variables:			
	cand1 cand2 cand3	->	cand

---

```
. list
```

	rowid	candnr	state	year	cand
1.	MA2002	1	MA	2002	John
2.	MA2002	2	MA	2002	Jim
3.	MA2002	3	MA	2002	Jack
4.	MA2003	1	MA	2003	Jim
5.	MA2003	2	MA	2003	Jill
6.	MA2003	3	MA	2003	Joan
7.	MA2005	1	MA	2005	John
8.	MA2005	2	MA	2005	Jill
9.	MA2005	3	MA	2005	Jim

10.	TX2001	1	TX	2001	Tom
11.	TX2001	2	TX	2001	Dick
12.	TX2001	3	TX	2001	Harry
13.	TX2005	1	TX	2005	Dick
14.	TX2005	2	TX	2005	Jane
15.	TX2005	3	TX	2005	Harry

```
. save cb5along, replace
file cb5along.dta saved
```

Alternatively, we could have created the `rowid` variable with

```
. generate rowid = state + string(year)
```

The `concat()` function has the advantage that it will perform any needed string conversions on the fly.

We now use `by-groups` and the `egen total()` function to produce the desired state-level tally. We return the data, now containing this state-level statistic, to the wide structure:

```
. bysort state cand: generate byte last=( _n == _N)
. egen totcand = total(last), by(state)
. drop last
. quietly reshape wide
. list, sepby(state)
```

	rowid	cand1	cand2	cand3	state	year	totcand
1.	MA2002	John	Jim	Jack	MA	2002	5
2.	MA2003	Jim	Jill	Joan	MA	2003	5
3.	MA2005	John	Jill	Jim	MA	2005	5
4.	TX2001	Tom	Dick	Harry	TX	2001	4
5.	TX2005	Dick	Jane	Harry	TX	2005	4

If only a table of states and the number of distinct candidates was needed, the `drop` and `egen` statements could be replaced with `tabstat` ([R] `tabstat`) applied to the `last` variable:

```
. tabstat last, stat(sum) nototal by(state)
```

```
Summary for variables: last
by categories of: state
```

state	sum
MA	5
TX	4

As an alternative, we could use the `tag()` function from `egen` which *tags* a single

observation in each distinct group defined by the `egen varlist`. Tagged observations are flagged by 1, while others have value 0. Thus, we could calculate the desired total for each state:

```
. use cb5along, clear
. egen indivcount = tag(state cand)
. egen totcand = total(indivcount), by(state)
. tabstat totcand, nottotal by(state)
```

Summary for variables: totcand  
by categories of: state

state	mean
MA	5
TX	4

Although we illustrate this concept of employing `reshape long` in the context of panel data, it is equally useful in many cross-section datasets. Many applications which would involve the use of row-wise operators in a spreadsheet can be better handled in Stata by transforming the data to the long structure and transforming it back to wide if desired.

## 6.5 Adding computed statistics to presentation-quality tables

**The problem:** you need to produce presentation-quality tables from estimation output that include quantities not available in the `ereturn list`. Stata's `mfx` command (`[R] mfx`) can compute many measures of marginal effects, and its computed quantities can be stored with the saved estimates via `estimates store`. However, there is no way to access those stored quantities with `estimates table`.

A solution to this problem, removing the need for manual editing of the tables, is available from Ben Jann's `estout` suite, described in Section 5.4.1. First of all, the quantities to be retrieved from the estimates must be made into additional scalars and stored with the estimates using `estadd`. Then, those scalars may be requested in the `esttab` output as additional statistics, and given appropriate labels.

In the example below, we estimate two forms of an equation from the `usairquality` dataset (Rabe-Hesketh and Everitt (2006)) using OLS (`regress`) and IV (`ivregress 2sls`). The variable of interest is `so2`, the sulphur dioxide concentration in each city's atmosphere. This pollutant is modeled as a function of the city's population, number of manufacturing establishments and average wind speed. In the instrumental variables estimation, we consider population as possibly endogenous, and instrument it with average temperature and mean precipitation.

After each estimation, we use `mfx compute`, `eyex` to compute the elasticities of `so2` with respect to each regressor.<sup>9</sup> As `mfx` is an e-class command, its results are accessible: in this case, in matrices `e(Xmfx_eyex)` and `e(Xmfx_se_eyex)` for the elasticity point estimates and their standard errors, respectively. The `[1,1]` element of each matrix refers to `mpg`, as it is the first regressor. We store that element of the matrix as a scalar, `nu` for the elasticity and `nuse` for its standard error, before storing the estimates.

```
. use airquality, clear
. // estimate with OLS
. qui regress so2 pop manif wind
. mfx compute, eyex
Elasticities after regress
      y = Fitted values (predict)
      = 30.04878
```

variable	ey/ex	Std. Err.	z	P> z	[ 95% C.I. ]	X
pop	-1.158096	.30621	-3.78	0.000	-1.75826 - .55793	608.61
manuf	1.291947	.25205	5.13	0.000	.797928 1.78597	463.098
wind	-.4346578	.55942	-0.78	0.437	-1.53111 .661794	9.4439

```
. matrix nu = e(Xmfx_eyex)
. estadd scalar nu = nu[1, 1]
added scalar:
      e(nu) = -1.158096
```

9. Elasticities are discussed in Section 9.5.

```

. matrix nuse = e(Xmfx_se_eyex)
. estadd scalar nuse = nuse[1, 1]
added scalar:
      e(nuse) = .30621274
. estimates store one
. // reestimate using IV
. qui ivregress 2sls so2 (pop = temp precip) manuf wind
. mfx compute, eyex
Elasticities after ivregress
      y = Fitted values (predict)
      = 30.04878

```

variable	ey/ex	Std. Err.	z	P> z	[	95% C.I.	]	X
pop	-2.599056	.83744	-3.10	0.002	-4.24041	-.957699		608.61
manuf	2.37258	.64775	3.66	0.000	1.10301	3.64215		463.098
wind	-.5755015	.68932	-0.83	0.404	-1.92655	.775546		9.4439

```

. matrix nu = e(Xmfx_eyex)
. estadd scalar nu = nu[1, 1]
added scalar:
      e(nu) = -2.5990558
. matrix nuse = e(Xmfx_se_eyex)
. estadd scalar nuse = nuse[1, 1]
added scalar:
      e(nuse) = .83744228
. estimates store two

```

We now are ready to use `esttab` to present the estimates. The `stat()` option allows us to name the `nu` and `nuse` scalars as added statistics and give them appropriate labels.

```

. esttab one two, mtitles("OLS" "IV") stat(nu nuse, labels("Elas.(pop)" "SE"))

```

	(1) OLS	(2) IV
pop	-0.0572*** (-3.97)	-0.128** (-3.26)
manuf	0.0838*** (5.63)	0.154*** (3.93)
wind	-1.383 (-0.78)	-1.831 (-0.84)
_cons	39.09* (2.32)	54.15* (2.47)
Elas.(pop)	-1.158	-2.599
SE	0.306	0.837

```

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

```

Using additional options on `esttab`, we could create a table in L<sup>A</sup>T<sub>E</sub>X, HTML, CSV, RTF or tab-delimited format.

## 6.5.1 Presenting marginal effects rather than coefficients

When presenting the results from limited dependent variable estimation commands such as `probit` ([R] `probit`) or `logit` ([R] `logit`), it is usual practice to display the effects on the probability of observing unity rather than the raw coefficient estimates. The latter estimates reflect  $\partial I/\partial X_j$ , that is, the change in the *index variable* or *latent variable* resulting from a change in  $X_j$ . Stata can readily compute the quantities  $\partial Pr[y = 1]/\partial X_j$  with `mf`, but how may you present them in a publication-quality table for a set of equations?

The `margin` option on Ben Jann's `esttab` and `estout` commands provide this capability. With that option specified, display of the raw coefficient estimates is suppressed, and the desired marginal effects and their standard errors are displayed in their place. As an example, let's generate an indicator variable for cities with sulphur dioxide concentration above and below the median level, and estimate two forms of a `probit` model:

```
. qui summarize so2, detail
. generate hiso2 = (so2 > r(p50)) & !missing(so2)
. summarize precip, meanonly
. generate hiprecip = (precip > r(mean)) & !missing(precip)
. qui probit hiso2 pop manif
. mfx compute
Marginal effects after probit
  y = Pr(hiso2) (predict)
  = .50262647
```

variable	dy/dx	Std. Err.	z	P> z	[	95% C.I.	]	X
pop	-.0008596	.00055	-1.57	0.115	-.00193	.000211		608.61
manuf	.001419	.00068	2.08	0.037	.000084	.002754		463.098

```
. estimates store three
. qui probit hiso2 pop manif hiprecip
. mfx compute
Marginal effects after probit
  y = Pr(hiso2) (predict)
  = .503741
```

variable	dy/dx	Std. Err.	z	P> z	[	95% C.I.	]	X
pop	-.0009268	.00056	-1.67	0.095	-.002016	.000163		608.61
manuf	.0015382	.00071	2.17	0.030	.000151	.002925		463.098
hiprecip*	.1562071	.17248	0.91	0.365	-.181851	.494265		.560976

(\*) dy/dx is for discrete change of dummy variable from 0 to 1

```
. estimates store four
```

It is straightforward to present the marginal effects using `esttab`:

```
. esttab three four, margin
```

	(1)	(2)
	hiso2	hiso2
pop	-0.000860 (-1.57)	-0.000927 (-1.67)
manuf	0.00142* (2.08)	0.00154* (2.17)
hiprecip (d)		0.156 (0.91)
N	41	41

Marginal effects; t statistics in parentheses  
(d) for discrete change of dummy variable from 0 to 1  
\* p<0.05, \*\* p<0.01, \*\*\* p<0.001

As in the prior example, this tabular output could be presented in any of several formats in addition to the default SMCL.

## 6.6 Generating time series data at a lower frequency

**The problem:** your data are on a time series calendar, but you want to express them at a lower time series frequency. For instance, you may have monthly data, but you would like to present them as quarterly data. You might want to retain only one observation per quarter (such as the quarter-end value), or sum the values over the quarter, or average the values over the quarter depending on the type of data.

To solve this problem, I will make use of a handy tool, `tsmktim` (Baum and Wiggins (2000)), which will compute a time series calendar variable given the first observation's value.<sup>10</sup> The `tsmktim` command also automatically applies `tsset` with the appropriate frequency so that time series operators and functions may be used. It is your responsibility to ensure that the data are correctly sorted in time order and have no missing time periods before invoking `tsmktim`.

We access the `air2` dataset of airline passenger boardings. This contains a variable `time` taking on values 1949.0, 1949.083, 1949.167, etc. but no proper Stata calendar variable. We generate such a variable with `tsmktim` as `ym`. The option `start(1949m1)` tells the command that these data are to be placed on a monthly calendar. To compute the month of each observation, we use the Stata date functions `month()` and `dofm()`. The last month of each quarter can be found with the `mod()` function; quarter-end month numbers are evenly divisible by 3, providing the indicator variable `eoq`.

```
. use air2, clear
(TIMESLAB: Airline passengers)
. * put a timeseries calendar on the data
. tsmktim ym, start(1949m1)
      time variable:  ym, 1949m1 to 1960m12
      delta: 1 month
. * get the month number
. generate mnr = month(dofm(ym))
. * find the end-of-quarter months
. generate eoq = (mod(mnr, 3) == 0)
. list ym mnr eoq air in 1/16, sep(4) noobs
```

ym	mnr	eoq	air
1949m1	1	0	112
1949m2	2	0	118
1949m3	3	1	132
1949m4	4	0	129
1949m5	5	0	121
1949m6	6	1	135
1949m7	7	0	148
1949m8	8	0	148
1949m9	9	1	136
1949m10	10	0	119
1949m11	11	0	104
1949m12	12	1	118

10. The most recent version of `tsmktim` is available from the SSC Archive ([R] `ssc`).

1950m1	1	0	115
1950m2	2	0	126
1950m3	3	1	141
1950m4	4	0	135

We now can consider each of the proposed tasks. To retain only the quarter-end observations, we need only `keep` the values indicated by `eoq`, and use `tsmktim` on the new series to define it as quarterly data:

```
. // keep only last month of quarter
. keep if eoq
(96 observations deleted)
. tsmktim yq, start(1949q1)
      time variable: yq, 1949q1 to 1960q4
      delta: 1 quarter
. list yq air in 1/16, sep(4) noobs
```

yq	air
1949q1	132
1949q2	135
1949q3	136
1949q4	118
1950q1	141
1950q2	149
1950q3	158
1950q4	140
1951q1	178
1951q2	178
1951q3	184
1951q4	166
1952q1	193
1952q2	218
1952q3	209
1952q4	194

To sum the values over the quarter, we must compute the quarter associated with each month in Stata's calendar system, using the `qofd()` function. We can then use `collapse` to create the new dataset of quarterly values, each of which is the sum of the monthly values of `air`. We again use `tsmktim` to generate the new quarterly calendar variable.

```
. // sum the values over the quarter
. generate qtr = qofd(dofm(ym))
. format qtr %tq
. collapse (sum) airsum=air, by(qtr)
. tsmktim yq, start(1949q1)
      time variable: yq, 1949q1 to 1960q4
      delta: 1 quarter
```

```
. list yq airsum in 1/16, sep(4) noobs
```

yq	airsum
1949q1	362
1949q2	385
1949q3	432
1949q4	341
1950q1	382
1950q2	409
1950q3	498
1950q4	387
1951q1	473
1951q2	513
1951q3	582
1951q4	474
1952q1	544
1952q2	582
1952q3	681
1952q4	557

If instead we wanted the average values over each quarter, we would merely apply `collapse` which computes the mean as a default:

```
. // average the values over the quarter
. generate qtr = qofd(dofm(ym))
. format qtr %tq
. collapse airavg=air, by(qtr)
. tsmktime yq, start(1949q1)
    time variable: yq, 1949q1 to 1960q4
    delta: 1 quarter
. list yq airavg in 1/16, sep(4) noobs
```

yq	airavg
1949q1	120.667
1949q2	128.333
1949q3	144
1949q4	113.667
1950q1	127.333
1950q2	136.333
1950q3	166
1950q4	129
1951q1	157.667
1951q2	171
1951q3	194
1951q4	158
1952q1	181.333

1952q2	194
1952q3	227
1952q4	185.667

As these tasks with time series data are encountered quite commonly, a variation on the official `collapse` command is available in the `tscollapse` routine (Baum (2000)).<sup>11</sup> The syntax of `tscollapse` mirrors that of `collapse`, with one additional mandatory option: the frequency to which the time series are to be collapsed. In this case, `to(q)` specifies that the monthly data are to be collapsed to quarterly. Optionally, the `generate()` option can be used to name the time series calendar variable that will be created. To illustrate:

```
. tsset ym
      time variable:  ym, 1949m1 to 1960m12
                delta: 1 month
. tscollap (last) aireoq=air (sum) airsum=air (mean) airavg=air, to(q) gen(yq)
```

Converting from M to Q

```
      time variable:  yq, 1949q1 to 1960q4
                delta: 1 quarter
. list in 1/16, sep(4) noobs
```

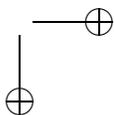
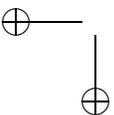
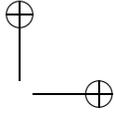
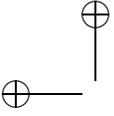
aireoq	airsum	airavg	yq
132	362	120.667	1949q1
135	385	128.333	1949q2
136	432	144	1949q3
118	341	113.667	1949q4
141	382	127.333	1950q1
149	409	136.333	1950q2
158	498	166	1950q3
140	387	129	1950q4
178	473	157.667	1951q1
178	513	171	1951q2
184	582	194	1951q3
166	474	158	1951q4
193	544	181.333	1952q1
218	582	194	1952q2
209	681	227	1952q3
194	557	185.667	1952q4

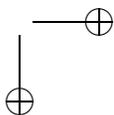
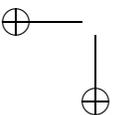
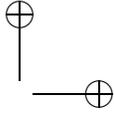
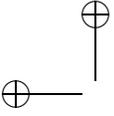
In this case, we see that all three operations on the `air` time series may be performed by a single invocation of `tscollapse`.

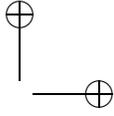
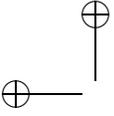
For another recipe involving generating lower-frequency measures from time series

11. The most recent version of `tscollapse` is available from the SSC Archive ([R] `ssc`).

data, see Section 8.3.







# 7 Do-file programming: prefixes, loops and lists

## 7.1 Introduction

Stata's facility for efficient data management, statistical analysis and graphics is largely based on the ability to program repetitive tasks, avoiding manual effort and reducing errors. In developing your use of these techniques, you should always consider how you can get the computer to do what it does best. Any research project involves repetitive tasks of some sort and a modest amount of time taken automating those tasks will greatly reduce your workload and likelihood of errors.

In this chapter, we discuss three programming features specifically applicable to repetitive tasks: Stata's prefix operators, loop commands and list constructs.

### 7.1.1 What you should learn from this chapter

- How to use the `by` and `xi` prefix operators effectively
- How to use `statsby` and `rolling` to collect statistics
- How to perform Monte Carlo simulations
- How to compute `bootstrap` and `jackknife` estimates of precision
- How to perform loops with `forvalues` and `foreach`

## 7.2 Prefix operators

Stata's prefix operators perform repetitive tasks without explicit specification of the range of values over which the tasks are to be performed. This is of particular value when the distribution of values may be discontinuous or forms no particular pattern. These operators will often serve your needs in performing tasks with minimal programming, but they also have limitations. For instance, the `by` (`[D]` `by`) prefix repetitively executes a single command but cannot perform multiple commands. In terms of ease of use, it is a good strategy to consider whether a prefix operator will serve your needs before turning to more complicated programming constructs.

### 7.2.1 The `by` operator

Many Stata users are already familiar with the `by` ([D] `by`) prefix operator, as discussed in Section 3.5. The syntax

```
by varlist [, sort]: command
```

specifies that *command* is to be repeated for each distinct value of the *varlist*. Consider the simplest case, where *varlist* contains a single variable: if numeric, an integer (categorical) variable, or a string variable. If the data are not sorted by that variable (or in general terms by the *varlist*) before employing `by`, the `sort` option or the form `bysort varlist` should be used. The *command* will be repeated for each distinct value of the variable regardless of how many values that may entail. Repetitions will follow the sorting order of the variable, whether string or numeric.

If the *varlist* contains multiple variables, the same principle applies. The data must be sorted by the *varlist*, or `bysort` may be used. The *command* will be repeated for each distinct combination of values in the *varlist*. Consider the `bpress` dataset containing blood pressure measurements of individuals categorized by gender (with an indicator `sex`, 0=male) and one of three `agegrp` codes (1=30-45, 2=46-59, 3=60+).

```
. use bpress, clear
(fictional blood-pressure data)
. bysort sex agegrp: summarize bp
```

```
-> sex = Male, agegrp = 30-45
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	119.95	12.53498	95	146

```
-> sex = Male, agegrp = 46-59
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	128.15	13.90914	102	155

```
-> sex = Male, agegrp = 60+
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	134.075	10.27665	116	155

```
-> sex = Female, agegrp = 30-45
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	116.05	9.483995	101	138

```
-> sex = Female, agegrp = 46-59
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	117.725	10.10201	97	140

```
-> sex = Female, agegrp = 60+
```

Variable	Obs	Mean	Std. Dev.	Min	Max
bp	40	127.475	12.02985	108	155

The `summarize` ([R] `summarize`) command will be executed for each combination of `sex` and `agegrp`. If a combination did not exist in the data (for instance, if there were no elderly males in our sample) it will merely be skipped.

Another way in which you might approach this problem makes use of the `egen` function `group()`. This function creates a variable taking on values 1, 2, ... for the groups formed by `varlist`. To create groups by gender and age group, we could use

```
. egen group = group(sex agegrp), label
. by group, sort: summarize bp
```

The `label` option causes the groups defined by `egen` to be labeled with the elements of each group, so that the `summarize` headers will read

```
-> group = Male 30-45
```

and so on. For additional pointers on using `by:`, see Cox (2002a).

A `by:` option `rc0` (return code zero), specified before the colon, is often useful. You might specify `command` to be an estimation command which would fail if insufficient observations existed in a particular `by`-group. This would normally abort the do-file, which might be appropriate if you expected that all `by`-groups could be successfully processed. In many cases, though, you may know that there are some infeasible `by`-groups. Rather than having to program for that eventuality, you can specify `rc0` to force `by` to continue through the remaining `by`-groups.

## 7.2.2 The xi operator

While `by` repeats a command based on the distinct values of `varlist`, we often want to produce indicator (binary, or dummy) variables for each of those distinct values. The `xi` ([R] `xi`) command prefix serves two roles. It may be used by itself to produce a set of indicator variables from one or more *terms*. More commonly, it is used in conjunction with another command in which those terms play a role. To understand its function, we must first define the terms which `xi` comprehends.

In the simplest form, a *term* may be just `i.varname`, where `varname` refers to a numeric or string categorical variable.<sup>1</sup> For instance, using

```
. xi i.agegrp
```

Stata will create two indicator variables, omitting the lowest value (which Stata refers to as *naturally coded* indicators). By default the indicator variables will be named `_Iagegrp2` and `_Iagegrp3` and their variable labels will contain the name of the cat-

1. `I.varname` (with a capital I) may also be used.

egorical variable and its level. Using the `prefix(string)` option, the prefix may be specified as something other than `_I`. You may refer to the set of indicator variables with a wildcard: for instance,

```
. regress bp _I*
```

will include both `agegrp` indicator variables in the regression. When you use `xi`, all previously created variables with the same prefix (for example, `_I`) will be automatically dropped.

For a single term (such as `i.agegrp`) similar functionality is available using the command

```
tabulate varname, generate( prefix )
```

with the distinction that `tabulate` will generate a full set of indicator variables.

More commonly, `xi` may be used as a prefix operator, preceding another Stata command to produce the needed indicator variables on the fly:

```
. xi: regress bp i.agegrp
```

More than one *term* may be included in either format of `xi`. For instance,

```
. xi: regress income i.agegrp i.sex
```

would include both two `agegrp` dummies and one `sex` dummy (denoting females) in the regression:

```
. xi: regress bp i.agegrp i.sex
i.agegrp      _Iagegrp_1-3      (naturally coded; _Iagegrp_1 omitted)
i.sex         _Isex_0-1        (naturally coded; _Isex_0 omitted)

+-----+-----+-----+-----+-----+-----+
Source |           SS       df       MS              Number of obs =    240
-----+-----+-----+-----+-----+-----+              F(   3,   236) =   23.98
Model  |  9559.19583        3   3186.39861          Prob > F       =   0.0000
Residual|  31353.6          236  132.854237          R-squared      =   0.2336
-----+-----+-----+-----+-----+-----+          Adj R-squared =   0.2239
Total  |  40912.7958      239  171.183246          Root MSE     =  11.526

+-----+-----+-----+-----+-----+-----+
bp      |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----+-----+-----+-----+-----+-----+
_Iagegrp_2 |   4.9375   1.822459     2.71  0.007   1.347134   8.527866
_Iagegrp_3 |  12.775    1.822459     7.01  0.000   9.184634  16.36537
_Isex_1    |  -6.975    1.488031    -4.69  0.000  -9.906521 -4.043479
_cons     |  121.4875  1.488031    81.64  0.000  118.556   124.419
+-----+-----+-----+-----+-----+-----+
```

The advantages of `xi` are clearly evident when *interactions* of variables are to be used in a model. In the example above, you may want to allow `agegrp` and `sex` to have non-independent effects on `bp`. This implies that two interaction terms must also be created, one for each combination of included `agegrp` and `sex` terms. This can be achieved by using

```
. xi: regress bp i.agegrp*i.sex
```

This model will include both the *main effects* of the qualitative factors `agegrp` and `sex` as well as the *interaction effects* of those two factors. The interaction terms will be named to specify their elements: for instance, `_IsexXage_1_3` is the interaction (X) of `sex = 1` and `agegrp = 3`. Note that the variable name `agegrp` has been shortened to ensure that the variable names obey length limits.

```
. xi: regress bp i.agegrp*i.sex
i.agegrp      _Iagegrp_1-3      (naturally coded; _Iagegrp_1 omitted)
i.sex         _Isex_0-1         (naturally coded; _Isex_0 omitted)
i.age~p*i.sex  _IageXsex_#_#     (coded as above)
```

Source	SS	df	MS	Number of obs = 240		
Model	9989.17083	5	1997.83417	F( 5, 234) =	15.12	
Residual	30923.625	234	132.152244	Prob > F =	0.0000	
Total	40912.7958	239	171.183246	R-squared =	0.2442	
				Adj R-squared =	0.2280	
				Root MSE =	11.496	

bp	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
_Iagegrp_2	8.2	2.570528	3.19	0.002	3.135666	13.26433
_Iagegrp_3	14.125	2.570528	5.49	0.000	9.060666	19.18933
_Isex_1	-3.9	2.570528	-1.52	0.131	-8.964334	1.164334
_IageXse-2_1	-6.525	3.635275	-1.79	0.074	-13.68705	.6370503
_IageXse-3_1	-2.7	3.635275	-0.74	0.458	-9.86205	4.46205
_cons	119.95	1.817638	65.99	0.000	116.369	123.531

A similar syntax may also be used to interact a categorical variable such as `agegrp` with a continuous variable. If you had a measurement of blood pressure from the previous year's examination (`bp0`) you could use the syntax

```
. xi: regress bp i.agegrp*bp0
```

to estimate a model in which each `agegrp` has its own constant term and slope. The coefficient on `bp0` is the effect of that variable for `agegrp = 1`, and the coefficients on `_IageXbp0_2` and `_IageXbp0_3` are the contrasts between the slopes of `agegrp = 2, 3` and `agegrp = 1`, respectively.

```
. xi: regress bp i.agegrp*bp0
i.agegrp      _Iagegrp_1-3      (naturally coded; _Iagegrp_1 omitted)
i.agegrp*bp0  _IageXbp0_#_#     (coded as above)
```

Source	SS	df	MS	Number of obs = 240		
Model	39135.1347	5	7827.02693	F( 5, 234) =	1030.30	
Residual	1777.66117	234	7.59684259	Prob > F =	0.0000	
Total	40912.7958	239	171.183246	R-squared =	0.9565	
				Adj R-squared =	0.9556	
				Root MSE =	2.7562	

bp	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
_Iagegrp_2	-6.916522	4.092998	-1.69	0.092	-14.98036	1.147314
_Iagegrp_3	-.4387195	4.423308	-0.10	0.921	-9.153316	8.275876
bp0	.9269775	.0262564	35.30	0.000	.8752485	.9787066
_IageXbp0_2	.0527261	.0352761	1.49	0.136	-.0167733	.1222255

<code>_IageXbp0_3</code>	.0079293	.0368904	0.21	0.830	-.0647505	.0806091
<code>_cons</code>	13.58902	2.97342	4.57	0.000	7.730927	19.44712

One other type of *term* may be handled by `xi` for the interaction of categorical and continuous variables.<sup>2</sup> The syntax

```
. xi: regress bp i.agegrp|bp0
```

specifies that the interaction variables should be included in the model, but that the main effects of the categorical variable should not. The constant term of this regression pertains to all observations, while the slope with respect to `bp0` is allowed to differ by `agegrp` categories.

### 7.2.3 The statsby operator

As mentioned above, a limitation of `by:` is that only a single `command` may be specified. When performing an estimation command such as `regress` ([R] `regress`), you may want to both view the regression output for each `by`-group and save some of the statistics produced in each regression. These might include some or all of the estimated coefficients, their standard errors and summary statistics from the regression. This functionality is provided by the `statsby` ([D] `statsby`) prefix operator. With the syntax

```
statsby exp_list, by( varlist ) [options] : command
```

the *command* will be executed for each element of the `by`-list, as with `by`. However, the *exp\_list* specifies that for each repetition, the results of evaluating one or more expressions are to be saved. By default, the dataset in memory will be replaced by the saved expressions. To preserve the existing contents of memory, you may use the `saving(filename)` option of `statsby` (before the colon) to specify the name of a new dataset.

Using the example given above for `by:`, you could use the command

```
. statsby mean=r(mean) sd=r(sd) n=r(N), by(agegrp sex) saving(bpstats, replace): summarize bp
```

to produce a new dataset named `bpstats` with one observation per `by`-group. The dataset will contain three variables specified in the *exp\_list*: the mean, standard deviation and number of observations in each `by`-group. It will also contain one variable for each element of the `by`-list to identify from which combination of variables the observation was calculated (in this example, `agegrp` and `sex`).

```
. statsby mean=r(mean) sd=r(sd) n=r(N), by(agegrp sex) saving(bpstats, replace)
> : summarize bp
(running summarize on estimation sample)
      command: summarize bp
      mean:   r(mean)
```

<sup>2</sup> If you are using `anova` ([R] `anova`), note that it has its own specific syntax for defining interaction effects.

```

sd: r(sd)
n: r(N)
by: agegrp sex

Statsby groups
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
      1 |      2 |      3 |      4 |      5
.....
. use bpstats, clear
(statsby: summarize)
. list, sepby(agegrp)

```

	agegrp	sex	mean	sd	n
1.	30-45	Male	119.95	12.53498	40
2.	30-45	Female	116.05	9.483994	40
3.	46-59	Male	128.15	13.90914	40
4.	46-59	Female	117.725	10.10201	40
5.	60+	Male	134.075	10.27665	40
6.	60+	Female	127.475	12.02985	40

The `total` option on `statsby` specifies that an additional observation should be generated for the entire dataset specified by the *command*. The values of the `by`-variables are set to missing for the observation corresponding to the total.

## 7.2.4 The rolling operator

The `statsby` ([D] `statsby`) prefix computes statistics for *non-overlapping* subsamples. In the context of time series data, you often want to compute statistics for *overlapping* subsamples: so-called *rolling window* estimation using the `rolling` ([TS] `rolling`) prefix. For instance, you may want to forecast a variable for a number of time periods, using only the observations available at the time to make a one-period-ahead forecast. The window may be an ever-widening window, including more observations over time (referred to as *recursive* estimation), or the window width may be fixed, so that a chosen number of past time periods are considered in each computation. In the latter case, the number of available observations in each window may vary due to holidays, weekends, etc. in the case of daily data.<sup>3</sup>

Like the `statsby` prefix, the `rolling` prefix can create a new dataset of results from the specified statistical command. With the syntax

```
rolling exp_list [if exp] [in range] [, options] : command
```

the *command* will be executed as specified by the *options*. For instance, if `window(12)` is specified, twelve time periods will be included in each estimation. The *exp\_list* specifies that for each repetition, one or more expressions are to be saved. By default, the dataset

<sup>3</sup> The `rolling` prefix also supports *reverse recursive* analysis, where the endpoint is held fixed and the starting period varies.

in memory will be replaced by the saved expressions. To preserve the existing contents of memory, you may use the `saving(filename)` option of `rolling` (before the colon) to specify the name of a new dataset.

To illustrate, we estimate a quantile regression (`qreg`, [R] `qreg`) of the daily return on IBM stock on the S&P 500 index return, using a 90-day window. This regression represents the celebrated Capital Asset Pricing Model (CAPM) in which the slope coefficient measures the sensitivity of the stock's return to that of the market (the so-called *CAPM beta*). Finance theory predicts that stocks with higher betas are more risky, and require a higher return.

```
. use ibm, clear
(Source: Yahoo! Finance)
. rolling _b _se, window(90) saving(capm, replace) nodots: qreg ibm spx
file capm.dta saved
```

We may now examine the resulting Stata data file created by `rolling`. The `start` and `end` variables indicate the endpoints of each moving window. The variable of particular interest is `_b_spx`, the coefficient of the S&P 500 index return.

```
. use capm, clear
(rolling: qreg)
. label var _b_spx "quantile reg IBM beta"
. label var end "date"
. list in 1/5
```

	start	end	_b_spx	_b_cons	_se_spx	_se_cons
1.	02jan2003	01apr2003	1.066401	.1961641	.0866684	.1246594
2.	03jan2003	02apr2003	1.123538	.2001785	.0668068	.0978385
3.	04jan2003	03apr2003	1.123538	.2001785	.0667553	.097853
4.	05jan2003	04apr2003	1.094441	.1730048	.0870072	.126642
5.	06jan2003	05apr2003	1.094441	.1730048	.0870072	.126642

You could graph the movements of the rolling CAPM beta coefficients:

```
. tsset end
      time variable: end, 01apr2003 to 16dec2004
                delta: 1 day
. format end %tdMonYY
. tsline _b_spx, yline(1) saving(fig7_1, replace) scheme(s2mono)
(file fig7_1.gph saved)
```

In the CAPM model, a beta of one implies that the volatility of the stock price is equal to that of the market index. Values above one imply that the stock price is more volatile than the market index, and *vice versa*. From Figure 7.1, it appears that IBM shares became less sensitive to stock market movements over the period.

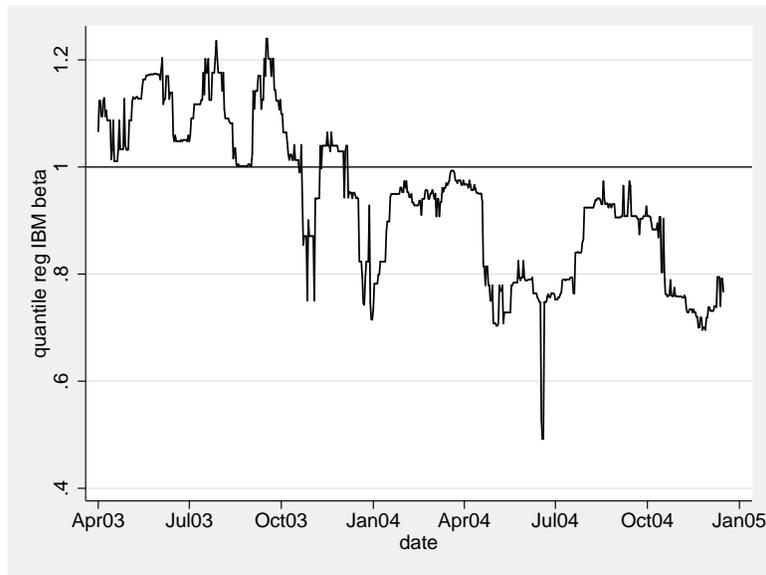


Figure 7.1: Rolling robust regression coefficients.

## 7.2.5 The simulate and permute operators

The `simulate` ([R] `simulate`) prefix provides Stata's facilities for Monte Carlo simulation. Like the other prefix commands, `simulate` repeatedly executes a specified *command*. In this case, the `reps()` option specifies how many repetitions of the command are to be performed, each one producing a set of results in the *exp-list*. With formal syntax

```
simulate exp-list, reps( # ) [options] : command
```

`simulate` works quite similarly to other prefix commands, with one important difference: the *command* often will refer to a user-written program or ado-file.<sup>4</sup> You could, for instance, simulate the behavior of several percentiles of a randomly distributed random variable with the following program. In this case, the program you must write is quite formulaic: it clears memory, sets the number of observations in the dataset, creates a random variable and generates its descriptive statistics. Those statistics are passed back to `simulate` as scalars through the return list (see Section 5.3).

```
. type simpctile.ado
capture program drop simpctile
program simpctile, rclass
    version 10.1
    drop _all
```

4. We defer a full discussion of writing an ado-file to Chapter 11.

```

set obs 200
generate z = invnormal(uniform())
summarize z, detail
return scalar p25 = r(p25)
return scalar p50 = r(p50)
return scalar p75 = r(p75)
end

```

Once we have written this program and stored it in `simpctile.ado`, we are ready to execute it, specifying that we want to perform 1,000 repetitions. Setting the `seed` of Stata's pseudo-random number generator guarantees that the results will be identical for multiple runs of the experiment (preferable during debugging of our program).

```

. clear
. set seed 2007062926
. simulate p25=r(p25) p50=r(p50) p75=r(p75), reps(1000) nodots ///
> saving(pctiles, replace): simpctile
command: simpctile
p25: r(p25)
p50: r(p50)
p75: r(p75)

```

We can examine the distribution of these three percentiles of our  $N(0, 1)$  random variables statistically, and graph the distribution of sample median in a histogram.

```

. use pctiles, clear
(simulate: simpctile)
. summarize

```

Variable	Obs	Mean	Std. Dev.	Min	Max
p25	1000	-.6727567	.0944072	-.9533168	-.3055624
p50	1000	-.001541	.0884508	-.2731787	.3048038
p75	1000	.6694791	.0912676	.3836729	.9612866

```

. label var p50 "Sample median"
. histogram p50, normal saving(fig7_2, replace) scheme(s2mono)
(bin=29, start=-.2731787, width=.01993043)
(file fig7_2.gph saved)

```

Figure 7.2 illustrates that the distribution of the sample median is slightly skewed relative to that of a standard Normal variate in this example. The overlay of the standard Normal distribution is produced by the `normal` option. This is confirmed by the descriptive statistics for `p50`, in which nonzero skewness is apparent:

```

. use bpress, clear
(fictional blood-pressure data)
. set seed 2007062926
. ttest bp, by(sex)
Two-sample t test with equal variances

```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
-------	-----	------	-----------	-----------	----------------------

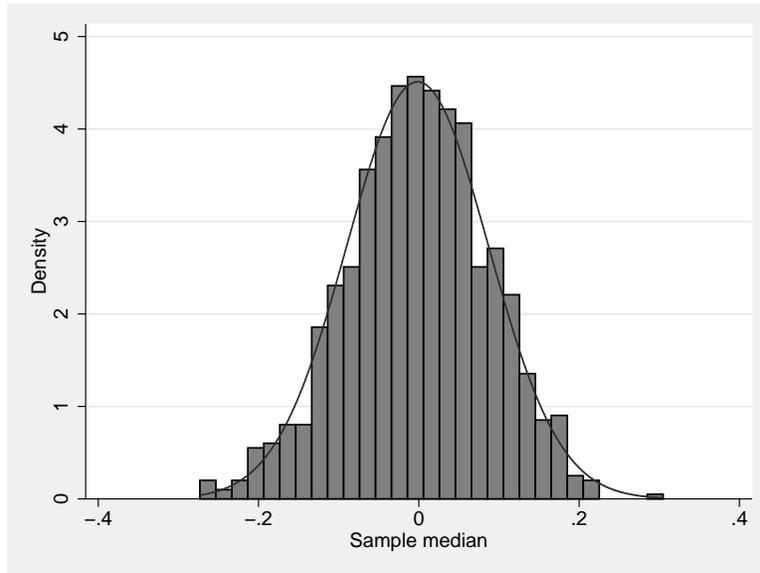


Figure 7.2: Distribution of sample median via Monte Carlo simulation.

Male	120	127.3917	1.236031	13.54004	124.9442	129.8391
Female	120	120.4167	1.064357	11.65944	118.3091	122.5242
combined	240	123.9042	.8445493	13.0837	122.2405	125.5679
diff		6.975	1.631143		3.761679	10.18832

```
diff = mean(Male) - mean(Female)                t = 4.2761
Ho: diff = 0                                    degrees of freedom = 238
```

```
Ha: diff < 0                                Ha: diff != 0                                Ha: diff > 0
Pr(T < t) = 1.0000                          Pr(|T| > |t|) = 0.0000                          Pr(T > t) = 0.0000
```

```
. bootstrap diff=( r(mu_1) - r(mu_2) ), nodots: ttest bp, by(sex)
```

```
Warning: Since ttest is not an estimation command or does not set e(sample),
bootstrap has no way to determine which observations are used in
calculating the statistics and so assumes that all observations are
used. This means no observations will be excluded from the
resampling because of missing values or other reasons.
```

```
If the assumption is not true, press Break, save the data, and drop
the observations that are to be excluded. Be sure that the dataset
in memory contains only the relevant data.
```

```
Bootstrap results                                Number of obs    =    240
                                                Replications     =    50
```

```
command: ttest bp, by(sex)
diff: r(mu_1) - r(mu_2)
```

	Observed	Bootstrap	Normal-based
--	----------	-----------	--------------

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
diff	6.975	1.271685	5.48	0.000	4.482544 9.467456

Alternatively, we can examine the distribution of sample median with a Q-Q plot, using `qnorm` ([R] **diagnostic plots**):

```
. use pctiles, clear
(simulate: simptile)
. qnorm p50, saving(fig7_3, replace) scheme(s2mono)
(file fig7_3.gph saved)
```

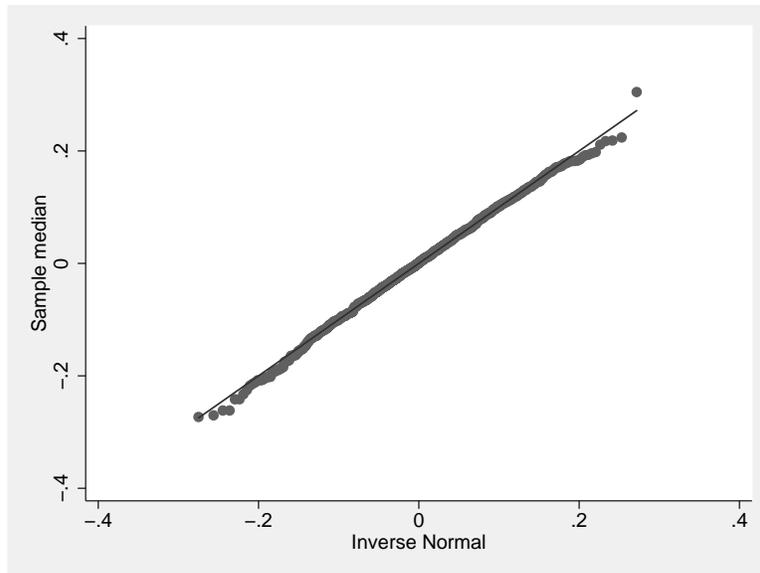


Figure 7.3: Q-Q plot of the distribution of sample median.

A related prefix operator, `permute` ([R] **permute**) is also based on Monte Carlo methods. It is used to estimate  $p$ -values for permutation tests from simulation results, where the randomness refers to reordering of the observations of a particular variable.

## 7.2.6 The bootstrap and jackknife operators

The `bootstrap` ([R] **bootstrap**) prefix is used to perform *bootstrap estimation*. Like `simulate` ([R] **simulate**), it executes a *command* for a certain number of repetitions, gathering statistics in an `exp_list` (by default the estimated coefficient vector, `_b`, from a standard estimation (e-class) command). The crucial difference is that whereas

`simulate` draws (pseudo-) random values from a specified distribution, `bootstrap` draws random samples *with replacement* from a variable in your dataset. For instance, you may run a regression in which you doubt the classical assumption of Normally distributed errors. The assumption of identically and independently distributed (*i.i.d.*) errors underlies the classical calculation of the covariance matrix of the regression coefficients. You could develop an alternative measure of the coefficients' precision by computing their *bootstrap standard errors*. These statistics are computed by randomly sampling (with replacement) from the regression residuals, taking their empirical distribution as a given. For estimation commands such as `regress` ([R] `regress`), you may use the `vce(bootstrap)` option to produce this estimator of the covariance matrix. However, if you are using a nonestimation (`r-class`) command such as `summarize` ([R] `summarize`) or `correlate` ([R] `correlate`), or writing your own program as a *command*, the `bootstrap` prefix is essential. The formal syntax:

```
bootstrap [exp_list] [,options] : command
```

The *command* may be a standard statistical command or it may refer to a user-written program. By default, `bootstrap` conducts 50 replications. The bootstrap samples are by default of size `_N`, the current sample size. They may be chosen to be either smaller or larger than the sample size with the `size()` option.

Let us consider the case of computing a bootstrap standard error for a two-sample *t*-test of sample means. We employ the `bpress` dataset of fictitious blood pressure measurements, and test whether mean blood pressure is affected by the patient's gender. For comparison, we present the standard `ttest` ([R] `ttest`) results as well as those produced by `bootstrap`. As shown, the *exp\_list* may contain expressions involving the return values of the *command*.

```
. use bpress, clear
(fictional blood-pressure data)
. set seed 2007062926
. ttest bp, by(sex)
Two-sample t test with equal variances
```

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
Male	120	127.3917	1.236031	13.54004	124.9442	129.8391
Female	120	120.4167	1.064357	11.65944	118.3091	122.5242
combined	240	123.9042	.8445493	13.0837	122.2405	125.5679
diff		6.975	1.631143		3.761679	10.18832

```

diff = mean(Male) - mean(Female)                                t = 4.2761
Ho: diff = 0                                                    degrees of freedom = 238
Ha: diff < 0                                                    Ha: diff != 0                                                    Ha: diff > 0
Pr(T < t) = 1.0000        Pr(|T| > |t|) = 0.0000        Pr(T > t) = 0.0000
. bootstrap diff=( r(mu_1) - r(mu_2) ), nodots: ttest bp, by(sex)
Warning: Since ttest is not an estimation command or does not set e(sample),
bootstrap has no way to determine which observations are used in
calculating the statistics and so assumes that all observations are
```

used. This means no observations will be excluded from the resampling because of missing values or other reasons.

If the assumption is not true, press **Break**, save the data, and drop the observations that are to be excluded. Be sure that the dataset in memory contains only the relevant data.

```
Bootstrap results          Number of obs    =      240
                          Replications      =       50

command:  ttest bp, by(sex)
diff:    r(mu_1) - r(mu_2)
```

	Observed Coef.	Bootstrap Std. Err.	z	P> z	Normal-based [95% Conf. Interval]	
diff	6.975	1.271685	5.48	0.000	4.482544	9.467456

We see that the bootstrap standard error for the difference of means of 1.272 is considerably smaller than the classical standard error of 1.631, resulting in a narrower confidence interval.

Similar to `bootstrap`, you may use the `jackknife` ([R] `jackknife`) prefix to calculate an alternative measure of coefficients' precision. The concept of the jackknife is to execute a *command* for each observation in the dataset leaving out one observation each time. As with the `bootstrap` prefix, you usually will prefer to use the `vce(jackknife)` option on an estimation command that supports it. The usefulness of the `jackknife` prefix arises when you are using a nonestimation (`r-class`) command such as `summarize` or `correlate`, or writing your own program as a *command*.

## 7.2.7 Other prefix operators

As [U] **prefix commands** indicates, there are three other prefix operators in official Stata: `svy` ([SVY] `svy`), `nestreg` ([R] `nestreg`) and `stepwise` ([R] `stepwise`). The first is the most widely employed as it provides access to Stata's extensive list of commands for the handling of complex survey data. These datasets are not produced by simple random sampling from a population of interest. In contrast, their survey design may make use of an elaborate multi-stage sampling process, which is specified to Stata by the `svyset` ([SVY] `svyset`) command. Once the data have been `svyset`, many of Stata's standard estimation commands may be used following the `svy:` prefix.

Four other commands are technically prefixes: `capture`, `quietly`, `noisily` and `version`. They are all useful for programming. For historical reasons, the first three do not require the use of a trailing colon (:).

## 7.3 The forvalues command

One of Stata's most powerful features is the ability to write a versatile Stata program without a large number of repetitive statements. Many Stata commands con-

tribute to this flexibility. As discussed in Section 3.5, `egen` ([R] `egen`) with a `by` option makes it possible to avoid many explicit statements such as `compute mean of age for race==1; compute mean of age for race==2;` etc. But two of Stata's most useful commands are not to be found in the *Reference Manual*: `forvalues` ([P] `forvalues`) and `foreach` ([P] `foreach`). These versatile tools have essentially supplanted other mechanisms in Stata for looping. You could also use `while` ([P] `while`) to construct a loop: most commonly, when you are unsure how many times to repeat the loop contents. This is a common task when seeking convergence of a numeric quantity to some target value: for instance,

```
.   while reldif( newval, oldval ) > 0.001 {
.   .   .
.   }

```

would test for the *relative difference* ([D] `functions`) between successive values of a criterion, and would exit the loop when that difference was less than 0.1%. Conversely, if the computational method is not guaranteed to converge, this could become an infinite loop.

In contrast, when you have a defined set of values over which to iterate, the `forvalues` and `foreach` commands are the tools of choice. These commands are followed by a left brace (`{`), one or more following command lines, and a terminating line containing only a right brace (`}`). You may place as many commands in the loop body as you wish. A simple numeric loop may thus be constructed as:

```
. forvalues i = 1/4 {
2.     generate double lngdp'i' = log(gdp'i')
3.     summarize lngdp'i'
4. }

```

Variable	Obs	Mean	Std. Dev.	Min	Max
lngdp1	400	7.931661	.59451	5.794211	8.768936
Variable	Obs	Mean	Std. Dev.	Min	Max
lngdp2	400	7.942132	.5828793	4.892062	8.760156
Variable	Obs	Mean	Std. Dev.	Min	Max
lngdp3	400	7.987095	.537941	6.327221	8.736859
Variable	Obs	Mean	Std. Dev.	Min	Max
lngdp4	400	7.886774	.5983831	5.665983	8.729272

In this example, we define the local macro `i` as the loop index. Following an equals sign, we give the *range* of values that `i` is to take on as a Stata *numlist*.<sup>5</sup> A range may be as simple as `1/4`, or `10(5)50`, indicating 10 to 50 in steps of 5; or `100(-10)20`, from 100 to 20 counting down by tens. Other syntaxes for the range are available. See [P] `forvalues` for details.

5. See Section 3.2.2. Note that not all Stata *numlists* are compatible with `forvalues`.

This example provides one of the most important uses of `forvalues`: looping over variables where the variables have been given names with an integer component. This avoids the need for separate statements to transform each of the variables. The integer component need not be a suffix. We could loop over variables named `ctyNgdp` just as readily. Or, say that we have variable names with more than one integer component, but we want to summarize the data only for countries 2 and 4:

```
. forvalues y = 1995(2)1999 {
2.     forvalues i = 2(2)4 {
3.         summarize gdp'i'_'y'
4.     }
5. }
```

Variable	Obs	Mean	Std. Dev.	Min	Max
gdp2_1995	400	3242.162	1525.788	133.2281	6375.105
Variable	Obs	Mean	Std. Dev.	Min	Max
gdp4_1995	400	3093.778	1490.646	288.8719	6181.229
Variable	Obs	Mean	Std. Dev.	Min	Max
gdp2_1997	400	3616.478	1677.353	153.0657	7053.826
Variable	Obs	Mean	Std. Dev.	Min	Max
gdp4_1997	400	3454.322	1639.356	348.2078	6825.981
Variable	Obs	Mean	Std. Dev.	Min	Max
gdp2_1999	400	3404.27	1602.077	139.8895	6693.86
Variable	Obs	Mean	Std. Dev.	Min	Max
gdp4_1999	400	3248.467	1565.178	303.3155	6490.291

As we see here, a nested loop is readily constructed with two `forvalues` statements.

## 7.4 The `foreach` command

As useful as `forvalues` may be, the `foreach` ([P] `foreach`) command is even more useful in constructing efficient do-files. This command interacts perfectly with some of Stata's most common constructs: the macro, the *varlist* and the *numlist*. Like `forvalues`, a local macro is defined as the loop index. Rather than cycling through a set of numeric values, `foreach` specifies that the loop index iterates through the elements of a local (or global) macro, or the variable names of a *varlist*, or the elements of a *numlist*. The list can also be an arbitrary *list of elements* on the command line, or a *newvarlist* of valid names for variables not present in the data set.

This syntax allows `foreach` to be used in a very flexible manner with any set of items, regardless of pattern. In several of the examples above, we employed `foreach` with the elements of a local macro defining the list. We illustrate its use here with a *varlist* from the `lifeexp` *Reference Manual* data set. We compute summary statistics,

correlations with `popgrowth` and generate scatterplots (not shown) for each element of a *varlist* versus `popgrowth`:

```
. sysuse lifeexp,clear
(Life expectancy, 1998)
. foreach v of varlist lexp-safewater {
2.     summarize 'v'
3.     correlate popgrowth 'v'
4.     scatter popgrowth 'v'
5. }
```

Variable	Obs	Mean	Std. Dev.	Min	Max
lexp (obs=68)	68	72.27941	4.715315	54	79
	popgro-h	lexp			
popgrowth	1.0000				
lexp	-0.4360	1.0000			
Variable	Obs	Mean	Std. Dev.	Min	Max
gnppc (obs=63)	63	8674.857	10634.68	370	39980
	popgro-h	gnppc			
popgrowth	1.0000				
gnppc	-0.3580	1.0000			
Variable	Obs	Mean	Std. Dev.	Min	Max
safewater (obs=40)	40	76.1	17.89112	28	100
	popgro-h	safewa-r			
popgrowth	1.0000				
safewater	-0.4280	1.0000			

Given the order of variables in this dataset, we could have also written the first line as

```
. foreach v of varlist lexp-safewater {
```

but that depends on the *order* of variables in this dataset. As you are free to reorder the variables in a dataset,<sup>6</sup> a do-file that depends on variable ordering may produce unpredictable results if variables have been reordered.

In the following example, we automate the construction of a `recode` (`[D] recode`)<sup>7</sup> statement for a dataset containing values of gross domestic product (`gdp`) for several countries and several years. The country codes are labeled as 1, 2, 3, 4 in the `cc` variable. We would like to embed their three-digit International Monetary Fund country codes into a copy of `cc`, `newcc`, so that we could use these values elsewhere: for instance, in a `merge` operation. The resulting statement could just be typed out for four elements,

6. See `[D] order`.

7. See Section 3.3.3.

but imagine its construction if we had 180 country codes! Note the use of `local ++i`, a shorthand way of incrementing the counter variable within the loop. The loop is used to build up the local macro `rc` which defines the set of transformations that are to be applied to the `cc` variable.

```
. use gdp4cty, clear
. local ctycode 111 112 136 134
. local i 0
. foreach c of local ctycode {
2.     local ++i
3.     local rc "'rc' ('i'='c')"
4. }
. display "'rc'"
(1=111) (2=112) (3=136) (4=134)
. recode cc 'rc', gen(newcc)
(400 differences between cc and newcc)
. tabulate newcc
```

RECODE of cc	Freq.	Percent	Cum.
111	100	25.00	25.00
112	100	25.00	50.00
134	100	25.00	75.00
136	100	25.00	100.00
Total	400	100.00	

The `foreach` statement can also be used to advantage with nested loops. You may combine `foreach` and `forvalues` in a nested loop structure, as illustrated here:

```
. use gdp4cty, clear
. local country US UK DE FR
. local yrlist 1995 1999
. forvalues i = 1/4 {
2.     local cname: word 'i' of 'country'
3.     foreach y of local yrlist {
4.         rename gdp'i'_y' gdp'cname'_y'
5.     }
6. }
```

```
. summarize gdpUS*
```

Variable	Obs	Mean	Std. Dev.	Min	Max
gdpUS_1995	400	3226.703	1532.497	328.393	6431.328
gdpUS_1999	400	3388.038	1609.122	344.8127	6752.894

It is a good idea to use indentation (either spaces or tabs) to align the loop body statements as shown here. Stata does not care as long as the braces appear as required, but it makes the do-file much more readable and easier to revise at a later date.

Alternatively, we could store the elements of the `country` list in numbered macros

with `tokenize` ([P] `tokenize`), which places them into the macros 1, 2, 3, 4:

```
. use gdp4cty, clear
. describe gdp*_*
```

variable name	storage type	display format	value label	variable label
gdp1_1995	float	%9.0g		
gdp1_1999	float	%9.0g		
gdp2_1995	float	%9.0g		
gdp2_1999	float	%9.0g		
gdp3_1995	float	%9.0g		
gdp3_1999	float	%9.0g		
gdp4_1995	float	%9.0g		
gdp4_1999	float	%9.0g		
gdp1_1997	float	%9.0g		
gdp2_1997	float	%9.0g		
gdp3_1997	float	%9.0g		
gdp4_1997	float	%9.0g		

```
. local country US UK DE FR
. local yrlist 1995 1999
. local ncty: word count country
. tokenize 'country'
. forvalues i = 1/'ncty' {
2.     foreach y of local yrlist {
3.         rename gdp'i'_y' gdp'_'_y'
4.     }
5. }
. summarize gdpUS*
```

Variable	Obs	Mean	Std. Dev.	Min	Max
gdpUS_1995	400	3226.703	1532.497	328.393	6431.328
gdpUS_1999	400	3388.038	1609.122	344.8127	6752.894

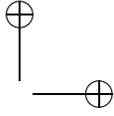
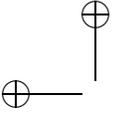
Note that in this case the country names are stored as the *values* of the numbered macros. To extract those values on the right-hand side of the `generate` statement, we must doubly dereference the macro `i`. The content of that macro the first time through the loop is the number 1. To access the first country code, we must dereference the macro `'1'`. Putting these together, within the loop we dereference `i` twice: `'i'` is the string US.

This latter technique, making use of `tokenize`, should be used with caution within an ado-file. Stata uses the numbered macros to reference positional arguments (the first, second, ... words on the command line) in an ado-file. Use of `tokenize` within an ado-file will redefine those numbered macros, so care should be taken to move their contents into other macros. See Chapter 11 for details of ado-file programming.

In summary, the `foreach` and `forvalues` statements are essential components of any do-file writer's toolkit. Whenever you see a set of repetitive statements in a Stata do-file, it is likely to mean that its author did not understand how one of these loop constructs could have made the program, its upkeep and her life simpler. An excellent

discussion of the loop commands is to be found in Cox (2002b).

The `forvalues` and `foreach` commands often require the manipulation of local macros and lists. Stata's macro extended functions and macro list functions are very useful in this regard. For more information on macro extended functions (`help extended_fcn`, [P] **macro**) and macro list functions (`help macrolists`, [P] **macro lists**) see Section 3.8.



## 8 Cookbook: Do-file programming III

This cookbook chapter presents a number of recipes for Stata do-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in a do-file.

### 8.1 Handling parallel lists

**The problem:** For each of a set of variables, you want to perform some steps that involve another group of variables, perhaps creating a third set of variables. These are *parallel lists*, but the variable names of the other lists may not be deducible from those of the first list.<sup>1</sup> How can these steps be automated?

First, let's consider that we have two arbitrary sets of variable names, and want to name the resulting variables based on the first set's variable names. For instance, you might have some time series of population data for several counties and cities:

```
. local county Suffolk Norfolk Middlesex Worcester Hampden
. local cseat Boston Dedham Cambridge Worcester Springfield
. local wc 0
. foreach c of local county {
.     local ++wc
.     local sn : word 'wc' of 'cseat'
.     generate seatshare'county' = 'sn' / 'c'
. }
```

This `foreach` loop will operate on each pair of elements in the parallel lists, generating a set of new variables `seatshareSuffolk`, `seatshareNorfolk`...

Another form of this logic would use a set of numbered variables in one of the loops. In that case, you could use a `forvalues` loop over the values (assuming they were consecutive or otherwise patterned) and the extended macro function `word of...` to access the elements of the other loop. The `tokenize` command could also be used, as illustrated in Section 7.4.

Alternatively, you could use a `forvalues` loop over both lists, employing the `word count` extended macro function:

---

1. This recipe borrows from Kevin Crow's Stata FAQ, "How do I process parallel lists?", at <http://www.stata.com/support/faqs/lang/parallel.html>.

```

. local n: word count 'county'
. forvalues i = 1/'n' {
.     local a: word 'i' of 'county'
.     local b: word 'i' of 'cseat'
.     generate seatshare'a' = 'b'/'a'
. }

```

yielding the same results as the previous approach.

You may also find this logic useful in handling a set of constant values that align with variables. Let's say that you have a cross-sectional dataset of hospital budgets over various years, in the wide structure: that is, separate variables for each year (e.g., `exp1994`, `exp1997`,...). You would like to apply a health care price deflator to each variable to place them in comparable terms. For instance:

```

. local yr 1994 1997 2001 2003 2005
. local defl 87.6 97.4 103.5 110.1 117.4
. local n: word count 'yr'
. forvalues i = 1/'n' {
.     local y: word 'i' of local yr
.     local pd: word 'i' of local defl
.     generate rexp'y' = exp'y' * 100 / 'pd'
. }

```

This loop will generate a set of new variables measuring real expenditures, `rexp1994`, `rexp1997`,... by scaling each of the original (nominal valued) variables by  $(100/defl)$  for that year's value of the health care price deflator. This could also be achieved by using `reshape` ([D] **reshape**) to transform the data into the *long structure* as described in Section 5.5, but that is not really necessary in this context.

## 8.2 Calculating moving-window summary statistics

**The problem:** you would like to calculate moving-window statistics for a variable in your dataset. As discussed in Section 7.2.4, these computations over *overlapping subsamples* cannot be handled with the `statsby:` prefix. Each observation can only appear in one `by`-group. These statistics could be generated by the `rolling:` prefix, but that approach creates a new dataset which must then be merged back into the original dataset.

A solution is provided by Cox and Baum's `mvsumm` routine, which calculates moving summary statistics.<sup>2</sup> These include all statistics available from `summarize`, `detail` as well as several additional derived values such as the inter-quartile range. The command works with either a single time-series or a panel. Its only restriction: there can be no internal gaps in the time-series. Values may be missing, but an observation must be defined for each consecutive time period. If this is not the case in your data, you can use `tsfill` ([TS] `tsfill`) to rectify that problem.

In a question raised on Statalist, a user wanted to calculate the average rate of growth over the past three years as a new variable. We can use the `grunfeld` dataset, containing ten firms' time series, to illustrate how that might be done. The growth rate is approximated by the difference of the logarithm of the variable: in this case, `invest`, the firms' capital investment expenditure. We want the average of the three past years' values, so we use the `LD.` time-series operator to specify the lag of the first difference of `invest` and the `stat(mean)` option to specify the statistic to be computed in the `mvsumm` command.

```
. use grunfeld, clear
. generate linvest = log(invest)
. mvsumm LD.linvest, generate(invrate) stat(mean) window(3) end
```

In the `mvsumm` command, the `window()` option specifies the *window width*: how many time periods are to be included in the moving-window estimate. The `end` option specifies that the summary value should be aligned with the last period included in the window.

Having computed these moving average growth rates for each firm, we can now display several firms' growth rate histories with `tsline` ([G] `tsline`):

```
. tsline invrate if inrange(company, 1, 4) & year >= 1937, by(company, ti(" "))
> ///
> yline(0) ysc(range(-0.2 0.3)) ytick(-0.2(0.1)0.3) ylab(-0.2(0.1)0.3) ///
> scheme(s2mono)
```

### 8.2.1 Producing summary statistics with rolling and merge

We could also use the `rolling:` prefix to generate these summary statistics:

---

2. The `mvsumm` routine is available from `ssc` ([R] `ssc`).

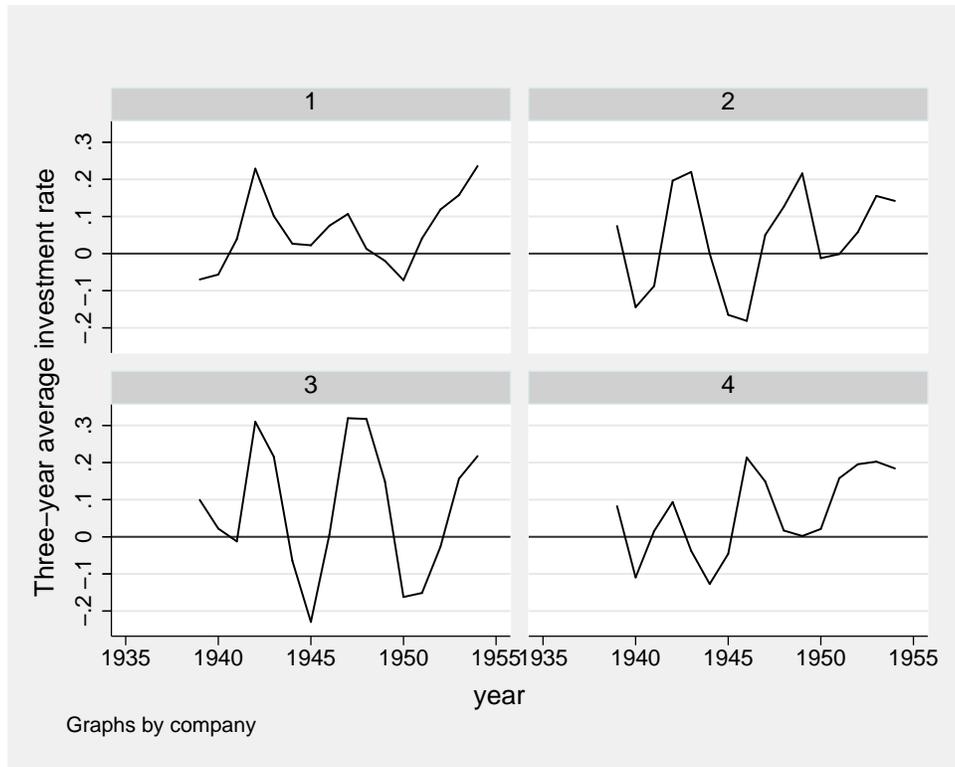


Figure 8.1: Moving average growth rates.

```
. qui rolling r(mean), window(3) saving(ldinvest, replace): summarize LD.linves
> t
```

Some additional work is needed to get the statistics produced by `rolling`: back into our dataset. The prefix operator creates new variables `start` and `end` indicating the first and last periods included in each window. As we adopted the convention that a rolling-window statistic should be aligned with the last time period included in the window, we rename the `end` variable to `year`, and give a more meaningful name to the summary variable `_stat_1`. Finally, we must take into account `rolling`'s convention of dealing with missing values. You could argue that a three-period window estimate of the mean of the lagged difference of a time-series variable may first be calculated from observations 3–5 and stored in observation 5, as observations 1, 2 will be lost by the lag and differencing operations (and `mvsum` makes that assumption). However, `rolling` will produce a value for observations 3 and 4. We choose to omit those values (corresponding to years 1937–1938 in the Grunfeld dataset). We use `xtset` (`[XT] xtset`) and save the revised dataset as `ldinvest`. We may then restore our original dataset

and use `merge` ([D] `merge`) to include the summary statistics in the dataset:

```
. preserve
. use ldinvest, clear
(rolling: summarize)
. rename end year
. rename _stat_1 rolling_ldinvest
. keep if year >= 1939
(20 observations deleted)
. xtset company year
      panel variable:  company (strongly balanced)
      time variable:  year, 1939 to 1954
                  delta:  1 unit
. save ldinvest, replace
file ldinvest.dta saved
. restore
. merge company year using ldinvest, unique
. drop _merge
. summarize invrate rolling_ldinvest
```

Variable	Obs	Mean	Std. Dev.	Min	Max
invrate	160	.0602769	.1303373	-.2292838	.475313
rolling_ld-t	160	.0602769	.1303373	-.2292838	.475313

We see that over the 160 observations (16 years per firm) in common, the `mvsumm` and `rolling:` approaches produced the same summary statistics.

## 8.2.2 Calculating moving-window correlations

In a number of applications in finance you may need to calculate a *moving correlation* between two time-series. For instance, the calculation of an optimal hedge ratio involves computing the correlation between two series in a moving-window context. A companion program to `mvsumm`, Cox and Baum's `mvcorr`, uses a similar syntax to support the computation of moving-window correlations between two time-series, `x1` and `x2`. If the two time-series are specified as `x1` and `Ln.x1`, a moving  $n^{\text{th}}$ -order autocorrelation is calculated.<sup>3</sup>

As shown above, we could also use `rolling:` to produce moving-window correlations.

---

3. The `mvcorr` routine is available from `ssc` ([R] `ssc`).

### 8.3 Computing monthly statistics from daily data

**The problem:** you have *trading-day* data from the stockmarket, with one observation for each day when the market is open. You want to calculate a measure of monthly volatility defined by Merton (1980). His method uses the intra-month price movements to compute a measure of volatility for the month. This takes account of both the changes in the price series ( $\Delta p_t$ ) and the number of days elapsed between the price observations ( $\phi_t$ ). Merton's daily volatility measure is computed from  $100 \times$  the change in the price variable divided by the square root of the number of elapsed days. Algebraically, we want to calculate this quantity for each trading day:

$$\zeta_t = \left( 100 \frac{\Delta p_t}{\sqrt{\Delta \phi_t}} \right)^2 \quad (8.1)$$

In our Stata dataset, each observation contains that day's closing price, `p`, and the date variable `date`, a proper Stata date variable which represents each day as an integer value (see Section 2.4.2). As trading days are not consecutive calendar days given weekends and holidays, we do not use the time series lag operator `L.` to calculate price changes, as they would be missing at those times.<sup>4</sup> We calculate the elements of the formula for  $\zeta_t$  as the Stata variable `ds2`:

```
. use fictprice, clear
. qui generate dscorr = 100 * (p - p[_n-1])
. qui generate deld = date - date[_n-1]
. qui generate dscorrd = dscorr / sqrt(deld)
. qui generate ds2 = dscorrd^2
```

The series of daily values of `ds2`, is then aggregated to monthly frequency to produce the monthly volatility measure:

$$\Phi_t = \sqrt{\sum_{t=1}^T \zeta_t} \quad (8.2)$$

To compute monthly volatility, we generate a month variable, `mon`, and use the `bysort`: prefix to cumulate the `ds2` variable over each month, recalling that the `sum()` function generates a *running sum*:

```
. gen mon = mofd(date)
. bysort mon: generate cumds2 = sum(ds2)
```

For each month, we take the square root of the last observation of the month and define it as `ssq`:

```
. qui bysort mon: generate ssq = sqrt(cumds2) if _n == _N
```

---

4. See Section 2.4.3.

We now can drop all daily observations for days prior to the last day of each month, define the time series calendar to be monthly, and save the new monthly dataset:

```
. drop if ssq == .  
(2044 observations deleted)  
. tsset mon, monthly  
    time variable: mon, 1998m5 to 2006m7  
                delta: 1 month  
. save myvolat, replace  
file myvolat.dta saved
```

We may now graph our fictitious monthly volatility timeseries with the `tsline` ([G] `tsline`) command:

```
. tsline ssq, ti("Monthly volatility from Merton method")
```

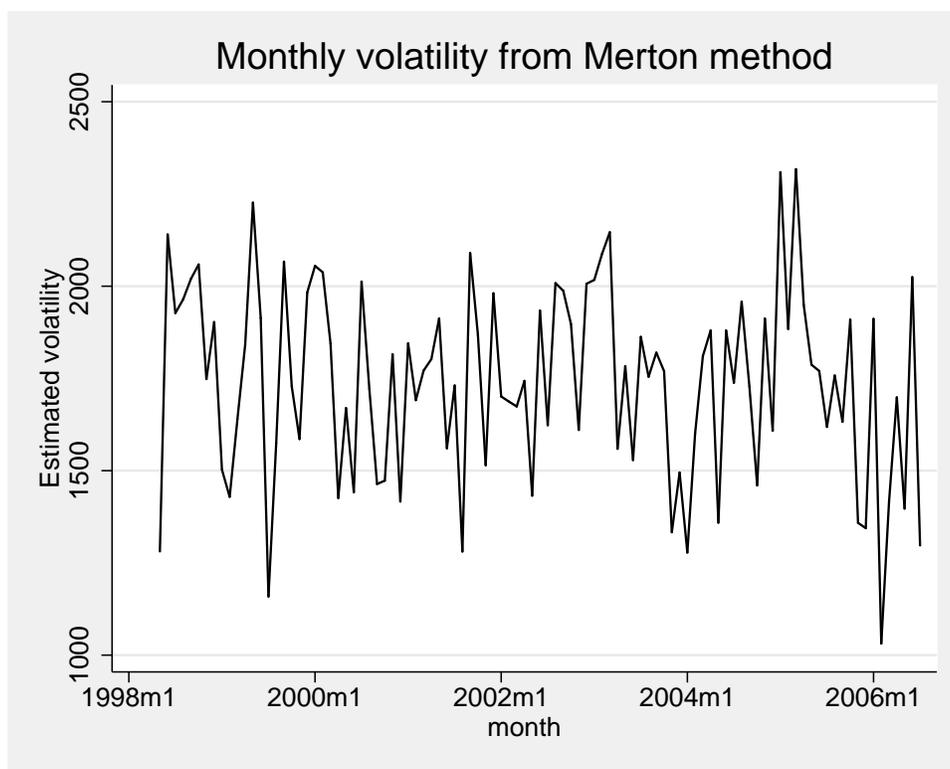


Figure 8.2: Estimated monthly volatility from daily data.

## 8.4 Requiring at least $n$ observations per panel unit

**The problem:** per a common question to Statalist, if you have unbalanced panel data, how do you ensure that each unit has at least  $n$  observations available?

It is straightforward to calculate the number of available observations for each unit:

```
. xtset patient date
. by patient: generate nobs = _N
. generate want = (nobs >= n)
```

These commands will produce an indicator variable, `want`, which selects those units which satisfy the condition of having at least  $n$  available observations.

This works well if all you care about is the number of observations available, but you may have a more subtle concern: you want to count *consecutive* observations. You may want to compute statistics based on changes in various measurements using Stata's L. or D. time series operators.<sup>5</sup> Applying these operators to series with gaps will create missing values.

A solution to this problem is provided by Nicholas J. Cox and Vince Wiggins in a Stata FAQ, "How do I identify runs of consecutive observations in panel data?"<sup>6</sup> The sequence of consecutive observations is often termed a *run* (a term commonly used in nonparametric statistics: see [R] `runtest`) or a *spell*.<sup>7</sup> They propose defining the runs in the timeseries for each panel unit:

```
. generate run = .
. by patient: replace run = cond(L.run == ., 1, L.run + 1)
. by patient: egen maxrun = max(run)
. generate wantn = (maxrun >= n)
```

The second command replaces the missing values of `run` with either 1 (denoting the start of a run) or the prior value + 1. For observations on consecutive dates, that will produce an integer series 1, . . . ,  $len$  where  $len$  is the last observation in the run. When a break in the series occurs, the prior (lagged) value of `run` will be missing, and `run` will be reset to 1. The variable `maxrun` then contains, for each patient, the highest value of `run` in that unit's sequence.

Although this identifies (with indicator `wantn`) those patients who do (or do not) have a sequence or *spell* of  $n$  consecutive observations, it does not allow you to immediately identify this spell. You may want to retain only this longest spell, or run of observations, and discard other observations from this patient. To carry out this sort of screening, you should become familiar with Nicholas J. Cox's `tsspell` program (available from `ssc`), which provides comprehensive capabilities for spells in time series and panel data. A "canned" solution to the problem of retaining only the longest spell per patient is also available from Christopher F Baum's `onespell` routine (`findit onespell`), which makes use of `tsspell`.

5. See Section 2.4.3.

6. <http://www.stata.com/support/faqs/data/panel.html>

7. See Section 4.4.

## 8.5 Counting the number of distinct values per individual

**The problem:** per a question to Statalist, if you have data on individuals that indicate their association with a particular entity, how do you count the number of entities associated with each individual? For instance, we may have a dataset of consumers who purchase items from various Internet vendors. Each observation identifies the consumer (`pid` and the vendor (`vid`), where 1=amazon.com, 2=llbean.com, 3=overstock.com, and so on. Several solutions were provided by Nicholas J. Cox in a Statalist posting:<sup>8</sup>

```
. bysort pid vid: generate count = ( _n == 1 )
. by pid : replace count = sum(count)
. by pid : replace count = count(_N)
```

Here, we consider each combination of consumer and vendor and set `count = 1` for their first observation. We then replace `count` with its `sum()` for each consumer, keeping in mind that this is a *running sum*, so that it takes on 1 for the first vendor, 2 for the second, and so on. Finally, `count` is replaced with its value in observation `_N` for each consumer: the maximum number of vendors with whom she deals.

A second, somewhat less intuitive but shorter solution:

```
. bysort pid (vid) : generate count = sum( vid != vid[_n-1] )
. by pid: replace count = count(_N)
```

This solution takes advantage of the fact that when (`vid`) is used on the `bysort` prefix, the data are sorted in order of `vid` within each `pid`, even though the `pid` is the only variable defining the `by`-group. When the `vid` changes, another value of 1 is generated and summed. When subsequent transactions pertain to the same vendor, `vid != vid[_n-1]` evaluates to 0, and those zero values are added to the sum.

This problem is common enough that an official `egen` function has been developed to *tag* observations:

```
. egen tag = tag( pid vid )
. egen count = total(tag), by(pid)
```

The `tag()` function returns 1 for the first observation of a particular combination of `pid` `vid`, and zero otherwise. Thus, its `total()` for each `pid` is the number of `vids` with whom she deals.

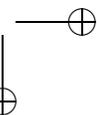
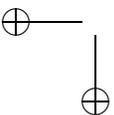
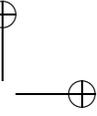
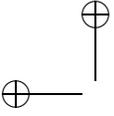
As a last solution, Cox's `egenmore` package (see Section 3.4) contains the `nvals()` function, which allows you to say

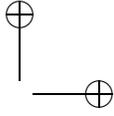
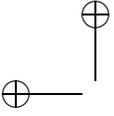
```
. egen count = nvals(vid), by(pid)
```

For more information, see the Stata FAQ by Nicholas J. Cox and Gary Longton, "How do I compute the number of distinct observations?"<sup>9</sup>

8. <http://www.hsph.harvard.edu/cgi-bin/lwgate/STATALIST/archives/statalist.0705/Author/article-461.html>

9. <http://www.stata.com/support/faqs/data/distinct.html>





## 9 Do-file programming: other topics

### 9.1 Introduction

This chapter presents a number of do-file programming techniques which you can use to reduce your workload and improve the reliability and replicability of your work. The first section discusses the use of Stata matrices for the storage and presentation of computed quantities. The `post` ([P] `post`) and `postfile` commands' ability to create a new Stata dataset are discussed, followed by mention of the several commands that can create external files for use in other software. The next two sections of the chapter discuss the automation of estimation and graphics.

#### 9.1.1 What you should learn from this chapter

- How to use Stata matrices to organize and present computed results
- The uses of `postfile` and `post` to generate Stata datasets
- How you may use `outsheet` and `outfile` to export Stata variables' contents
- The use of `file` to create a completely flexible output file
- How to automate the production of standard format tables
- How to automate the production of standard format graphs
- How to use characteristics

### 9.2 Storing results in Stata matrices

A number of Stata commands may be used to generate new Stata datasets containing the results of repetitive computations. For instance, the `statsby` ([D] `statsby`) prefix, discussed in Section 7.2.3, can execute a statistical (`r`-class) or estimation (`e`-class) command for each `by`-group and save one or more results as observations in new variables. The `rolling` ([TS] `rolling`) prefix, described in Section 7.2.4, performs the same function for rolling-window estimates in a time series context.<sup>1</sup> But these prefix commands have a limitation: unless you have written your own statistical or estimation command,

---

1. The `simulate` ([R] `simulate`) prefix, as discussed in Section 7.2.5, does the same for the results specified in a user-written Monte Carlo simulation program. In that context, you may use any number of commands to generate the desired results, circumventing the limitations of `by` ([D] `by`).

they can only execute one Stata command, and they can only place results generated by that command in the resulting dataset.<sup>2</sup>

In many cases, your goal may involve tabular output of statistical and estimation results, requiring the execution of several Stata commands to create each row of the table. It may be very convenient to store these results in a *Stata matrix* rather than in a separate Stata dataset.

As an example, let us consider an enhanced version of the `grunfeld` dataset available from the *Stata Reference Manual*. It is a balanced panel of 10 companies' time series of several variables. Our version of that dataset contains two additional variables: the average levels of firms' investment expenditures `invavg` and stock of fixed capital `kapavg`. Let us say that we want to generate a table, one row per company, containing the 25th, 50th and 75th percentiles of firm investment; the timeseries correlation of the firm's investment with that of the average firm; the correlation of firm capital stock with that of the average firm; and a regression coefficient (and its standard error) from the regression of investment on the lagged values of the firm's capital stock and the average firm.

To produce this table from the `grunfeldavg` dataset, we first generate a list of the values of the `company` variable using the `levelsof` (`[P] levelsof`) command, storing that list in a local macro `colist`. We find the number of companies with the macro extended function<sup>3</sup> `word count` of the local `colist`, which tells us how many rows we need in our matrix. We want to tabulate seven statistics per firm: three quantiles, two correlation coefficients, an estimated coefficient and its standard error. We thus define the `table1` matrix with the `J(#rows, #cols, value)` function as a null matrix of `ncomp` rows and seven columns.

```
. use grunfeldavg, clear
. levelsof company, local(colist)
1 2 3 4 5 6 7 8 9 10
. local ncomp : word count 'colist'
. matrix table1 = J('ncomp', 7, 0)
```

We are now ready to set up a `foreach` (`[P] foreach`) loop over companies. In this case, the `company` variable merely takes on values 1, ..., 10, but we want our program to work regardless of its values. Storing the distinct values of that variable in the local macro `colist` provides that feature. At the same time, we need a counter to address the successive rows of the matrix `table1`, which we provide with the local macro `i`, incremented within the loop.

The `summarize` command computes the desired percentiles, which we place in the first three columns of the company's row of the `table1` matrix. Likewise, we use `correlate` to generate the desired correlations and place them in columns 4 and 5, and a `regress` to generate the desired statistics for the last two columns of the matrix. The

2. For a solution circumventing this limitation, see Section 12.1.

3. See Section 3.8.

entire set of commands is wrapped in a `quietly` block to suppress their output. Now we need only apply labels to the matrix with `matrix rownames` and `matrix colnames`.

```
. local i 0
. levelsof company, local(colist)
1 2 3 4 5 6 7 8 9 10
. foreach c of local colist {
2.     quietly {
3.         local ++i
4.         summarize invest if company == 'c', detail
5.         matrix table1['i', 1] = r(p25)
6.         matrix table1['i', 2] = r(p50)
7.         matrix table1['i', 3] = r(p75)
8.         correlate invest invavg if company == 'c'
9.         matrix table1['i', 4] = r(rho)
10.        correlate kstock kapavg if company == 'c'
11.        matrix table1['i', 5] = r(rho)
12.        regress invest L.kstock L.kapavg if company == 'c'
13.        matrix table1['i', 6] = _b["L.kstock"]
14.        matrix table1['i', 7] = _se["L.kstock"]
15.    }
16. }
. matrix rownames table1 = 'colist'
. matrix colnames table1 = p25 p50 p75 r_invest r_kap beta_k se_k
```

The matrix of results we have generated can be viewed with `matrix list`, which offers us limited functionality over its appearance.

```
. mat list table1, format(%9.3f) ti("Grunfeld company statistics")
table1[10,7]:  Grunfeld company statistics
               p25      p50      p75  r_invest    r_kap    beta_k    se_k
1    429.300    538.350    665.500    0.964    0.985    0.150    0.361
2    321.750    419.550    471.350    0.808    0.898   -0.626    0.299
3     59.050     93.550    146.750    0.899    0.991   -0.180    0.249
4     55.990     71.085     95.010    0.928    0.957    0.298    0.160
5     51.525     60.385     72.290    0.848    0.966   -0.019    0.059
6     27.685     43.110     72.750    0.959    0.990   -0.281    0.265
7     33.245     44.200     57.680    0.876    0.944    0.045    0.060
8     30.305     38.540     53.920    0.928    0.963   -0.132    0.177
9     29.715     38.110     55.405    0.723    0.975    0.350    0.118
10     1.925      2.215      4.440    0.797    0.887    0.113    0.182
```

To produce a version of the table that we could include in our  $\text{\LaTeX}$  research paper, we rely on Baum and Azevedo's `outtable` routine.<sup>4</sup> The resulting table is displayed as Table 9.1.

```
. outtable using ch9.02t, mat(table1) replace ///
> format(%9.3f) center caption("Grunfeld company statistics")
```

You might also use the flexibility of Stata matrices to juxtapose estimation results

4. If you wanted tab-delimited output, suitable for a word processor or spreadsheet, you could use Michael Blasnik's `mat2txt`, available from the SSC Archive.

Table 9.1: Grunfeld company statistics

	<i>p25</i>	<i>p50</i>	<i>p75</i>	<i>rinvest</i>	<i>rkap</i>	<i>betak</i>	<i>sek</i>
1	429.300	538.350	665.500	0.964	0.985	0.150	0.361
2	321.750	419.550	471.350	0.808	0.898	-0.626	0.299
3	59.050	93.550	146.750	0.899	0.991	-0.180	0.249
4	55.990	71.085	95.010	0.928	0.957	0.298	0.160
5	51.525	60.385	72.290	0.848	0.966	-0.019	0.059
6	27.685	43.110	72.750	0.959	0.990	-0.281	0.265
7	33.245	44.200	57.680	0.876	0.944	0.045	0.060
8	30.305	38.540	53.920	0.928	0.963	-0.132	0.177
9	29.715	38.110	55.405	0.723	0.975	0.350	0.118
10	1.925	2.215	4.440	0.797	0.887	0.113	0.182

in a matrix with coefficients on the columns. This facility is not readily available from `estimates table` or Ben Jann's `estout` (see Section 5.4.1). We again loop over companies with `forvalues` and run a regression of each company's investment expenditures on two lags of its capital stock and the lagged value of the average firm's capital stock. This will estimate four coefficients per firm, counting the constant term. Those coefficients will be made available in the `ereturn list` as Stata matrix `e(b)`, a row vector (see 5.3). We use Stata's *row join* operator (`\`) to concatenate each firm's vector of coefficients into a matrix named `allbeta`.<sup>5</sup> Unlike the previous example, we do not predefine this matrix. How can, then, this concatenation be done for the first firm? By employing the `nullmat()` matrix function, as shown below, in which a null matrix of the appropriate size is prepended to the first firm's coefficient vector. We also build up the `local row` so that we may provide `matrix rownames` for the `allbeta` matrix.

```
. levelsof company, local(colist)
1 2 3 4 5 6 7 8 9 10
. local ncomp : word count `colist'
. forvalues i = 1/`ncomp' {
2.     local c : word `i' of `colist'
3.     quietly regress invest L(1/2).kstock L.kapavg if company == `c'
4.     matrix beta`i' = e(b)
5.     matrix allbeta = (nullmat(allbeta) \ beta`i')
6.     local row "row' `c'"
7. }
. matrix rownames allbeta = `row'
```

We are now ready to invoke `outtable` to produce the desired L<sup>A</sup>T<sub>E</sub>X table, which we display as Table 9.2.

```
. outtable using ch9.03t, mat(allbeta) replace ///
> format(%9.4f) center caption("Grunfeld company estimates")
```

<sup>5</sup> A similar technique would make use of the *column join* operator (`,`) to concatenate matrices by column.

Table 9.2: Grunfeld company estimates

	<i>L.kstock</i>	<i>L2.kstock</i>	<i>L.kapavg</i>	<i>cons</i>
1	0.0070	0.0437	1.8377	118.8346
2	-0.8291	0.3487	0.9758	312.8891
3	-0.6049	0.4138	0.6065	37.7697
4	0.2517	0.0032	0.1267	27.2760
5	-0.2762	0.2523	0.1081	54.6390
6	-0.6712	0.4115	0.3612	-6.3536
7	0.4983	-0.4442	0.0695	5.0020
8	-0.5233	0.4040	0.1471	19.9655
9	0.2177	0.1351	-0.1390	-21.3947
10	0.0567	0.0110	0.0095	0.2617

A “canned” solution for the generation of Stata matrices of descriptive statistics is provided by Cox and Baum’s `statsmat`, available from the SSC Archive. That routine can provide a wide range of descriptive statistics as a matrix, or in transposed form.<sup>6</sup> By default, `statsmat` will calculate the maximum, minimum, 25th, 50th and 75th percentiles, mean and standard deviation of each variable. This command can work with a single variable to produce descriptive statistics for each value of a `by-list`, and can use either the default *casewise deletion* or *listwise deletion*. Casewise deletion will cause any observation which is missing anywhere in the `statsmat varlist` to be omitted, while listwise deletion will use all available observations per variable.

### 9.3 The post and postfile commands

In most data management and statistical tasks, you work with an existing Stata dataset and may create a new version of the dataset in the process of the `do-file`. But what if you want to create a completely new Stata dataset with quite different contents, in the process, without disrupting the existing dataset? You could, of course, use the `preserve` ([P] `preserve`) command, perform whatever steps are needed to create the new dataset, save it, and then use the `restore` command to return to the preexisting structure of data in memory. That is the preferred way of using `collapse` ([D] `collapse`) or `contract` ([D] `contract`) which necessarily replace the data in memory. In some cases, however, it might be very useful to be able to create a new Stata dataset while processing the existing data.

This sort of task is handled by several of the *prefix commands* described in Section 7.2. As discussed in that context, the `statsby` ([D] `statsby`), `rolling` ([TS] `rolling`) and `simulate` ([R] `simulate`) prefixes each provide a `saving(filename)` option that

6. A similar functionality is available from `tabstat` ([R] `tabstat`), but that routine usually produces several matrices rather than a single matrix.

specifies the name of the new Stata dataset to be created. But what if the items you wish to place in the new dataset are not those readily computed by one of these prefix operators? Then you will want to learn how to use the `postfile` ([P] `postfile`) command suite.

This suite of command is described as containing “...utilities to assist Stata programmers in performing Monte Carlo-type experiments.” But these commands are quite general, and may be used to create new datasets with no relation to Monte Carlo experiments. They allow you to circumvent the restriction that Stata can only work with a single dataset at a time, in that you can construct a new Stata dataset “on-the-fly” with these commands without disturbing the contents of the dataset in memory. To set this up, you first use `postfile` to specify a *newvarlist* for the new dataset and a *filename* where it is to be stored. In order to reference this file, you must use a *postname*: an identifier or “handle” to be used in subsequent commands. It is best to obtain the *postname* from the `tempname` ([P] `macro`) command. As each `postfile` command requires a *postname*, it is possible to post results to more than one postfile at a time.

After defining the structure and location of the new dataset, you use the `post` command to fill in each observation, referencing the *postname*. The individual variables’ values are specified as *exps*, or expressions, which must appear in parentheses. After the dataset is complete, you use the `postclose` command to close the file, referenced by its *postname*.

Consider the example given in the last section in which we created a Stata matrix containing a number of different firm-level statistics. Let’s see how you might make that into a new Stata dataset with `postfile`.

We use the same logic as above to construct a list of the companies in local `colist`, and then invoke the `postfile` command. The syntax of this command is:

```
. postfile postname newvarlist using filename [, replace]
```

The *postname*, only used within your do-file, is best created using a temporary name with the `tempname` command. You then must define the *newvarlist*: the new dataset’s variables and optionally their data types. For instance, you could store one or more string variables in the dataset, declaring their data type before their name in the `postfile` variable list. The `using` clause specifies the external filename of the new Stata dataset.

```
. use grunfeldavg, clear
. levelsof company, local(colist)
1 2 3 4 5 6 7 8 9 10
. local ncomp : word count 'colist'
. tempname p
. postfile 'p' compnr p25 p50 p75 r_invest r_kap beta_k se_k using firmstats, r
> eplace
```

The command to write a single observation to the dataset is `post`, with syntax

```
. post postname ( exp ) ( exp ) ( exp ) ...
```

where each expression's value must be enclosed in parentheses. The value may be, as in this example, a local macro, or a global macro, scalar, or constant. Rather than creating a matrix with one row per firm, you create a new dataset with one observation per firm. At the end of the loop over observations, you use `postclose postname` to close the file.

```
. forvalues i = 1/'ncomp' {
2.     local c : word 'i' of 'colist'
3.     quietly {
4.         summarize invest if company == 'c', detail
5.         local p25 = r(p25)
6.         local p50 = r(p50)
7.         local p75 = r(p75)
8.         correlate invest invavg if company == 'c'
9.         local r_invest = r(rho)
10.        correlate kstock kapavg if company == 'c'
11.        local r_kap = r(rho)
12.        regress invest L.kstock L.kapavg if company == 'c'
13.    }
14.    post 'p' ('i') ('p25') ('p50') ('p75') ('r_invest') ('r_kap') ///
>      (_b["L.kstock"]) (_se["L.kstock"])
15. }
. postclose 'p'
```

Notice that as the `post` command accepts expressions as its arguments, we can reference the `_b` and `_se` elements from the `regress` command directly, without having to store them in local macros. You can verify that the new dataset contains the desired contents:

```
. use firmstats, clear
. summarize
```

Variable	Obs	Mean	Std. Dev.	Min	Max
compr	10	5.5	3.02765	1	10
p25	10	104.049	146.2543	1.925	429.3
p50	10	134.9095	185.0054	2.215	538.35
p75	10	169.5095	218.1057	4.44	665.5
r_invest	10	.87306	.0785282	.7234149	.9635566
r_kap	10	.9555067	.0364744	.8865225	.9906394
beta_k	10	-.0282959	.2910943	-.6264817	.3501322
se_k	10	.1930768	.1002899	.0594801	.3614677

## 9.4 Output: outsheet, outfile and the file command

You may often encounter the need to export the contents of a Stata dataset to another application. Stata contains several commands that facilitate the export of a dataset's contents. You must keep in mind that this sort of export generally will not be able to capture every aspect of Stata's variables: for instance, value labels will generally be

lost on export, unless they are used in place of the numeric variable's values. For that reason, it is usually preferable to use a third-party application such as Stat/Transfer to move data between applications.<sup>7</sup> Nevertheless, you may need to export the data as an ASCII text file.

The `outsheet` ([D] **outsheet**) command writes data in “spreadsheet-style” format: either tab-delimited or comma-separated values (CSV). Tab-delimited format is usually a better choice as it avoids the issue of commas embedded in string variables.<sup>8</sup> The command syntax is:

```
outsheet [ varlist ] using filename [ if exp ] [ in range ] [ ,options ]
```

If the *varlist* is not provided, all variables in memory are written to the output file in the order of their appearance (see `order`, ([D] **order**). By default the first line of the file will contain the variable names (which may be suppressed, but are useful if you plan to read this file into a spreadsheet). You may choose to write numeric values of labeled variables rather than their labels. If the *filename* is specified without a suffix, the suffix `.out` is assumed.

Just as `insheet` reads tab-delimited (or comma-separated) values, while `infile` ([D] **infile**) reads space-delimited files, `outsheet` has a counterpart, `outfile` ([D] **outfile**) which writes an ASCII text-format file, by default space-delimited. Optionally a comma-separated file may be written. The `outfile` command is also capable of writing a Stata *dictionary file*. That is, a separate `.dct` text file documents the contents of the datafile.<sup>9</sup> By default, `outfile` writes a file with suffix `.raw`. The command syntax is identical to that of `outsheet`.

The most flexible form of output is provided by the `file` ([P] **file**) command suite. Using the `file` commands, you may both write and read ASCII text or binary files. Unlike `post`, `outsheet` and `outfile`, which can only write a fixed number of fields per output record, `file` is capable of writing (or reading) a file of any arbitrary format. For instance, some statistical packages use a format in which a set of variables is stored in a file with a header record containing two integer values: the number of observations (rows) and the number of columns (variables) in the subsequent data matrix. To write such a file from Stata, you must use the `file` command (or Mata functions with similar capability). You may also write arbitrary string content into an output file. As an example, let us write the matrix created in Section 9.2 into an external file, prefixed with two header lines: a timestamp and a line containing the matrix dimensions.

To use the `file` commands, we must first set up a file *handle*,<sup>10</sup> best done as above with a `tempname`, and open that file handle:

```
file open handle using filename, {read|write|read write} [ options ]
```

7. Those concerned with export to SAS should be aware of Stata's `fdasave` ([D] **fdasave**) command, which despite its name is a general-purpose export routine that creates a SAS XPORT Transport file.

8. You do have to be careful with string variables that could contain tab characters.

9. See [D] **infile (fixed format)** for the description of dictionary files.

10. The file *handle* plays the same role as the *postname* in the `postfile` suite of commands.

The `file open` command must specify whether the file is to be used for input, output, or possibly both. We may also specify `text` or `binary` format, with default `text` (meaning ASCII).

```
. tempname fh
. file open 'fh' using matout.raw, write replace
```

Once the file is open, we may use `file write` to create each record. We must explicitly write line-end characters (denoted as `_newline`) where they should appear. Note that the symbol `_newline`—which may be abbreviated to `_n`—in this context has nothing to do with the observation number as described in Section 3.5.1. In the `file` command, `_n` is used to indicate that a *newline* symbol should be written to the file. If separate lines are to be written, the *newline* (or line-end) characters must be explicitly specified. As Stata runs on systems with different *newline* conventions, it will write the appropriate *newline* characters for your operating system.

First, we determine how many rows and columns are in the matrix and assemble the two header records. We are then ready to write out each matrix element using a double `forvalues` ([P] `forvalues`) loop. Notice that we do not write the *newline* character (`_newline`) within the inner `forvalues` loop, but only at the completion of each row of the output file.

```
. local rows = rowsof(table1)
. local cols = colsof(table1)
. local timestamp "Matrix created 'c(current_date)' 'c(current_time)'"
. file write 'fh' "timestamp" _n
. file write 'fh' "rows' cols" _n
. forvalues i = 1/'rows' {
2.     forvalues j = 1/'cols' {
3.         file write 'fh' (table1['i', 'j']) " "
4.     }
5.     file write 'fh' _n
6. }
. file close 'fh'
```

This works well, but suppose we want to label the matrix rows and columns with their `rownames` and `colnames`. In our case, the `rownames` are merely the integers 1..10, but imagine that they are firm code numbers, or their stockmarket ticker symbols. We enhance the previous do-file to extract the row and column names using macro extended functions and add them to the output. We guard against quotation marks appearing in the firm's name by using compound double quotes to display that item (see Section 3.2.5).

```
. tempname fh
. file open 'fh' using matout2.raw, write replace
. local rows = rowsof(table1)
. local cols = colsof(table1)
```

```

. local timestamp "Matrix created `c(current_date)' `c(current_time)'"
. file write `fh' "'timestamp'" _n
. file write `fh' "'rows' `cols'" _n
. local coln : colnames table1
. local rown : rownames table1
. file write `fh' "firmno `coln'" _n
. forvalues i = 1/`rows' {
2.     local rn : word `i' of `rown'
3.     file write `fh' "'rn' "
4.     forvalues j = 1/`cols' {
5.         file write `fh' (table1[`i', `j']) " "
6.     }
7.     file write `fh' _n
8. }
. file close `fh'

```

You may now use `type ([D] type)` to examine the new file:

```

. type matout2.raw
Matrix created 26 Jul 2008 16:41:11
10 7
firmno p25 p50 p75 r_invest r_kap beta_k se_k
1 429.3 538.35001 665.5 .96355661 .98464086 .14971282 .36146776
2 321.75 419.54999 471.34999 .80775991 .89819793 -.62648164 .29878812
3 59.049999 93.549999 146.75 .89941256 .99063942 -.1804446 .24927241
4 55.99 71.085003 95.010002 .92792669 .9570222 .29802565 .16047287
5 51.525 60.385 72.289997 .8478581 .96597103 -.01904298 .05948012
6 27.685 43.110001 72.75 .9593111 .98986261 -.28145697 .26466183
7 33.244999 44.199999 57.679998 .87604314 .9442384 .04509232 .05995572
8 30.305 38.540001 53.92 .92841638 .96329808 -.13167999 .176705
9 29.715 38.109999 55.405001 .7234149 .97467447 .3501322 .11761613
10 1.925 2.215 4.4400001 .79690054 .88652247 .11318377 .1823479

```

This example only scratches the surface of the `file` command's capabilities. You can use `file` to produce any format of output file that you need, incorporating text strings, local and global macros, scalar and matrix values as well as the contents of Stata variables. This same flexibility is afforded by `file read`, allowing you to read a file of arbitrary format without disturbing the contents of Stata's memory.

## 9.5 Automating estimation output

One of the primary advantages to mastery of do-file programming is the ability to automate the production of datasets, tables and graphs. Prior sections of this chapter have dealt with various methods of producing new datasets in Stata or ASCII text format. In this section, we present an extended example illustrating how production of a set of tables of statistical output may be fully automated. In this example, we create seven tables, each relating to underlying data for a specific year in a panel (longitudinal) dataset of individual workers' wages and hours. It should be clear that the same do-file

could serve as a model for similar automation of statistical results for a set of hospitals, cancer trials, industries or countries.

We illustrate using the `wagepan` dataset. These longitudinal data, 4,360 observations on 48 variables, are presented in Rabe-Hesketh and Everitt (2006). We read the data and generate one additional variable: `lhours`, the log of hours worked.

```
. use wagepan, clear
. xtset nr year
      panel variable:  nr (strongly balanced)
      time variable:  year, 1980 to 1987
                   delta: 1 unit
. generate lhours = log(hours)
```

As indicated by `xtset` (`[XT] xtset`), this dataset is a balanced panel of eight years' annual observations on 545 young males from the U.S. National Longitudinal Survey's Youth Sample. We want to estimate three *wage equations* for each year's wave of these data, and eventually produce a separate table of regression results for each year. We may use Ben Jann's `estout` package's<sup>11</sup> (Jann (2007)) `eststo` to generate stored estimates and `esttab` to tabulate them. Our target is a set of  $\text{\LaTeX}$  tables, although we could also produce SMCL, HTML, RTF or tab-delimited output.

We construct a `forvalues` (`[P] forvalues`) loop over the years 1980–1987 with local macro `y` as the loop index. For each regression explaining `lwage`, the log of the worker's hourly wage, we estimate the model with the qualifier `if year == 'y'`. For all three models, we want to add two statistics to the output: the semi-elasticity of the log wage with respect to the worker's years of education `educ` and its standard error, which we may calculate with the `[R] mfx` command. For the third model, we also want to calculate an additional statistic. The model contains a measure of years of experience and its square. Thus, the partial effect  $\frac{\partial \text{lwage}}{\partial \text{exper}}$  must be computed from both of those coefficients for a given level of `exper`.

A digression on measures of marginal effects: the *elasticity* of  $y$  with respect to  $x$  is approximately the percentage change in  $y$  with regard to a one percent change in  $x$ , or  $\frac{\partial \log y}{\partial \log x}$ . If  $y$  or  $x$  is already in logarithmic terms, we need a *semi-elasticity* such as  $\frac{\partial y}{\partial \log x}$  or  $\frac{\partial \log y}{\partial x}$ . The full elasticity measure is specified in the `mfx` (`[R] mfx`) command with the option `eyex`. The former semi-elasticity is specified as `dyex`—that is, we want the change in  $y$  (already in logs) from a one percent change in  $x$ —and the latter is `eydx`. The fourth option, `dydx`, is the regression coefficient itself. Although a regression coefficient is unchanged through the range of its regressor's values, any of the other measures will vary depending on the values of  $y$  and  $x$ . By default, `mfx` computes these values at the means of the estimation sample. A discussion of elasticities and semi-elasticities is provided in Wooldridge (2006), pp. 719–720 and Wooldridge (2002), pp. 16–18.

In the case at hand, as the dependent variable is already in log terms, we use `mfx`, `dyex`. The `mfx` command stores its results in matrices, and from those matrices we may

11. The `estout` package was presented in Section 5.4.1.

recover the semi-elasticity point estimates (from matrix `e(Xmfx_dyex)`, a row vector) and their standard errors (from matrix `e(Xmfx_se_dyex)`, also a row vector). We stack those vectors into matrix `eta` and extract the relevant estimates for use in the `eststo` command.

For the third model, we extract the mean level of `exper` from the `[R] mfx` return list's matrix `Xmfx_X` and use `[R] lincom` to compute the expression  $\hat{\beta}_{exper} + 2\hat{\mu}_{exper}\hat{\beta}_{exper}^2$  in point and interval form. The `lincom ([R] lincom)` command leaves its results in the return list, from which we extract `r(estimate)` and `r(se)`. Those values are passed to `eststo` for posting with the stored estimates.

Finally, we invoke `esttab` for the particular year's table, composing the output filename and table title to contain the year of analysis. The `scalar()` option allows us to include the statistics we have computed for each model in the table, and the `addnotes()` option is used to annotate the output, defining those statistics. We wrap the computation commands in `quietly` to suppress their output.

```
. forvalues y = 1980/1987 {
2.     quietly {
3.         eststo clear
4.         regress lwage educ hours if year == 'y'
5.         mfx compute, dyex
6.         mat eta = e(Xmfx_dyex) \ e(Xmfx_se_dyex)
7.         eststo, add(eta_educ eta[1, 1] etase eta[2, 1])
8.         regress lwage educ hours black hisp if year == 'y'
9.         mfx compute, dyex
10.        mat eta = e(Xmfx_dyex) \ e(Xmfx_se_dyex)
11.        eststo, add(eta_educ eta[1, 1] etase eta[2, 1])
12.        regress lwage educ exper expersq hours black hisp if year
> == 'y'
13.        mfx compute, dyex
14.        mat eta = e(Xmfx_dyex) \ e(Xmfx_se_dyex)
15.        mat xbar = e(Xmfx_X)
16.        scalar mu2 = 2 * xbar[1, 2]
17.        lincom exper + mu2 * expersq
18.        eststo, addscalars(eta_educ eta[1, 1] etase eta[2, 1] expe
> r r(estimate) se r(se))
19.    }
20.    esttab _all using lwage'y'.tex, replace ti("Wage equations for 'y'
> ") ///
>         nomtitles nodepvars not se noobs ar2 booktabs ///
>         scalar(eta_educ etase exper se) ///
>         addnotes("eta_educ: semi-elasticity of lwage with respect to e
> duc" ///
>         "etase: standard error of the semi-elasticity" ///
>         "exper: effect of exper on lwage at mean exper") ///
>         substitute("_cons" "Constant" "eta_educ" "$\eta_{educ}$" ///
>         "etase" "$\eta_{se}$")
21. }
(output written to lwage1980.tex)
(output written to lwage1981.tex)
(output written to lwage1982.tex)
(output written to lwage1983.tex)
(output written to lwage1984.tex)
(output written to lwage1985.tex)
```

```
(output written to lwage1986.tex)
(output written to lwage1987.tex)
```

We may now include the separate L<sup>A</sup>T<sub>E</sub>X tables produced by our do-file in our research paper with the L<sup>A</sup>T<sub>E</sub>X commands

```
\input{lwage1981}
\input{lwage1982}
...
\input{lwage1987}
```

This approach has the advantage that the tables themselves need not be included in the L<sup>A</sup>T<sub>E</sub>X document, so that if we revise the tables (to include a different specification, for instance) we need not copy and paste the tables. To illustrate, we display one of the tables here. L<sup>A</sup>T<sub>E</sub>X output is most convenient as L<sup>A</sup>T<sub>E</sub>X is itself a programming language, and Stata code may easily write programs in that language. The example above could be easily adapted to produce a set of tab-delimited files for use in Word or Excel, or alternatively a set of HTML web pages. For an excellent example of the automation of a web site containing many tables, see Gini and Pasquini (2006).

## 9.6 Automating graphics

Just as you may use do-files to automate the production of tabular output, you will find that Stata's graphical environment is particularly amenable to automation. In a research project, you often may need a number of essentially identical graphs: the same variables plotted for each unit of analysis or time period. Although Stata's graphics language is quite complex, it offers you the facility of complete customization of every aspect of the graph, including exporting the graph to a format usable by other applications. In this section, we present an extended example of the automation of graphs, building upon the example of the previous section. We present various examples of Stata graphics without explanation of the full syntax of Stata's graphics language. For an introduction to Stata graphics, please see `help graph intro` and [G] `graph intro`. An in-depth presentation of Stata's graphics capabilities is provided by Mitchell's *A Visual Guide to Stata Graphics* (Mitchell (2008)) and a number of Nicholas Cox's *Speaking Stata* columns in the *Stata Journal* (Cox (2004a,b,d,e, 2005b,c,d, 2006b)).

Let's imagine that you want to produce a set of graphs for one of the wage equations estimated from the U.S. National Longitudinal Survey's Youth Sample. You would like two graphs for each year's regression. First, you want a scatterplot of the log wage (dependent) variable against the log hours variable, but you'd like to distinguish minority workers (Black and Hispanics) from non-minority workers in the plot. Second, after estimating a wage equation,

```
regress lwage educ exper lhours if year == 'y'
```

you would like to examine one of the *added-variable plots* available from [R] `regress`

Table 9.3: Wage equations for 1984

	(1)	(2)	(3)
educ	0.0759*** (0.0124)	0.0758*** (0.0127)	0.0923*** (0.0158)
lhours	-0.162 (0.0949)	-0.173 (0.0950)	-0.173 (0.0948)
black		-0.123 (0.0689)	-0.126 (0.0691)
hisp		0.0160 (0.0619)	0.00976 (0.0620)
exper			-0.0660 (0.0765)
expersq			0.00551 (0.00461)
Constant	2.046** (0.741)	2.140** (0.741)	2.122** (0.807)
adj. $R^2$	0.064	0.067	0.070
$\eta_{educ}$	0.893	0.892	1.086
$\eta_{se}$	0.146	0.150	0.185
exper			0.0113
se			0.0190

Standard errors in parentheses

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

$\eta_{educ}$ : semi-elasticity of lwage with respect to educ

$\eta_{se}$ : standard error of the semi-elasticity

exper: effect of exper on lwage at mean exper

**postestimation.**

The added-variable plot or `avplot` is a graphical technique designed to identify the important variables in a relationship. The technique decomposes the multivariate relationship into a set of two-dimensional plots.<sup>12</sup> Taking each regressor ( $x^*$ ) in turn, the added-variable plot is based on two residual series. The first series,  $e_1$ , contains the residuals from the regression of  $x^*$  on all other  $x$ , while the second series,  $e_2$ , contains the residuals from the regression of  $y$  on all  $x$  variables except  $x^*$ . That is,  $e_1$  represents that part of  $x^*$  which is not linearly related to those other regressors while  $e_2$  represents the information in  $y$  that is left unexplained by a linear combination of the other regressors (excluding  $x^*$ ). The added-variable plot for  $x^*$  is then the scatterplot of  $e_1$  versus  $e_2$ . Two polar cases (as discussed by Cook and Weisberg (1994), p. 194) are of interest. If most points are clustered around a horizontal line at the level of zero in the added-variable plot,  $x^*$  is irrelevant. On the other hand, if most points are clustered around a vertical line on the  $x$ -axis at zero for that predictor, the plot would indicate that near-perfect collinearity is evident. In this case as well, addition of  $x^*$  to the model would not be helpful.

The strength of a linear relationship between  $e_1$  and  $e_2$  (that is, the slope of a least squares line through this scatter of points) represents the marginal value of  $x^*$  in the full model. If the slope is significantly different from zero, then  $x^*$  makes an important contribution to the model over and above that of the other regressors. The more closely the points are grouped around a straight line in the plot, the more important is the marginal contribution of  $x^*$ . As an added check, if the specification of the full model (including  $x^*$ ) is correct, the plot of  $e_1$  versus  $e_2$  *must* exhibit linearity. Significant departures from linearity in the plot cast doubt on the appropriate specification of  $x^*$  in the model.

Suppose that you want to focus on the added-variable plot (`avplot`) of the log hours variable, `lhours`, in the wage equation. You would like the two graphs combined in a single figure for each year of the analysis, 1980–1987.

To produce your automated graphics, you must first generate an indicator (dummy) variable denoting minority status and use the `separate` ([D] `separate`) command to split the log wage variable into minority and non-minority groups. The syntax of this command is

```
separate varname [if exp] [in range] , by(byvar|exp) [options]
```

The `by` clause specifies the groups into which `varname` is to be separated.<sup>13</sup> You might, for instance, want to separate the variable into a number of categories. Alternatively, an `exp`, or algebraic expression, can be given to create two categories: for instance, `exper > 5`. The `shortlabels` option specifies that the variable name be omitted from the new variable labels, while the undocumented `veryshortlabels` option removes the `by`-variable name as well (see Cox (2005e).) By default, the `varname` will be used as

12. An excellent discussion of the rationale for the added-variable plot is given by Cook and Weisberg (1994), pp. 191–94.

13. The `separate` command was discussed in Section 5.9.4.

the *stub* of the new variables to be created. In your case, with `minority` as an indicator variable taking on values 0 and 1, two variables will be created: `lwage0` and `lwage1`. These variables may then be placed on the *y*-axis of a scatterplot in place of the single variable `lwage`.

Creating the set of eight combined figures then involves, as in our prior example, setting up a `forvalues` loop over `year` with `y` as the loop variable, running the regression and producing the two figures for each year. You may use the `nodraw` option on each graph command to prevent their display, and the `name` option to name them. Although the manual's description of `avplot` does not list all of these options, the command allows any `graph twoway` ([G] `graph twoway`) option to be employed. Finally, `graph combine` ([G] `graph combine`) puts the graphs together into a single figure. You could choose to juxtapose them horizontally or vertically using the `rows()` and `cols()` options. You might have four graphs or six graphs per year. In this case, we only have the two, so they are combined and the resulting graph is saved to a `.gph` file named `lwage'y` for each value of year.

```
. separate lwage, by(black | hisp) veryshortlabel
```

variable name	storage type	display format	value label	variable label
lwage0	float	%9.0g		!(black   hisp)
lwage1	float	%9.0g		black   hisp

```
. forvalues y = 1981/1987 {
2.   quietly {
3.     regress lwage educ exper lhours if year == 'y'
4.     scatter lwage0 lwage1 lhours if year=='y', msize(small) ///
>       scheme(s2mono) nodraw ///
>       name(scat'y',replace) ytitle(lwage) legend(pos(5) ring(0) col
> (1))
5.     avplot lhours, msize(small) nodraw scheme(s2mono) name(avplot'y',
> replace)
6.     graph combine scat'y' avplot'y', nodraw col(2) saving(lwage'y', re
> place) ///
>       ti("Log wage vs. log hours for 'y'")
7.   }
8. }
```

If you are satisfied with the graphs and want to include them in a document, you may translate the native-format Stata `.gph` file into another format. The highest-quality format for many purposes is Encapsulated PostScript, or `.eps`. This may be performed with

```
. graph export lwage'y'.eps, replace
```

within the `forvalues` loop. Alternative high-quality export formats available from `graph export` ([G] `graph export`) include `.png` for HTML pages, `.tif` for page-layout programs and `.pdf` (only available in Stata for Macintosh).

You may also change the aspect of the graph before exporting it with a command such as

```
. graph display, xsize(5) ysize(3)
```

where the arguments of these two options are in inches. An example of the graphs produced is given as Figure 9.1. In summary, the complete flexibility of Stata's graphics



Figure 9.1: Automated graphics.

language lends itself to generating graphs automatically, with no resort to manual modification of each graph.<sup>14</sup> In this example, we demonstrated producing a set of graphs for subsets of the data on which statistical analyses have been performed. Alternatively, you may need to produce the same set of graphs in a repetitive process, such as a monthly update of a web site based on the latest statistics. For an excellent example of a graph-rich web site automatically updated when new data become available, see Gini and Pasquini (2006).

Many user-written graphics commands are conveniences that help you produce the graphics you need without having to master more complex details of Stata's graphics language. A useful guide to Nicholas Cox's many contributions in this area is available on the SSC Archive as `njc_stuff` (Cox (2007a)).

<sup>14</sup> Stata's Graph Editor permits complete manual customization of the graph. Its Recorder option allows the changes made to be written to a script. See `help graph editor`.

## 9.7 Characteristics

Characteristics are described in [U] **12.8 Characteristics** as “an arcane feature of Stata but are of great use to Stata programmers.” Each saved dataset and each variable within the dataset may have any number of characteristics associated with them. The characteristics are saved with the data, so that they are persistent. Dataset characteristics include indicators for data saved as panel (longitudinal) data with `xtset` or `tsset`, as survival-time data with `stset` or as complex survey data with `svyset`. Storing these characteristics with the data allow the datasets to retain this useful information, so that they may be exchanged with other users who need not reestablish the panel (or survival-time, or complex survey) qualifiers of the data.

Characteristics may be examined, defined or renamed with the `char` ([P] **char**) command. `char list` will show the characteristics of the current dataset as `_dta[charname]` as well as those defined for any variables in the dataset. `char list varname` will display characteristics associated with that *varname*. Characteristics may be defined with

```
. char varname [ charname ] "text"
```

where *varname* may be either `_dta` or the name of a variable. This command will define the characteristic *charname* for that *varname* as the string *text*. If you are defining your own characteristics, you should include at least one capital letter in its name, as lower-case characteristics are reserved for official Stata. Characteristics' values may contain 8,681 characters in Small Stata and 67,784 characters in all other flavors of Stata. The `char rename` command allows you to move a set of characteristics from one variable to another.

One interesting use for characteristics involves defining the *varname* characteristic for one or more variables. This characteristic interacts with the `subvarname` option of the `list` ([D] **list**) command. With that option invoked, the name of the variable is replaced in the output with the value of the *varname* characteristic. As an example, let us define characteristics for several variables in `auto.dta`:

```
. sysuse auto, clear
(1978 Automobile Data)
. char make[varname] "modle"
. char price[varname] "prix"
. char weight[varname] "poids"
. char length[varname] "longueur"
```

We may now display the data with either English or French labels:

```
. list make price weight length in 1/10, sep(0)
```

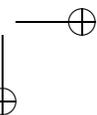
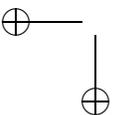
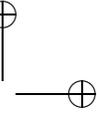
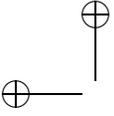
	make	price	weight	length
1.	AMC Concord	4,099	2,930	186
2.	AMC Pacer	4,749	3,350	173
3.	AMC Spirit	3,799	2,640	168

4.	Buick Century	4,816	3,250	196
5.	Buick Electra	7,827	4,080	222
6.	Buick LeSabre	5,788	3,670	218
7.	Buick Opel	4,453	2,230	170
8.	Buick Regal	5,189	3,280	200
9.	Buick Riviera	10,372	3,880	207
10.	Buick Skylark	4,082	3,400	200

. list make price weight length in 1/10, sep(0) subvarname

	modle	prix	poids	longueur
1.	AMC Concord	4,099	2,930	186
2.	AMC Pacer	4,749	3,350	173
3.	AMC Spirit	3,799	2,640	168
4.	Buick Century	4,816	3,250	196
5.	Buick Electra	7,827	4,080	222
6.	Buick LeSabre	5,788	3,670	218
7.	Buick Opel	4,453	2,230	170
8.	Buick Regal	5,189	3,280	200
9.	Buick Riviera	10,372	3,880	207
10.	Buick Skylark	4,082	3,400	200

For a large-scale example of the use of characteristics in data validation, see Bill Rising's `ckvar` command, described in Rising (2007).



## 10 Cookbook: Do-file programming IV

This cookbook chapter presents a number of recipes for Stata do-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in a do-file.

### 10.1 Computing firm-level correlations with multiple indices

**The problem:** a user on Statalist posed a question involving a very sizable dataset of firm-level stock returns and a set of index fund returns. He wanted to calculate, for each firm, the average returns and the set of correlations with the index funds, and determine with which fund they were most highly correlated.

We illustrate this problem with some actual daily stock returns data for 291 firms, 1992–2006, from CRSP (the Center for Research on Securities Prices): 311,737 firm-daily observations in total. We have constructed nine simulated index funds' returns. The hypothetical funds, managed by a group of Greek investment specialists, are labeled the Kappa, Lambda, Nu, Xi, Tau, Upsilon, Phi, Chi and Psi funds. To solve the problem, we define a loop over firms. For each firm of the `nf` firms, we want to calculate the correlations between firm returns and the set of `nind` index returns, and find the maximum value among those correlations. The variable `hiord` takes on values 1–9, while `permno` is an integer code assigned to each firm by CRSP. We set up a Stata matrix `retcorr` to hold the correlations, with `nf` rows and `nind` columns. The number of firms and number of indices are computed by the `word count` extended macro function<sup>1</sup> applied to the local macro produced by `levelsof` (`[R] levelsof`).

```
. qui levelsof hiord, local(indices)
. local nind : word count 'indices'
. qui levelsof permno, local(firms)
. local nf : word count 'firms'
. matrix retcorr = J('nf', 'nind', .)
```

We calculate the average return for each firm with `summarize`, `meanonly` (`[R] summarize`). In a loop over firms, we use `correlate` (`[R] correlate`) to compute the correlation matrix of each firm's returns, `ret`, with the set of index returns. For firm `n`, we move

---

1. See Section 3.8.

the elements of the last row of the matrix corresponding to the correlations with the index returns into the  $n^{\text{th}}$  row of the `retcorr` matrix. We also place the mean for the  $n^{\text{th}}$  firm into that observation of variable `meanret`.

```
. local n 0
. qui gen meanret = .
. qui gen ndays = .
. local row = 'nind' + 1
. foreach f of local firms {
2.     qui correlate index1-index'nind' ret if permno == 'f'
3.     matrix sigma = r(C)
4.     local ++n
5.     forvalues i = 1/'nind' {
6.         matrix retcorr['n', 'i'] = sigma['row', 'i']
7.     }
8.     summarize ret if permno == 'f', meanonly
9.     qui replace meanret = r(mean) in 'n'
10.    qui replace ndays = r(N) in 'n'
11. }
```

We now may use the `svmat` command ([P] `matrix mkmat`) to convert the `retcorr` matrix into a set of variables, `retcorr1-retcorr9`. The `egen` function `rowmax()` computes the maximum value for each firm. We then must determine which of the nine elements is matched by that maximum value. This number is stored in `highcorr`.

```
. svmat double retcorr
. qui egen double maxretcorr = rowmax(retcorr*)
. qui generate highcorr = .
. forvalues i = 1/'nind' {
2.     qui replace highcorr = 'i' if maxretcorr == retcorr'i' ///
>     & !missing(maxretcorr)
3. }
```

We now can sort the firm-level data in descending order of `meanret`, using `gsort` ([D] `gsort`) and list firms and their associated index fund numbers. These values show, for each firm, which index fund their returns most closely resemble. For brevity, we list only the fifty best-performing firms.

```
. gsort -meanret highcorr
. label values highcorr ind
. list permno meanret ndays highcorr in 1/50, noobs sep(0)
```

permno	meanret	ndays	highcorr
24969	.0080105	8	Nu
53575	.0037981	465	Tau
64186	.0033149	459	Upsilon
91804	.0028613	1001	Psi
86324	.0027118	1259	Chi
60090	.0026724	1259	Upsilon
88601	.0025065	1250	Chi

73940	.002376	531	Nu
84788	.0023348	945	Chi
22859	.0023073	1259	Lambda
85753	.0022981	489	Chi
39538	.0021567	1259	Nu
15667	.0019581	1259	Kappa
83674	.0019196	941	Chi
68347	.0019122	85	Kappa
81712	.0018903	1259	Chi
82686	.0017555	987	Chi
23887	.0017191	1259	Lambda
75625	.0017182	1259	Phi
24360	.0016474	1259	Lambda
68340	.0016361	1259	Upsilon
34841	.001558	1259	Nu
81055	.0015497	1259	Lambda
85631	.0015028	1259	Chi
89181	.0015013	1259	Chi
76845	.0014899	1006	Phi
48653	.0014851	1259	Xi
90879	.0014393	1259	Psi
85522	.0014366	454	Chi
80439	.0014339	1186	Chi
85073	.0014084	1259	Phi
86976	.0014042	1259	Chi
51596	.0014028	1259	Tau
77971	.0013873	1259	Xi
25487	.0013792	1259	Chi
14593	.0013747	1072	Kappa
79950	.0013615	1259	Nu
79879	.0013607	127	Phi
12236	.0012653	858	Kappa
77103	.0012513	648	Lambda
81282	.0012314	1259	Chi
75034	.0012159	1259	Phi
46922	.0012045	1259	Xi
82488	.0011911	359	Chi
75912	.0011858	1173	Phi
82307	.0011574	1259	Kappa
83985	.0011543	1259	Kappa
79328	.0011498	1259	Phi
11042	.0011436	1259	Lambda
92284	.0011411	1259	Psi

An alternative approach to the computations, taking advantage of Mata, is presented in Section 14.3.

## 10.2 Computing marginal effects for graphical presentation

**The problem:** you would like to produce a graph showing how a regressor's marginal effect and its associated confidence interval (see [R] `mf`) vary across a range of values for the regressor. As discussed in Section 9.5, in a linear regression, the coefficients' point estimates are fixed, but derived estimates such as the *elasticities* (`mf`, `eyex`) vary throughout the range of the regressor and response variable.

To illustrate, we estimate a model of median housing prices as a function of several explanatory factors: `nox`, the concentration of pollutants; `dist`, the distance from an urban center; `rooms`, the number of rooms in the house; `stratio`, the student-teacher ratio in that community; and `proptax`, the level of local property taxes. We compute elasticities (by default, at the point of means) with the `eyex` option for each explanatory variable.

```
. use hprice2a, clear
. regress price nox dist rooms stratio proptax
```

Source	SS	df	MS	Number of obs = 506		
Model	2.6717e+10	5	5.3434e+09	F( 5, 500) =	165.85	
Residual	1.6109e+10	500	32217368.7	Prob > F =	0.0000	
Total	4.2826e+10	505	84803032	R-squared =	0.6239	
				Adj R-squared =	0.6201	
				Root MSE =	5676	

price	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
nox	-2570.162	407.371	-6.31	0.000	-3370.532	-1769.793
dist	-955.7175	190.7124	-5.01	0.000	-1330.414	-581.021
rooms	6828.264	399.7034	17.08	0.000	6042.959	7613.569
stratio	-1127.534	140.7653	-8.01	0.000	-1404.099	-850.9699
proptax	-52.24272	22.53714	-2.32	0.021	-96.52188	-7.963555
_cons	20440.08	5290.616	3.86	0.000	10045.5	30834.66

```
. mfx, eyex
Elasticities after regress
y = Fitted values (predict)
= 22511.51
```

variable	ey/ex	Std. Err.	z	P> z	[ 95% C.I. ]		X
nox	-.6336244	.10068	-6.29	0.000	-.830954	-.436295	5.54978
dist	-.1611472	.03221	-5.00	0.000	-.224273	-.098022	3.79575
rooms	1.906099	.1136	16.78	0.000	1.68344	2.12876	6.28405
stratio	-.9245706	.11589	-7.98	0.000	-1.15171	-.697429	18.4593
proptax	-.0947401	.04088	-2.32	0.020	-.174871	-.014609	40.8237

The significance levels of the elasticities are very similar to those of the original coefficients. The regressor `rooms` is elastic, with an increase in `rooms` having almost twice as large an effect on `price` in percentage terms.<sup>2</sup> The other three regressors are inelastic,

<sup>2</sup> In an elastic relationship, the elasticity is greater than one in absolute value, so that a one percent change in  $x$  causes more than a one percent change in  $y$ .

with estimated elasticities within the unit interval. Note, though, that the 95% confidence interval for `stratio` includes values less than  $-1.0$ , so that we cannot conclude that housing prices are inelastic with respect to the student-teacher ratio. They might drop by more than one percent with a one percent increase in `stratio`.

The `at()` option of `mf` is capable of computing point and interval estimates of the marginal effects or elasticities at any point. For ease of use, you may specify that one variable takes on a specific value while all others are held at their sample means or medians to trace out the effects of that regressor. For instance, we may calculate a house price elasticity over the range of values of `nox` in the sample. The command also handles the discrete changes appropriate for indicator variables.

In the example below we evaluate the variation in the elasticity of median house price with respect to the community's student-teacher ratio in both point and interval form. We first run the regression and compute selected percentiles of `stratio` using the `detail` option of `summarize`, saving them in a temporary variable `x` obtained from the `tempvar` ([P] `macro`) command.

```
. use hprice2a, clear
. // run regression
. quietly regress price nox dist rooms stratio
. // compute appropriate t-statistic for 95% confidence interval
. scalar tmfx = invttail(e(df_r), 0.975)
. tempvar y x eyex seyex1 seyex2
. foreach v in 'y' 'x' 'eyex' 'seyex1' 'seyex2' { // generate variables needed
2.     qui generate `v' = .
3. }
. // summarize, detail computes percentiles of stratio
. quietly summarize stratio if e(sample), detail
. local pct 1 10 25 50 75 90 99
. local i = 0
. foreach p of local pct {
2.     local pc`p' = r(p`p')
3.     local ++i
4. // set those percentiles into tempvar x
.     quietly replace `x' = `pc`p'' in `i'
5. }
```

To produce the graph, we must compute elasticities at the selected percentiles and store the `mf` results in temporary variable `y`. The `mf` command, like all estimation commands, leaves results behind that are described in `ereturn list`. The saved quantities include scalars such as `e(Xmfy)`, the predicted value of `y` generated from the regressors, and a number of matrices containing the marginal effects or elasticities. In the example above, we compute the elasticities with option `eyex`. They are returned in the matrix `e(xMfy_eyex)` with standard errors returned in the matrix `e(xMfy_se_eyex)`. The do-file extracts the appropriate values from those matrices and uses them to create variables containing the percentiles of `stratio`, the corresponding predicted values of `price`, the elasticity estimates and their confidence interval bounds.

```

. local i = 0
. foreach p of local pct {
2. // compute elasticities at those points
.   quietly mfx compute, eyex at(mean stratio = `pc`p`)
3.   local ++i
4. // save predictions at these points in tempvar y
.   quietly replace `y' = e(Xmfx_y) in `i'
5. // retrieve elasticities
.   matrix Meyex = e(Xmfx_eyex)
6.   matrix eta = Meyex[1, "stratio"] // for the stratio column
7.   quietly replace `eyex' = eta[1, 1] in `i' // and save in tempvar eye
> x
8. // retrieve standard errors of the elasticities
.   matrix Seyex = e(Xmfx_se_eyex)
9.   matrix se = Seyex[1, "stratio"] // for the stratio column
10. // compute upper and lower bounds of confidence interval
.   quietly replace `seyex1' = `eyex' + tmfx*se[1, 1] in `i'
11. quietly replace `seyex2' = `eyex' - tmfx*se[1, 1] in `i'
12. }

```

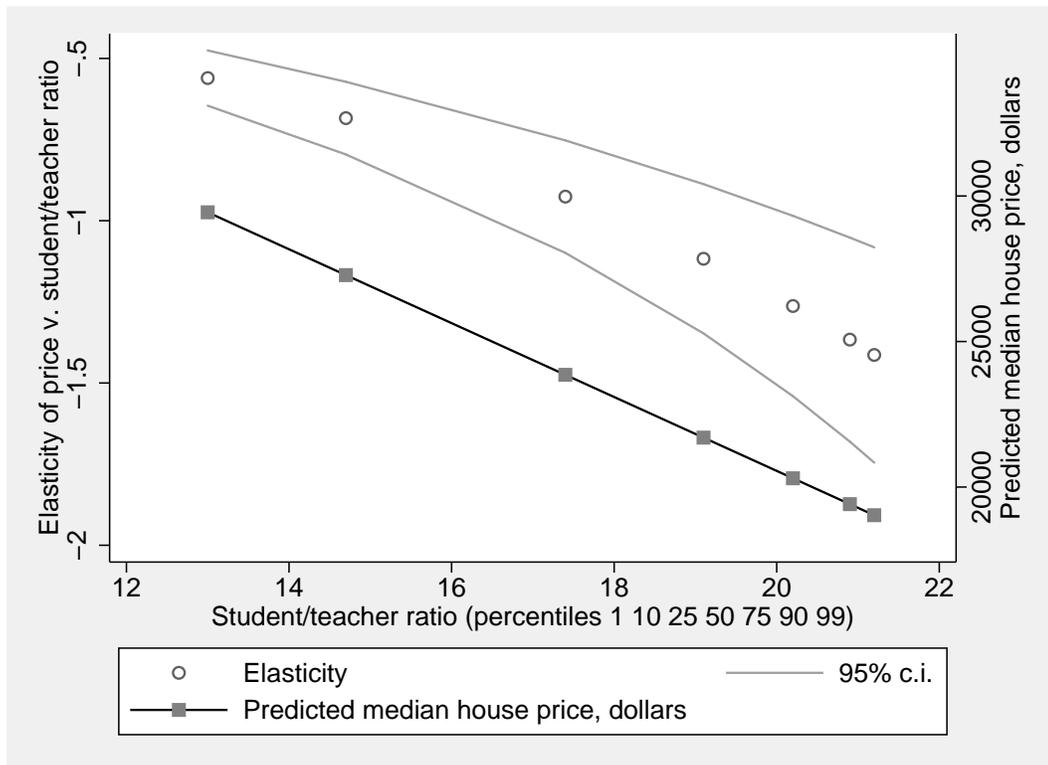


Figure 10.1: Point and interval elasticities computed with `mfx`.

These series are then graphed in Figure 10.1, combining three `twoway` graph types: `scatter` for the elasticities, `rline` for their standard errors and `connected` for the predicted values, with a second axis labeled with their magnitudes.<sup>3</sup>

```
. label variable 'x' "Student/teacher ratio (percentiles 'pct')"  
. label variable 'y' "Predicted median house price, dollars"  
. label variable 'eyex' "Elasticity"  
. label variable 'seyex1' "95% c.i."  
. label variable 'seyex2' "95% c.i."  
. // graph the scatter of elasticities vs. percentiles of stratio  
. // as well as the predictions with rline  
. // and the 95% confidence bands with connected  
. twoway (scatter 'eyex' 'x', ms(Oh) yscale(range(-0.5 -2.0)) ylabel(,nogrid))  
> ///  
> (rline 'seyex1' 'seyex2' 'x') ///  
> (connected 'y' 'x', yaxis(2) yscale(axis(2) range(18000 35000))), ///  
> ytitle(Elasticity of price v. student/teacher ratio)
```

The predictions of the model for various levels of the student-teacher ratio demonstrate that more crowded schools are associated with lower housing prices, other things being equal. The elasticities vary considerably over the range of `stratio` values.

---

3. For a presentation of Stata's more sophisticated graphics capabilities, including overlaying several plot types, please see *A Visual Guide to Stata Graphics, Second Edition* (Mitchell (2008)).

### 10.3 Automating the production of $\LaTeX$ tables

**The problem:** a group of researchers is working with a frequently updated dataset containing information on U.S. corporate directors. One of the deliverables for the research project is a set of tables of variables' descriptive statistics and tests on their subsample means to be included in a  $\LaTeX$  document. They want to automate the production of these tables so that when the data are updated the tables can be immediately regenerated without any manual effort.

The researchers can use Stata matrices as housekeeping devices in conjunction with the `file` command (discussed in Section 9.4) to achieve these goals. A particularly useful tool is Nicholas J. Cox's `makematrix` command (Cox (2003b)). This command makes a Stata matrix from the output of other Stata commands that do not store their results in a directly usable matrix form. For instance, consider the `tabstat` command (`[R] tabstat`), used here to tabulate the number of observations that fall into two categories defined by the indicator variable `insider` (signalling whether the director is an "inside" director, employed by the firm, or an "outside" (independent) director). The command will produce the subsample and total counts needed, but with the `save` option it places them in three separate matrices, as the `return list` shows.<sup>4</sup>

```
. use litgov_estsample.dta, clear
. tabstat insider, by(insider) stat(N) save
Summary for variables: insider
      by categories of: insider
  insider |          N
-----+-----
         0 |         1736
         1 |          984
-----+-----
      Total |         2720

. return list
macros:
      r(name2) : "1"
      r(name1) : "0"

matrices:
      r(Stat2) : 1 x 1
      r(Stat1) : 1 x 1
      r(StatTotal) : 1 x 1
```

We use `makematrix` to place the tabulated counts into a row vector, matrix `t2a`, and use the *column-join* operator (`,`) to add the total count:

```
. makematrix t2a, from(r(Stat1) r(Stat2)): tabstat insider, by(insider) stat(N)
> save
t2a[1,2]
```

---

4. If there were more than two categories of the variable being tabulated, additional matrices would be created by the `save` option. All of the subsample matrices could be combined using the technique below.

```

          Stat1 Stat2
insider  1736   984
. summarize insider, mean
. matrix temp = r(N)
. matrix t2a = t2a, temp

```

We use a similar command to produce the fraction of directors who are their company's CEOs; the variable `ceo` is an indicator variable for that characteristic. We assemble that information in matrix `t2aa`, and use the *row-join* operator (`\`) to combine that matrix with matrix `t2a`.

```

. makematrix t2aa, from(r(Stat1) r(Stat2)): tabstat ceo, by(insider) stat(mean)
> save
t2aa[1,2]
          Stat1   Stat2
ceo        0   .27845528
. mat t2aa[1,1] = .
. summarize ceo if insider, mean
. mat temp = r(N)
. mat t2aa = t2a \ (t2aa, temp)

```

We now want to produce descriptive statistics for a set of variables and conduct two statistical tests on their subsample means: a standard  $t$ -test for the difference of means (`ttest` ([R] `ttest`)) and a Mann–Whitney two-sample test (`ranksum`, [R] `ranksum`). For each test, we want to tabulate the  $p$ -value. This value is available in `r(p)` for the  $t$ -test, and may be calculated after `ranksum` from its computed  $z$ -statistic, stored in `r(z)`. We make use of one other useful function in this code fragment: the `nullmat()` matrix function, which allows you to include a matrix in an expression even if it does not yet exist.<sup>5</sup>

```

. foreach v of varlist audit defendant_ANY ins_trade_ANY departed age tenure st
> kholding {
2.   qui makematrix t2b, from(r(Stat1) r(Stat2)): tabstat 'v', by(insider)
> stat(mean) save
3.   summarize 'v', mean
4.   matrix 'v'1 = r(N)
5.   qui ttest 'v', by(insider)
6.   matrix 'v'2 = r(p)
7.   qui ranksum 'v', by(insider)
8.   matrix 'v'3 = 1 - normprob(abs(r(z)))
9.   matrix 'v' = t2b, 'v'1, 'v'2, 'v'3
10.  matrix t2bb = (nullmat(t2bb) \ 'v')
11. }

```

Before working on the output routine, we should check to see whether the two matrices we have constructed look sensible:

---

5. See Section 9.2.

```

. matrix colnames t2aa = Outsider Insider Total
. matrix rownames t2aa = Observations CEO
. matrix list t2aa
t2aa[2,3]
      Outsider    Insider    Total
Observations    1736      984    2720
      CEO          .    .27845528    984

. matrix colnames t2bb = Outsider Insider N t_pval MW_pval
. matrix list t2bb
t2bb[7,5]
      Outsider    Insider      N    t_pval    MW_pval
audit    .49884793 .14126016   2720  4.498e-82      0
defendant_ANY .1013986 .50102249   2694  8.83e-132      0
ins_trade_ANY .03484062 .21733333   2099  2.260e-42      0
  departed    .38652074 .4949187   2720  3.656e-08  1.977e-08
      age    59.703341  54.963415   2720  1.608e-41      0
      tenure  7.734764  9.3958844   2720  9.011e-10  .00005246
  stkholding .17106612  2.6251817   2720  3.311e-27      0

```

The very small  $p$ -values result from the considerable differences between the means for outside and inside directors.

Having validated the matrices' contents, we are now ready to use the `file` command to produce the output file `table2.tex`. We set up a `tempname` ([P] `macro`) for the file handle as local macro `hh`. This file handle is referenced in each subsequent invocation of `file`.<sup>6</sup> When using this command to produce an ASCII text file, we must explicitly write line-end markers (`_newline`) at the end of each line.<sup>7</sup> Using standard L<sup>A</sup>T<sub>E</sub>X table syntax, we separate column entries with ampersands (&) and mark the table line endings with a double backslash (`\\`).<sup>8</sup> Where a dollar sign (\$) is needed in the output, we must “quote” it with a preceding backslash so that the dollar sign is not considered as the beginning of a global macro.<sup>9</sup> Within each row of the table, we reference the appropriate cells of the `t2aa` and `t2bb` matrices.

```

. local inv Audit Defendant Ins\_Trading Departed Age Tenure Voting\_Share
. local inv1 "Member Audit Committee (0/1)"
. local inv2 "Defendant (0/1)"
. local inv5 "Age (Years)"
. local inv6 "Board Tenure (Years)"
. local inv7 "Voting Share (\%)"
. tempname hh
. file open 'hh' using table2.tex, write replace
. file write 'hh' "\\begin{table}[htbp]\caption{Director-Level Variables}\bigski
> p" _newline

```

6. Note that you may open more than one file handle, and write to different handles in turn. See Section 9.3 for a discussion of file handles.

7. You may use the abbreviation `_n` for the line-end marker. We avoid that notation to prevent confusion with the use of `_n` in Stata to refer to the current observation.

8. Where a percent sign (%) is needed in L<sup>A</sup>T<sub>E</sub>X, it must be “escaped” with a preceding backslash.

9. See Section 4.6.

```

.
. file write 'hh' "\begin{tabular}{lrrrrr}" _newline "\hline" _newline
. file write 'hh' " Variable & Outside & Inside & & \multicolumn{2}{c}{P-value
> of Difference} \\" _newline
. file write 'hh' "& Directors & Directors & & \multicolumn{2}{c}{in Location}
> \\" _newline
. file write 'hh' "\hline & Mean & Mean & \\\$N\$ & t-test & Mann--Whitney \\" _n
> ewline
. file write 'hh' "\hline" _newline
. file write 'hh' "Observations (N) & " (t2aa[1, 1]) " & " (t2aa[1, 2]) " & " (
> t2aa[1, 3]) " \\" _newline
. file write 'hh' "\\{\it Involvement} \\" _newline
. file write 'hh' "CEO (0/1) & N/A & " %7.3f (t2aa[2, 2]) " & " (t2aa[2, 3]) "
> \\" _newline
. forv i = 1/2 {
2. file write 'hh' "inv'i' & " %7.3f (t2bb['i', 1]) " & " %7.3f (
> t2bb['i', 2]) " & " (t2bb['i', 3]) " & " %7.3f (t2bb['i', 4]) " & " %7.3f (
> t2bb['i', 5]) " \\" _newline
3. }
. file write 'hh' "\\{\it Outcome} \\" _newline
. local i 4
. file write 'hh' "Departed (0/1) & " %7.3f (t2bb['i', 1]) " & " %7.3f (t2bb[
> 'i', 2]) " & " (t2bb['i', 3]) " & " %7.3f (t2bb['i', 4]) " & " %7.3f (t2bb[
> 'i', 5]) " \\" _newline
. file write 'hh' "\\{\it Demographics} \\" _newline
. forv i = 5/7 {
2. file write 'hh' "inv'i' & " %7.3f (t2bb['i', 1]) " & " %7.3f (
> t2bb['i', 2]) " & " (t2bb['i', 3]) " & " %7.3f (t2bb['i', 4]) " & " %7.3f (
> t2bb['i', 5]) " \\" _newline
3. }
. file write 'hh' "\hline" _n "\end{tabular}" "\medskip" _newline
. file write 'hh' "\end{table}" _newline
. file close 'hh'

```

We are ready to view the finished product. We could readily add information to the table, in the form of headings or notes, stored in separate L<sup>A</sup>T<sub>E</sub>X files referenced in the table environment.

Table 10.1: Director-Level Variables

Variable	Outside	Inside	P-value of Difference		
	Directors	Directors	in Location		
	Mean	Mean	<i>N</i>	t-test	Mann-Whitney
Observations (N)	1736	984	2720		
<i>Involvement</i>					
CEO (0/1)	N/A	0.278	984		
Member Audit Committee (0/1)	0.499	0.141	2720	0.000	0.000
Defendant (0/1)	0.101	0.501	2694	0.000	0.000
<i>Outcome</i>					
Departed (0/1)	0.387	0.495	2720	0.000	0.000
<i>Demographics</i>					
Age (Years)	59.703	54.963	2720	0.000	0.000
Board Tenure (Years)	7.735	9.396	2720	0.000	0.000
Voting Share (%)	0.171	2.625	2720	0.000	0.000

## 10.4 Tabulating downloads from the SSC Archive

**The problem:** the webserver log of SSC Archive activity ([R] `ssc`) counts the number of downloads of each ado-file. I want to present the number of *package downloads*, rather than individual ado-file downloads, as many packages contain multiple ado-files. Packages have one or more authors, so I would also like to present the download statistics for each author, adjusting for multiple authorship.

The raw data are of the form:

```
1464:  1.38%:  51.428:  3.36%: Nov/ 1/07  5:11 AM: /repec/bocode/o/outreg.ado
1244:  1.17%:  96.083:  6.28%: Nov/ 1/07  4:34 AM: /repec/bocode/o/outreg2.ado
1173:  1.11%: 143.543:  9.38%: Nov/ 1/07  5:37 AM: /repec/bocode/e/estout.ado
1168:  1.10%:  47.396:  3.10%: Nov/ 1/07  5:37 AM: /repec/bocode/e/esttab.ado
1164:  1.10%:   0.915:  0.06%: Nov/ 1/07  5:37 AM: /repec/bocode/_/_eststo.ado
```

For each observation, the first variable gives the number of ado-file downloads, while the last variable contains the name of the ado-file. I read those fields with `infix` ([D] `infix`; see Section 2.7.1)) and save them as a Stata dataset, `hits.dta`:

```
. local mmyy oct2007
. infix nhit 1-5 str url 53-92 using "'mmyy'.ssc.raw", clear
. format url %40s
. sort url
. drop if nhit == .
. save hits, replace
```

Separately, I have prepared another ASCII file, `extrAU.raw`, which contains five vari-

ables: `package`, `url`, `nmods`, `author` and a sequence number. This file contains one observation for each `package/author` combination, with `nmods` listing the number of ado-files in the package. These data are of the form:

```
_PEERS  /repec/bocode/_/_gpeers.ado  1  Amine Ouazad  1
XTMIS   /repec/bocode/x/xtmis.ado   1  Minh Nguyen   2
FTEST   /repec/bocode/f/ftest.ado    1  Maarten L. Buis 3
POWERQ  /repec/bocode/p/powerq.ado   1  Nikolaos A Patsopoulos 4
POWERQ  /repec/bocode/p/powerq.ado   1  Tiago V Pereira 4
A2REG   /repec/bocode/a/a2reg.ado    2  Amine Ouazad  5
A2REG   /repec/bocode/a/a2group.ado  2  Amine Ouazad  5
```

In this example, each package except `A2REG` contains one ado-file; that package contains two. We read this file with `insheet` ([D] `insheet`; see Section 2.7.1):

```
. insheet using "extraU.raw", clear
. gen module = reverse(substr(reverse(url), 1, strpos(reverse(url), "/" ) -1))
. sort url
. save authors, replace
```

This code fragment defines `module` as the last segment of the ado-file's URL: for instance, from `/repec/bocode/a/acplot.ado` we need just `acplot.ado`. The string manipulation functions `reverse()`, `substr()` and `strpos()` are used to extract the desired substring. This dataset is then saved as `authors.dta`. We are now ready to combine the `hits` and `authors` datasets using `merge` ([D] `merge`; see Section 5.8) with the `uniqmaster` option:

```
. use hits
. merge url using authors, uniqmaster
. drop if _merge < 3
. drop _merge
```

Any observations found in either file that are not matched in the `merge` may be discarded, based on the value of the `_merge` variable. Those with `_merge=2` are ado-files that were not downloaded. If there are any with `_merge=1`, problems with the `extraU.raw` file would be indicated.

The number of package hits can now be generated as the ratio of hits (downloads) to modules, or ado-files, in the package. The number of package hits can be non-integer, as a particular use of the `ssc` command may download only some of the ado-files in the package (those which have been updated on the archive). Given the number of package hits, the `collapse` ([D] `collapse`) command can generate a single record giving the sum of downloads for each author/package combination. Unlike some tallies of multiply-authored materials such as journal articles, the total number of package hits are assigned to each author for a package with multiple authors.

```
. generate npkghit = nhit / nmods
. collapse (sum) npkghit, by(author package)
. gsort -npkghit
```

We may now list package downloads in descending order:

```
. list npkghit author package, noobs
```

producing a list like

npkghit	author	package
2187.00	Roy Wada	OUTREG2
1149.00	John Luke Gallup	OUTREG
1125.00	Ben Jann	ESTOUT
914.33	Christopher F Baum	IVREG2
914.33	Mark E Schaffer	IVREG2
914.33	Steven Stillman	IVREG2
900.75	David Roodman	XTABOND2
835.67	Barbara Sianesi	PSMATCH2
835.67	Edwin Leuven	PSMATCH2
741.00	Sophia Rabe-Hesketh	GLLAMM
481.50	Mark E Schaffer	XTIVREG2

To produce a summary listing by authors, we can merely carry out another collapse by author:

```
. collapse (sum) npkghit, by(author)
. gsort -npkghit
. list if author != "", noobs
```

producing a list like

author	npkghit
Christopher F Baum	6620.70
Nicholas J. Cox	6610.82
Ben Jann	3044.17
Mark E Schaffer	2824.83
Roy Wada	2187.00
Steven Stillman	1886.33
David Roodman	1406.45
Stephen P. Jenkins	1268.32
Thomas Steichen	1201.66
John Luke Gallup	1168.00
Adrian Mander	1073.00
Vince Wiggins	1072.00
Roger Newson	1056.20

These statistics are saved in a Stata dataset for combination with two prior months' values, underlying the values displayed by the `ssc hot` command `help ssc`).

## 10.5 Extracting data from graph files' sersets

**The problem:** to revise a paper submitted to a professional journal some time ago, you must produce new graphs. You have the do-file that produced the graphs, its log file and the graph (.gph) files themselves, but the Stata dataset was lost in a hard disk crash (and was not backed up elsewhere—not a recommended practice!)

Fortunately, Stata graph (.gph) files are not merely bitmaps or lists of vector graphics instructions: a graph (.gph) file is actually a program to reproduce the graph.<sup>10</sup> This program also contains the data series that appear on the graph, stored in one or more *sersets* ([P] **serset**). Sersets are like datasets in that they contain information on one or more variables. Each serset associated with a graph is assigned a sequential number starting with zero. Your references to sersets use those numbers.

To illustrate the use of sersets to retrieve the data behind a graph file, let's first consider a do-file that creates the graph files:

```
. use airquality, clear
. drop if town == "Alburq"
(1 observation deleted)
. generate tabrv = upper(substr(town, 1, 3))
. summarize temp, meanonly
. generate hightemp = (temp > r(mean) & !missing(temp))
. label def tlab 0 "below mean temp" 1 "above mean temp"
. label values hightemp tlab
. scatter so2 temp, msize(tiny) mlabel(tabrv) mlabsize(vsmall) ///
> saving(fig10_4_1, replace) scheme(s2mono)
(file fig10_4_1.gph saved)
. scatter so2 precip, msize(tiny) mlabel(tabrv) mlabsize(vsmall) ///
> by(hightemp) saving(fig10_4_2, replace) scheme(s2mono)
(file fig10_4_2.gph saved)
. scatter so2 wind, msize(tiny) mlabel(tabrv) mlabsize(vsmall) ///
> by(hightemp) saving(fig10_4_3, replace) scheme(s2mono)
(file fig10_4_3.gph saved)
```

The *airquality* dataset was used in Section 5.4. For pedagogical purposes, we drop one city (Albuquerque) so that all cities' names may be distinctly abbreviated to three letters. The do-file produces three figures. The first includes variables *so2* and *temp*, with points labeled by *tabrv*. The second includes *so2* and *precip*, with *hightemp* used as a *by*-variable. The third includes *so2* and *wind*, also *by*(*hightemp*). Thus, the three graphs contain the city names (*tabrv*) and four measures: *so2*, *temp*, *precip* and *wind*. For illustration, we display the second graph as Figure 10.2.

We now imagine that the original *airquality.dta* dataset is no longer accessible, but you have the three .gph files produced above. In the following do-file, **graph use**

---

10. Strictly speaking, this pertains only to *live* graph files. If the *asis* option is used in **graph save**, or as a suboption to **saving()**, the file is “frozen” in its current state and can no longer be edited by the Graph Editor.

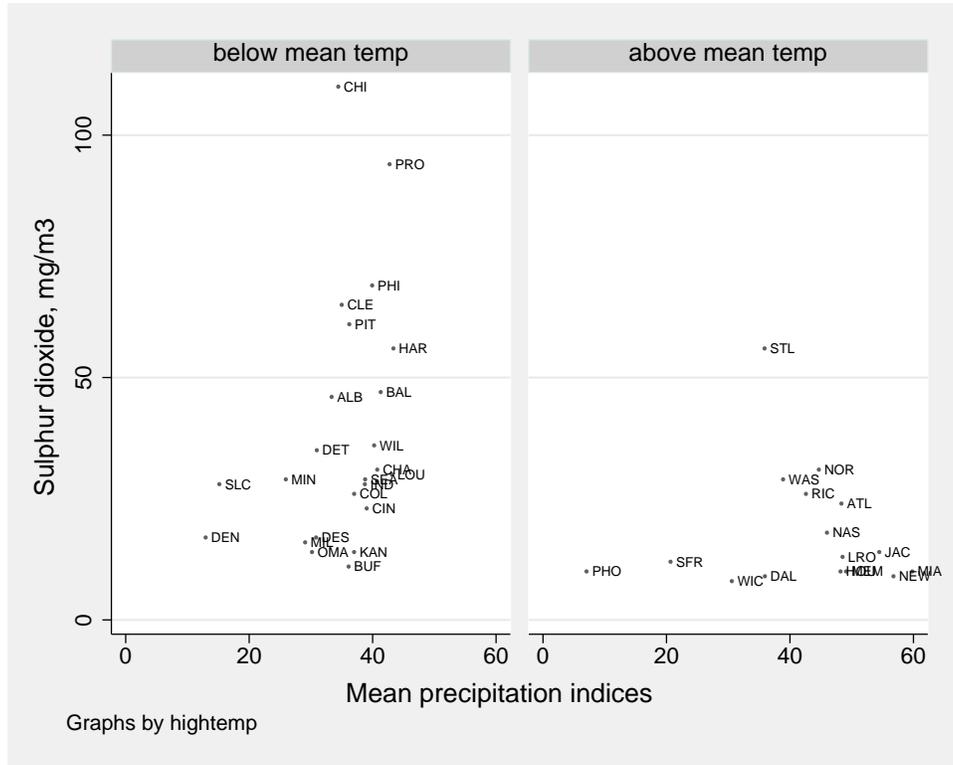


Figure 10.2: Air quality in U.S. cities.

accesses one of the graph files. `setsort dir` illustrates the available sersets from that graph file: in this case, a single serset. `setsort use` adds those variables to the dataset, which we then save as `f10_4_1.dta`.

```
. clear
. setsort clear
. graph use fig10_4_1
. setsort dir
0. 40 observations on 3 variables
   so2 temp tabrv
. setsort use
. sort tabrv
. save f10_4_1, replace
file f10_4_1.dta saved
```

We then go through the same steps for the second and third graph files. In these files, as there are two graph panels (see Figure 10.2), there are two sersets, numbered 0 and

1. As the `by()` option has been used to separate the dataset, each serset contains a subset of the original dataset. We access each serset and store its contents in a separate Stata dataset:

```
. serset clear
. graph use fig10_4_2
. serset dir
  0. 24 observations on 3 variables
    so2 precip tabrv
  1. 16 observations on 3 variables
    so2 precip tabrv
. serset set 0
. serset use
. sort tabrv
. save f10_4_2, replace
file f10_4_2.dta saved
. serset set 1
. serset use
. sort tabrv
. save f10_4_2a, replace
file f10_4_2a.dta saved
.
. serset clear
. graph use fig10_4_3
. serset dir
  0. 24 observations on 3 variables
    so2 wind tabrv
  1. 16 observations on 3 variables
    so2 wind tabrv
. serset set 0
. serset use
. sort tabrv
. save f10_4_3, replace
file f10_4_3.dta saved
. serset set 1
. serset use
. sort tabrv
. save f10_4_3a, replace
file f10_4_3a.dta saved
```

We are now ready to combine all the series and reconstruct a significant chunk of the missing Stata dataset. We use the first dataset, which contains observations for all cities, and `merge ([D] merge)` datasets `f10_4_2` and `f10_4_3`, which contain observations for a subset of observations of the `precip` and `wind` variables: those related to `hightemp = 0`. As two “using” datasets are being merged, three status variables are created: `_merge`, `_merge1` and `_merge2`. We use the wildcard `*` to drop them all.

At this point, the dataset in memory contains complete information for all observa-

tions on `so2`, `temp` and `tabrv`, but only a subset of observations on `precip` and `wind`. To incorporate the observations from the other subset (for which `hightemp = 1`), we use `merge` with the `update` option. This causes the additional observations to replace missing values in the `precip` and `wind` variables. At the end of this process, we have complete information on all five variables:

```
. use f10_4_1, clear
. merge tabrv using f10_4_2 f10_4_3, unique
. drop _merge
. sort tabrv
. merge tabrv using f10_4_2a, update unique
. drop _merge
. sort tabrv
. merge tabrv using f10_4_3a, update unique
. drop _merge
. save f10_4_all, replace
file f10_4_all.dta saved
. describe
Contains data from f10_4_all.dta
obs:           40
vars:           7                      6 Sep 2008 13:24
size:          1,160 (99.9% of memory free)
```

variable name	storage type	display format	value label	variable label
so2	float	%9.0g		
temp	float	%9.0g		
tabrv	str3	%9s		
precip	float	%9.0g		
_merge1	byte	%3.0g		_merge representing f10_4_2
wind	float	%9.0g		
_merge2	byte	%3.0g		_merge representing f10_4_3

```
Sorted by:
. summarize
```

Variable	Obs	Mean	Std. Dev.	Min	Max
so2	40	30.525	23.56985	8	110
temp	40	55.7375	7.317864	43.5	75.5
tabrv	0				
precip	40	37.494	10.9554	7.05	59.8
_merge1	40	.6	.4961389	0	1
wind	40	9.4575	1.444155	6	12.7
_merge2	40	.6	.4961389	0	1

We are now in a position to produce tables, statistics, or graphs for these data using the reconstructed dataset `f10_4_all.dta`.

## 10.6 Constructing continuous price and returns series

**The problem:** many important commodities and financial instruments trade on organized *futures markets*, where buyer and seller agree to exchange the commodity at a future date by means of a *futures contract*. Futures contract prices are quoted just as stock prices are quoted, but in the case of futures contracts, the price quotes refer to an instrument with a specific expiration date. Contracts expire on a fixed schedule: for the most heavily traded commodities, monthly. Many market participants never actually take delivery of the underlying commodity—such as crude oil—but rather maintain a continuous position in crude oil futures, “rolling over” that position when the nearest-to-maturity contract approaches its expiration date. This complicates analysis of data derived from futures prices, such as rates of return from maintaining a futures position. We would like to produce a continuous price series and returns series from the set of futures contract price quotations available, spanning the various contract maturity dates.

Industry analysts have noted that to avoid market disruptions, the large participants in the crude oil futures market roll over their positions from the near contract to the next-near contract over several days before the near contract’s expiration date. We can thus define a method of producing a continuous price series from a set of price quotations on multiple months’ contracts. Consider the last five trading days before expiration, and consider the midpoint of that interval the *rollover date*. Prior to the rollover date, the price is taken from the near contract: that which will imminently expire. On and after the rollover date, the price is taken from the next-near contract: the contract expiring next month.

For all but the rollover date, the return is the *log price relative*: that is, the logarithm of the ratio of price today to price yesterday, or  $\log(P_t/P_{t-1})$ . For the rollover date, we assume that the near-contract position is liquidated at the previous trading day’s settlement price, and instantaneously rolled into the next-near contract. Thus the return on the rollover date is the log price relative of the next-near contract for the rollover date and the previous trading day.

To illustrate, we display an excerpt of the crude oil futures contract quotations.

```
. list in 1/51, sepby(qmdy)
```

	qmdy	cmdy	settle	contract	qm	cm
1.	02jan1985	01feb1985	25.92	CL1985G	300	301
2.	02jan1985	01mar1985	25.81	CL1985H	300	302
3.	02jan1985	01apr1985	25.69	CL1985J	300	303
4.	02jan1985	01may1985	25.63	CL1985K	300	304
5.	02jan1985	01jun1985	25.60	CL1985M	300	305
6.	02jan1985	01jul1985	25.59	CL1985N	300	306
7.	02jan1985	01aug1985	25.57	CL1985Q	300	307
8.	02jan1985	01sep1985	25.57	CL1985U	300	308
9.	02jan1985	01oct1985	25.57	CL1985V	300	309
10.	02jan1985	01nov1985	25.57	CL1985X	300	310
11.	02jan1985	01dec1985	25.57	CL1985Z	300	311

12.	02jan1985	01jan1986	25.57	CL1986F	300	312
13.	02jan1985	01feb1986	25.57	CL1986G	300	313
14.	02jan1985	01mar1986	25.57	CL1986H	300	314
15.	02jan1985	01apr1986	25.57	CL1986J	300	315
16.	02jan1985	01may1986	25.57	CL1986K	300	316
17.	02jan1985	01jun1986	25.57	CL1986M	300	317
18.	03jan1985	01feb1985	25.84	CL1985G	300	301
19.	03jan1985	01mar1985	25.79	CL1985H	300	302
20.	03jan1985	01apr1985	25.68	CL1985J	300	303
21.	03jan1985	01may1985	25.65	CL1985K	300	304
22.	03jan1985	01jun1985	25.59	CL1985M	300	305
23.	03jan1985	01jul1985	25.58	CL1985N	300	306
24.	03jan1985	01aug1985	25.56	CL1985Q	300	307
25.	03jan1985	01sep1985	25.56	CL1985U	300	308
26.	03jan1985	01oct1985	25.56	CL1985V	300	309
27.	03jan1985	01nov1985	25.56	CL1985X	300	310
28.	03jan1985	01dec1985	25.56	CL1985Z	300	311
29.	03jan1985	01jan1986	25.56	CL1986F	300	312
30.	03jan1985	01feb1986	25.56	CL1986G	300	313
31.	03jan1985	01mar1986	25.56	CL1986H	300	314
32.	03jan1985	01apr1986	25.56	CL1986J	300	315
33.	03jan1985	01may1986	25.56	CL1986K	300	316
34.	03jan1985	01jun1986	25.56	CL1986M	300	317
35.	04jan1985	01feb1985	25.18	CL1985G	300	301
36.	04jan1985	01mar1985	25.19	CL1985H	300	302
37.	04jan1985	01apr1985	25.16	CL1985J	300	303
38.	04jan1985	01may1985	25.13	CL1985K	300	304
39.	04jan1985	01jun1985	25.10	CL1985M	300	305
40.	04jan1985	01jul1985	24.90	CL1985N	300	306
41.	04jan1985	01aug1985	25.06	CL1985Q	300	307
42.	04jan1985	01sep1985	25.06	CL1985U	300	308
43.	04jan1985	01oct1985	25.06	CL1985V	300	309
44.	04jan1985	01nov1985	25.06	CL1985X	300	310
45.	04jan1985	01dec1985	25.06	CL1985Z	300	311
46.	04jan1985	01jan1986	25.06	CL1986F	300	312
47.	04jan1985	01feb1986	25.06	CL1986G	300	313
48.	04jan1985	01mar1986	25.06	CL1986H	300	314
49.	04jan1985	01apr1986	25.06	CL1986J	300	315
50.	04jan1985	01may1986	25.06	CL1986K	300	316
51.	04jan1985	01jun1986	25.06	CL1986M	300	317

In this listing of three days' quotations, `qm` is the month number of the quote date and `cm` is the month number in which the contract expires. Recall that Stata's dates start from 1 January 1960, so that month 300 is January 1985 and month 301 is February 1985. `qmdy` is the quote date and `cmdy` is the maturity month of the contract. That is, contract CL1985G is the "Feb 85" contract which last traded on 18 January 1985, as contracts expire in roughly the third week of the previous calendar month. That contract was quoted at \$25.92 (per barrel of crude oil) on 2 January 1985 and \$25.84 on 3 January 1985.

We first must define the near contract (that closest to expiration) for each month:

```
. // identify last day of trading for near contract in each month
```

```
. bysort qmdy (qmdy): generate near = contract if _n == 1
(155907 missing values generated)
```

We now can identify the rollover date and the prior trading date:<sup>11</sup>

```
. // qmdy is the first date when the near contract is no longer quoted
. // that minus 3 trading days is the target rollover date
. bysort qmdy (qmdy): generate rolldate = qmdy[_n-3] if near[_n] != near[_n-1]
(161354 missing values generated)
. bysort qmdy (qmdy): generate roll1date = qmdy[_n-4] if near[_n] != near[_n-1]
>
(161354 missing values generated)
. bysort qmdy (qmdy): generate nnear = contract if near[_n] != near[_n-1]
(161353 missing values generated)
. // fixup for first obs
. replace nnear = . in 1
(1 real change made, 1 to missing)
```

We use the `egen mean()` function to set the `rolldate`, `roll1date` and `nnear` values into each trading day of the quote month:

```
. bysort qm: egen rollover = mean(rolldate)
. bysort qm: egen rollover1 = mean(roll1date)
. bysort qm: egen nextnear = mean(nnear)
```

With these variables defined, we are ready to calculate the continuous price and returns series:

```
. // calculate price series as settle(near) for pre-rollover dates
. bysort qm: generate futprice = settle if contract == near & qmdy < rollover
(158572 missing values generated)
. // calculate price series as settle(nnear) for rollover date et seq.
. bysort qm: replace futprice = settle if contract==nextnear & qmdy >= rollover
(2665 real changes made)
. format futprice %9.2f
. // calculate return series for the rollover date
. bysort qm: generate settleprev = settle if contract == nextnear & qmdy == rollover1
> rollover1
(161356 missing values generated)
. bysort qm: egen spreve = mean(settleprev)
. bysort qm: generate double futret = log(settle) - log(spreve) if qmdy == rollover1
> rollover1
(153860 missing values generated)
. // drop obs no longer needed, flagged by missing settle
. drop if futprice == .
(155907 observations deleted)
. // calc returns for all non-settle dates
. sort qmdy
```

---

11. In the code below, note that references to `near[_n]` could be replaced by `near`. We use the explicit subscript to clarify the meaning of the code.

```
. replace futret = log(settle) - log(settle[_n-1]) if missing(futret)
(5449 real changes made)
```

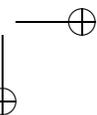
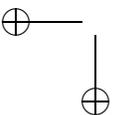
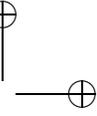
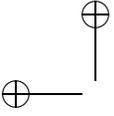
We now verify that the proper series have been constructed:

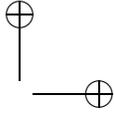
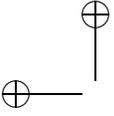
```
. sort qmdy cmdy
. list qmdy contract futprice futret if !missing(futprice) in 1/62, noobs sepb
> y(qm)
```

qmdy	contract	futprice	futret
02jan1985	CL1985G	25.92	.
03jan1985	CL1985G	25.84	-.00309119
04jan1985	CL1985G	25.18	-.02587364
07jan1985	CL1985G	25.56	.01497857
08jan1985	CL1985G	25.48	-.0031348
09jan1985	CL1985G	25.43	-.00196422
10jan1985	CL1985G	25.76	.01289332
11jan1985	CL1985G	25.77	.00038813
14jan1985	CL1985G	26.12	.01349029
15jan1985	CL1985G	25.91	-.00807235
16jan1985	CL1985H	25.57	-.01243699
17jan1985	CL1985H	25.69	.00468205
18jan1985	CL1985H	25.75	.0023328
21jan1985	CL1985H	25.97	.00850737
22jan1985	CL1985H	25.55	-.01630471
23jan1985	CL1985H	25.40	-.00588813
24jan1985	CL1985H	25.28	-.00473556
25jan1985	CL1985H	25.25	-.00118744
28jan1985	CL1985H	25.23	-.00079241
29jan1985	CL1985H	25.38	.00592768
30jan1985	CL1985H	25.67	.01136157
31jan1985	CL1985H	26.41	.02841972
01feb1985	CL1985H	26.74	.01241784
04feb1985	CL1985H	26.52	-.00826138
05feb1985	CL1985H	26.78	.00975618
06feb1985	CL1985H	27.07	.01077073
07feb1985	CL1985H	27.21	.00515843
08feb1985	CL1985H	27.59	.01386887
11feb1985	CL1985H	28.04	.0161787
12feb1985	CL1985H	27.36	-.02454998
13feb1985	CL1985J	27.06	.0186503
14feb1985	CL1985J	27.04	-.00073932
15feb1985	CL1985J	27.38	.0124955
19feb1985	CL1985J	27.29	-.00329242
20feb1985	CL1985J	27.18	-.00403895
21feb1985	CL1985J	27.14	-.00147279
22feb1985	CL1985J	26.76	-.01410039
25feb1985	CL1985J	26.44	-.01203021
26feb1985	CL1985J	26.79	.01315068
27feb1985	CL1985J	26.69	-.00373973
28feb1985	CL1985J	26.73	.00149753
01mar1985	CL1985J	27.20	.01743049
04mar1985	CL1985J	27.74	.01965841
05mar1985	CL1985J	27.55	-.0068729
06mar1985	CL1985J	27.77	.00795381

07mar1985	CL1985J	28.08	.01110126
08mar1985	CL1985J	27.74	-.01218217
11mar1985	CL1985J	27.57	-.00614719
12mar1985	CL1985J	27.92	.01261507
13mar1985	CL1985J	28.06	.00500178
14mar1985	CL1985J	28.19	.00462227
15mar1985	CL1985J	28.32	.00460093
18mar1985	CL1985K	28.25	.02182948
19mar1985	CL1985K	28.19	-.00212613
20mar1985	CL1985K	27.99	-.00712003
21mar1985	CL1985K	28.32	.01172096
22mar1985	CL1985K	28.24	-.00282885
25mar1985	CL1985K	28.09	-.00532576
26mar1985	CL1985K	28.45	.01273454
27mar1985	CL1985K	28.16	-.01024566
28mar1985	CL1985K	28.25	.00319093
29mar1985	CL1985K	28.29	.00141496

You should note in this recipe how business-daily data have been handled: no use has been made of the time series operators (such as `L.`), as the trading-day data are not evenly spaced in calendar time. Also note that the multiple price quotations per trading day have been transformed into simple time series of prices and returns in the process.





# 11 Ado-file programming

## 11.1 Introduction

In this chapter, we discuss *ado-file programming*: creating your own Stata commands to extend Stata's functionality. We discussed some special-purpose ado-file programs in presenting the `simulate` ([R] `simulate`) and `bootstrap` ([R] `bootstrap`) prefixes in Section 7.2. We now turn to a more general use of Stata's `program` command and discuss the advantages of developing an ado-file rather than a set of do-files.

Stata's design makes it quite easy for you to develop a new Stata command and equip that command with all the standard elements of Stata syntax such as `if exp` and `in range` qualifiers, weights and command options. Why should you consider writing your own command? Many users find that they may want to automate a frequently-executed procedure in your workflow, and that procedure may depend on items that change. You could write a do-file that relies on global macros,<sup>1</sup> but you would still have to insert new values in those macros every time you ran the do-file. Writing a command that implements this procedure may be a better approach.

Alternatively, you may want to implement a statistical, data management or graphical technique not available in official Stata nor from user-contributed routines in the *Stata Journal*, SSC Archive or elsewhere. New graphical procedures, statistical estimation techniques and tests are continually appearing in the literature. You may decide that it is easy enough to implement one of those techniques or tests as a Stata command, and perhaps even share it with other Stata users.<sup>2</sup>

This chapter provides an overview of how to develop your own ado-file, or Stata command, using the [P] `program` command. We consider both `r-class` and `e-class` programs, as well as programs for use with `egen` ([D] `egen`), `m1` ([R] `ml`), `n1` ([R] `nl`), `nlsur` ([R] `nlsur`) and prefix operators `simulate`, `bootstrap` and `jackknife`. If you want to further develop your understanding of the mechanics of developing Stata commands you might consider one of StataCorp's *NetCourses* on programming techniques.<sup>3</sup>

### 11.1.1 What you should learn from this chapter

- How to develop a Stata command as an `ado-file` program

---

1. See Section 3.7.

2. See `ssc` ([R] `ssc`) and `ssc describe sscsubmit`.

3. <http://stata.com/netcourse/>

- How to use the `syntax` and `return` statements
- How to provide program options and sample qualifiers
- How to write a SMCL help file
- How to make programs byable
- How to write an `egen` function
- How to write an `e-class` program
- How to certify your program's reliability
- How to write programs for `ml`, `nl`, `nlsur`, `simulate`, `bootstrap`, `jackknife`
- How to follow good `ado`-file programming style

## 11.2 The structure of a Stata program

A Stata program follows a quite simple structure. You must declare the name of the program, optionally specify its characteristics, and handle the program's *arguments*. When you invoke the program in Stata by typing its name, the arguments are the items, separated by spaces, following the program name on the command line.<sup>4</sup> You then perform the steps that this program is to take (compute one or more quantities, display some output, read or write a file, transform the data, or produce a graph) and, optionally, return various items to the user (or to the program which calls this one). As an example, we write the `parrot` command, which merely echoes whatever it is given as an argument:

```
. type parrot.ado
program parrot
    version 10.1
    display "'1'"
end
. parrot "This is Stata..."
This is Stata...
```

This program takes one *argument*. When you call a program, the arguments are assigned to local macros 1, 2, ..., 9 and so forth in order, while the local macro 0 contains everything typed after the command name. Thus, within the program, local macro 1 refers to the string typed on the command line as the first (and only) argument. We have placed the `parrot` command in an `ado`-file, `parrot.ado`, in a directory on the `adopath` (see Section 2.2.2). If the name of the `ado`-file does not match the name of the program defined, Stata will refuse to execute the program. Placing the `ado`-file in the appropriate `PERSONAL` directory will make the program permanently available in your copy of Stata.

---

4. If an argument is a string containing spaces as in the example below, it should be quoted on the command line.

The `parrot` program carries out one rudimentary step: it takes an argument and operates on it (albeit trivially). It does not access Stata's variables, nor does it return any computed quantities. Nevertheless, it illustrates the notion: once you have defined a Stata command with `program`, it becomes indistinguishable from any other Stata command. You should, of course, ensure that your command's name is not the same as any existing command, either in official Stata or among the user-written programs (including yours!) on your system. Before choosing a name, use the `which` ([R] **which**) command to ensure that the program does not already exist on your system. You might also want to use the `findit` command to ensure that the name has not been used by a user-written routine (in the *Stata Journal*, SSC Archive or in user sites) in case you install that routine at some later date.

In the next sections of this chapter, we first discuss the `program` statement, followed by a discussion of handling the program's arguments with the `syntax` statement and managing the sample to be used in the program. Finally, we consider how to return computed quantities to the calling program. We will develop a program, step-by-step, to generate several percentile-based statistics of interest.

## 11.3 The program statement

Let us say that you want to compute several statistics from the percentiles  $p...$  of a continuous variable. Researchers often use the interquartile range,  $(p75 - p25)$ , as an alternative to the standard deviation as a measure of a variable's spread. Those concerned with income distributions often use  $(p90 - p10)$  as a measure of inequality. If we are concerned about outliers, we might compute  $(p95 - p5)$  or  $(p99 - p1)$  to compare the variable's range  $(x_{max} - x_{min})$  with these percentile ranges.

Computing these percentile ranges in a do-file is easy enough. You merely need to use `summarize`, `detail` and access the appropriate percentiles in its `return list`. But you might like to have a program that would calculate the ranges from these percentiles and make them available for later use. What must you do to write one? The first step is to choose a name. As suggested above, `which` and `findit` should be used to ensure that the name is not already in use. Those commands indicate that `pctrange` is free for your use, so fire up the Do-File Editor (or your favorite text editor)<sup>5</sup> and create the file `pctrange.ado`. Our first crack at the code:

```
. type pctrange.ado
*! pctrange v1.0.0 CFBaum 11aug2008
program pctrange
    version 10.1
    syntax varlist(max=1 numeric)
    quietly summarize `varlist', detail
    scalar range = r(max) - r(min)
    scalar p7525 = r(p75) - r(p25)
    scalar p9010 = r(p90) - r(p10)
    scalar p9505 = r(p95) - r(p5)
```

---

5. See `ssc describe texteditors`.

```

scalar p9901 = r(p99) - r(p1)
display as result _n "Percentile ranges for 'varlist'"
display as txt "75-25: " p7525
display as txt "90-10: " p9010
display as txt "95-05: " p9505
display as txt "99-01: " p9901
display as txt "Range: " range
end

```

You start with a **capture program drop** *progrname* command. Once a program has been loaded into Stata's memory, it is usually retained for the duration of the session. Since we will be repeatedly defining our program during its development, we want to make sure that we're working with the latest version. The following comment line starting with **!** (termed *star-bang* in geekish) is a special comment that will show up if you issue the **findfile** ([P] **findfile**) or **which** commands. It is always a good idea to document an ado-file with a sequence number, author name, and date.

The **program** ([P] **program**) statement identifies the program name as **pctrange**. We define the program as **rclass**. Unless a program is defined as **rclass** or **eclass**, it cannot return values with the **return** or **ereturn** statements, respectively (see Section 5.3). Although we do not have any **return** statements in the current version of the program, we will want to add them in later versions. The following **version** ([P] **version**) line states that the ado-file requires Stata 10.1 and ensures that the program will obey Stata 10.1 syntax when executed by Stata 11 or Stata 12.

## 11.4 The syntax and return statements

The following line, **syntax** ([P] **syntax**), provides the ability for a Stata program to parse its command line and extract the program's arguments for use within the program. In this simple example, we only use one element of **syntax**: specifying that the program has a mandatory *varlist* with a maximum of one numeric variable. Stata will enforce the constraint that a single name appears on the command line and that the name refers to an existing numeric variable. In this case, we could have also used **syntax varname(numeric)** to allow a single variable, but we would still refer to '*varlist*' to access its name.

To calculate percentiles of the variable given as **pctrange**'s argument, we must use the **detail** option of **summarize** ([R] **summarize**). We use the **quietly** prefix to suppress output. The following five lines define *scalars*<sup>6</sup> containing the four percentile ranges and the standard range. We display a header, list each range, and end the program.

Let's try out the first version of **pctrange** on the Stock–Watson **mcas** data.<sup>7</sup> Vari-

6. See Section 3.9.

7. MCAS, the Massachusetts Comprehensive Assessment System, refers to the standardized tests administered in that state to all primary and secondary school students. See <http://www.doe.mass.edu/mcas/>.

able `tot_day` measures total spending per elementary-school pupil in each of 220 Massachusetts school districts.

```
. clear
. use mcas
. pctrange tot_day
Percentile ranges for tot_day
75-25: 1070
90-10: 2337.5
95-05: 3226
99-01: 4755
Range: 6403
. display p7525
1070
```

The scalars defined in the program have global scope (unlike local macros), so they are accessible after the program has run. As shown above, we may `display` ([P] **display**) them or use them in later computations.

One flaw in that logic, however: what if you already are using one of these names for a scalar, or for a variable in your dataset? Must you remember all of the names of scalars returned by various programs, and avoid reusing them? That's not very convenient, so let us name those scalars within the program with `tempnames`. A `tempname` is actually a local macro, assigned automatically by Stata, which allows you to create the equivalent of a local scalar or matrix. As the `tempnames` are local macros, we refer to their contents just as we would a local macro with left and right single quotes.<sup>8</sup>

```
. type pctrange.ado
*! pctrange v1.0.1 CFBaum 11aug2008
program pctrange
    version 10.1
    syntax varlist(max=1 numeric)
    local res range p7525 p9010 p9505 p9901
    tempname 'res'
    display as result _n "Percentile ranges for 'varlist'"
    quietly summarize 'varlist', detail
    scalar 'range' = r(max) - r(min)
    scalar 'p7525' = r(p75) - r(p25)
    scalar 'p9010' = r(p90) - r(p10)
    scalar 'p9505' = r(p95) - r(p5)
    scalar 'p9901' = r(p99) - r(p1)
    display as txt "75-25: " 'p7525'
    display as txt "90-10: " 'p9010'
    display as txt "95-05: " 'p9505'
    display as txt "99-01: " 'p9901'
    display as txt "Range: " 'range'
end
```

One of the important features of Stata commands is their ability to return results for use in further computations. We now add that feature to the `pctrange` command by using

---

8. See Section 3.6.

the `return` command to place the computed scalars in the `return list`. They will be accessible after the program runs, but will not collide with any other objects. One bit of trickery necessary with these `tempnames`: while the left-hand side of the `return scalar` refers to the macro's name, the right-hand side must *dereference* the macro one further time to extract the *value* stored in that name. The modified code:

```
. type pctrange.ado
*! pctrange v1.0.2 CFBaum 11aug2008
program pctrange, rclass
    version 10.1
    syntax varlist(max=1 numeric)
    local res range p7525 p9010 p9505 p9901
    tempname 'res'
    display as result _n "Percentile ranges for 'varlist'"
    quietly summarize 'varlist', detail
    scalar 'range' = r(max) - r(min)
    scalar 'p7525' = r(p75) - r(p25)
    scalar 'p9010' = r(p90) - r(p10)
    scalar 'p9505' = r(p95) - r(p5)
    scalar 'p9901' = r(p99) - r(p1)
    display as txt "75-25: " 'p7525'
    display as txt "90-10: " 'p9010'
    display as txt "95-05: " 'p9505'
    display as txt "99-01: " 'p9901'
    display as txt "Range: " 'range'
    foreach r of local res {
        return scalar 'r' = 'r'
    }
end
```

To reduce a bit of typing (and to make the program easier to maintain) we have listed the items to be created, and used a `foreach` ([P] `foreach`) loop to issue the `return` statements. When we run the program and view the `return list`, we see:

```
. quietly pctrange tot_day
. return list
scalars:
      r(p9901) = 4755
      r(p9505) = 3226
      r(p9010) = 2337.5
      r(p7525) = 1070
      r(range) = 6403
```

## 11.5 Implementing program options

In the last output, we used the `quietly` prefix to suppress output. But if you're going to use the `pctrange` command to compute (but not display) these ranges, perhaps you should be able to produce the output as an option. Square brackets [ ] in [P] `syntax` signify an optional component of the command. Our third version of the program adds [ , PRINT], indicating that the command has a print option, and that it is truly optional

(you can define non-optional or required options on a Stata command).

```
. type pctrange.ado
*! pctrange v1.0.3 CFBaum 11aug2008
program pctrange, rclass
    version 10.1
    syntax varlist(max=1 numeric) [, PRINT]
    local res range p7525 p9010 p9505 p9901
    tempname 'res'
    quietly summarize 'varlist', detail
    scalar 'range' = r(max) - r(min)
    scalar 'p7525' = r(p75) - r(p25)
    scalar 'p9010' = r(p90) - r(p10)
    scalar 'p9505' = r(p95) - r(p5)
    scalar 'p9901' = r(p99) - r(p1)
    if "'print'" == "print" {
        display as result _n "Percentile ranges for 'varlist'"
        display as txt "75-25: " 'p7525'
        display as txt "90-10: " 'p9010'
        display as txt "95-05: " 'p9505'
        display as txt "99-01: " 'p9901'
        display as txt "Range: " 'range'
    }
    foreach r of local res {
        return scalar 'r' = 'r'
    }
end
```

If you now execute the program with `pctrange tot_day, print`, its output is printed. We might also want to make the command print by default, and allow an option to suppress printing. We do this with a `noprint` option, as shown in this next version of the command:

```
. type pctrange.ado
*! pctrange v1.0.4 CFBaum 11aug2008
program pctrange, rclass
    version 10.1
    syntax varlist(max=1 numeric) [, noPRINT]
    local res range p7525 p9010 p9505 p9901
    tempname 'res'
    quietly summarize 'varlist', detail
    scalar 'range' = r(max) - r(min)
    scalar 'p7525' = r(p75) - r(p25)
    scalar 'p9010' = r(p90) - r(p10)
    scalar 'p9505' = r(p95) - r(p5)
    scalar 'p9901' = r(p99) - r(p1)
    if "'print'" != "noprint" {
        display as result _n "Percentile ranges for 'varlist'"
        display as txt "75-25: " 'p7525'
        display as txt "90-10: " 'p9010'
        display as txt "95-05: " 'p9505'
        display as txt "99-01: " 'p9901'
        display as txt "Range: " 'range'
    }
    foreach r of local res {
        return scalar 'r' = 'r'
    }
end
```

```

    }
end

```

Notice that to test the value of the option, we examine whether the local macro `print` contains the word `noprint`: that is, the name of the option is `print`. You can add many other types of options to a Stata program, some of which we will present below.

## 11.6 Including a subset of observations

All well and good, but a statistical command should accept `if exp` and `in range` qualifiers if it is to be useful. It turns out that very little work is needed to add these features to our program. The definition of `if exp` and `in range` qualifiers and program options is all handled by the `syntax` statement. In the improved program, `[if]` and `[in]` denote that each of these qualifiers may be used.

With an `if exp` or `in range` qualifier something less than the full sample will be analyzed. Before doing any computations on the subsample, we must ensure that the subsample is not empty. Accordingly, we calculate `r(N)` to indicate the sample size used in the computations, check to see that it is not zero, and add it to the display header.

The `marksample touse` command uses the information provided in a `if exp` or `in range` qualifier operative if one or both were given on the command line. The `marksample` command marks those observations which should enter the computations in an indicator variable `'touse'`, equal to 1 for the desired observations and 0 otherwise. The `'touse'` variable is a temporary variable, or `tempvar`, which will disappear when the ado-file ends, like a local macro. After defining this indicator variable, we use `count if 'touse'` to calculate the number of observations after applying the qualifiers and display an error if there are no observations (see Cox (2007b)). We must add `if 'touse'` to each statement in the program which works with the input `varlist`. In this case, we need only modify the `summarize` statement to include `if 'touse'`. The new version of the program is:

```

. type pctrange.ado

*! pctrange v1.0.5 CFBaum 11aug2008
program pctrange, rclass
    version 10.1
    syntax varlist(max=1 numeric) [if] [in] [, noPRINT]
    marksample touse
    quietly count if 'touse'
    if 'r(N)' == 0 {
        error 2000
    }
    local res range p7525 p9010 p9505 p9901
    tempname 'res'
    quietly summarize 'varlist' if 'touse', detail
    scalar 'range' = r(max) - r(min)
    scalar 'p7525' = r(p75) - r(p25)
    scalar 'p9010' = r(p90) - r(p10)
    scalar 'p9505' = r(p95) - r(p5)

```

```

scalar 'p9901' = r(p99) - r(p1)
if "'print'" != "noprint" {
    display as result _n "Percentile ranges for 'varlist', N = 'r(N)'"
}
}
display as txt "75-25: " 'p7525'
display as txt "90-10: " 'p9010'
display as txt "95-05: " 'p9505'
display as txt "99-01: " 'p9901'
display as txt "Range: " 'range'
}
foreach r of local res {
    return scalar 'r' = 'r'
}
return scalar N = r(N)
return local varname 'varlist'
end

```

We might want to compare the percentile ranges in communities with above-average per capita incomes those from the overall sample. The variable `percap` measures per capita income in each school district. We compute its statistics from a subsample of communities with above-average `percap`:

```

. summarize percap, meanonly
. pctrange tot_day if percap > r(mean) & !missing(percap)
Percentile ranges for tot_day, N = 78
75-25: 1271
90-10: 2572
95-05: 3457
99-01: 5826
Range: 5826

```

## 11.7 Generalizing the command to handle multiple variables

Perhaps by this time you're pleased with the `pctrange` command, but realize that it would be really handy to run it for a number of variables with a single command. You could always loop over those variables with a `foreach` ([P] **foreach**) loop, but assembling the output afterward might be a bit of work. As the program produces five statistics for each variable, perhaps a nicely-formatted table would be useful—and that will require some rethinking about how the command's results are to be displayed and returned.

First, you must tell the `syntax` ([P] **syntax**) statement that more than one numeric variable is allowed. The program will perform as it does now for a single variable, or produce a table if given several variables. As we are constructing a table, a Stata *matrix*<sup>9</sup> is a useful device to store the results we generate from [R] **summarize**. Rather than placing the elements in scalars, we declare a matrix with the `J()` function, calculating the number of rows needed with the macro extended function `word count`.<sup>10</sup> The `foreach`

9. See Section 3.10 and Section 9.2.

10. See Section 3.8.

loop then cycles through the *varlist*, placing the percentile ranges for each variable into one row of the matrix. The local macro `rown` is used to build up the list of row names, applied with `matrix rownames`.

We have added two additional options in the `syntax` statement for this version: a `format()` option, which allows you to specify the Stata format<sup>11</sup> used to display the matrix elements, and the `mat` option, discussed below.

```
. type pctrange.ado
*! pctrange v1.0.6 CFBaum 11aug2008
program pctrange, rclass byable(recall)
    version 10.1
    syntax varlist(min=1 numeric ts) [if] [in] [, noPRINT FORmat(passthru)
> MATrix(string)]
    marksample touse
    quietly count if `touse'
    if `r(N)' == 0 {
        error 2000
    }
    local nvar : word count `varlist'
    if `nvar' == 1 {
        local res range p7525 p9010 p9505 p9901
        tempname `res'
        quietly summarize `varlist' if `touse', detail
        scalar `range' = r(max) - r(min)
        scalar `p7525' = r(p75) - r(p25)
        scalar `p9010' = r(p90) - r(p10)
        scalar `p9505' = r(p95) - r(p5)
        scalar `p9901' = r(p99) - r(p1)
        if "'print'" != "noprint" {
            display as result _n "Percentile ranges for `varlist',
> N = `r(N)'"
                display as txt "75-25: " `p7525'
                display as txt "90-10: " `p9010'
                display as txt "95-05: " `p9505'
                display as txt "99-01: " `p9901'
                display as txt "Range: " `range'
        }
        foreach r of local res {
            return scalar `r' = ``r''
        }
        return scalar N = r(N)
    }
    else {
        tempname rmat
        matrix `rmat' = J(`nvar',5,..)
        local i 0
        foreach v of varlist `varlist' {
            local ++i
            quietly summarize `v' if `touse', detail
            matrix `rmat'[`i',1] = r(max) - r(min)
            matrix `rmat'[`i',2] = r(p75) - r(p25)
            matrix `rmat'[`i',3] = r(p90) - r(p10)
            matrix `rmat'[`i',4] = r(p95) - r(p5)
            matrix `rmat'[`i',5] = r(p99) - r(p1)
            local rown "'rown' `v'"

```

---

11. See [D] `format`.

```

    }
    matrix colnames `rmat' = Range P75-P25 P90-P10 P95-P05 P99-P01
    matrix rownames `rmat' = `rown'
    if "`print'" != "noprint" {
        local form ", noheader"
        if "`format'" != "" {
            local form "`form' `format'"
        }
        matrix list `rmat' `form'
    }
    if "`matrix'" != "" {
        matrix `matrix' = `rmat'
    }
    return matrix rmat = `rmat'
}
return local varname `varlist'
end

```

You may now invoke the program on a set of variables, and optionally specify a format for the output of matrix elements:

```

. pctrange regday specneed bilingua occupday tot_day tchratio, form(%9.2f)

```

	Range	P75-P25	P90-P10	P95-P05	P99-P01
regday	5854.00	918.50	2037.00	2871.00	4740.00
specneed	49737.01	2282.78	4336.76	5710.46	10265.45
bilingua	295140.00	0.00	6541.00	8817.00	27508.00
occupday	15088.00	0.00	5291.50	8096.00	11519.00
tot_day	6403.00	1070.00	2337.50	3226.00	4755.00
tchratio	15.60	3.25	5.55	7.55	10.60

The `mat` option allows the matrix to be automatically saved as a Stata matrix with that name. This is useful if you are running `pctrange` several times (perhaps in a loop) and want to avoid having to rename the result matrix `r(rmat)` each time. If we use this feature, we may use Baum and Azevedo's `outtable` routine (available from the SSC Archive) to convert the matrix into L<sup>A</sup>T<sub>E</sub>X:

```

. pctrange regday specneed bilingua occupday tot_day tchratio, mat(MCAS) noprin
> t
. outtable using MCAS, mat(MCAS) caption("MCAS percentile ranges") format(%9.2f
> ) nobox replace

```

Other SSC routines could be used to produce a table in tab-delimited, RTF or HTML formats.

## 11.8 Making commands byable

As a final touch, you might want the `pctrange` command to be *byable*: to permit its use with a *by varlist*: prefix. Since we are not creating any new variables with this version of the program, this can be done by just adding `byable(recall)` to the program

Table 11.1: MCAS percentile ranges

	P75-P25	P90-P10	P95-P05	P99-P01	Range
regday	918.50	2037.00	2871.00	4740.00	5854.00
specneed	2282.78	4336.76	5710.46	10265.45	49737.01
bilingua	0.00	6541.00	8817.00	27508.00	295140.00
occupday	0.00	5291.50	8096.00	11519.00	15088.00
tot day	1070.00	2337.50	3226.00	4755.00	6403.00
tchratio	3.25	5.55	7.55	10.60	15.60

statement.<sup>12</sup> The new program statement becomes:

```
program pctrange, rclass byable(recall)
```

The other enhancement you might consider is allowing the *varlist* to contain variables with time series operators such as `L.gdp` or `D.income`. We can easily incorporate that feature by changing the `[P] syntax` statement to add the `ts` suboption:

```
syntax varlist(min=1 numeric ts) [if] [in] [, noPRINT FORmat(passthru) MATrix(string)]
```

With these modifications, we may apply `pctrange` using the `by` prefix or employ time series operators in the *varlist*. As an illustration of the `byable` nature of the program, let us generate an indicator for teachers' average salaries above and below the mean and calculate the `pctrange` statistics for those categories:

```
. summarize avgsalry, meanonly
. generate byte highsal = avgsalry > r(mean) & !missing(avgsalry)
. label define sal 0 low 1 high
. label val highsal sal
. tabstat avgsalry, by(highsal) stat(mean N)
Summary for variables: avgsalry
    by categories of: highsal
highsal |      mean      N
-----|-----
    low | 33.5616     101
    high | 38.60484     94
-----|-----
    Total | 35.9927     195

. bysort highsal: pctrange regday specneed bilingua occupday tot_day tchratio

-> highsal = low
      Range   P75-P25   P90-P10   P95-P05   P99-P01
regday    4858         703        1740        2526        3716
specneed 49737.008 2030.8198 3997.9497 5711.2104 11073.81
bilingua   295140         0         6235         8500        13376
occupday   11519         0         5490         7095        11286
```

12. See `[P] byable` for details. You may also use `byable(onecall)`, but that option requires more work on your part. `byable(recall)` is usually suitable.

```

tot_day      5214      780      1770      2652      4597
tchratio     11.6    3.1999989  6.2999992  7.8000002  9.3999996

```

```

-> highsals = high

```

	Range	P75-P25	P90-P10	P95-P05	P99-P01
regday	5433	1052	2189	2807	5433
specneed	8570.4004	2486.3604	4263.9702	5620.54	8570.4004
bilingua	33968	0	8466	11899	33968
occupday	15088	0	5068	8100	15088
tot_day	5928	1179	2572	3119	5928
tchratio	15.6	2.4000006	4.7000008	6.2999992	15.6

We see that average salaries in low-salary school districts are over \$5,000 less than those in high-salary school districts. These differences carry over into the percentile ranges, where the ranges of `tot_day`, total spending per pupil, are much larger in the high-salary districts than in the low-salary districts.

### Program properties

User-written programs may also have *properties* associated with them. Some of Stata's prefix commands use these properties for command validation. If you are interested in writing programs for use with `nestreg` ([R] `nestreg`), `svy` ([SVY] `svy`) or `stepwise` ([R] `stepwise`) you should read [P] **program properties**.

Separately, several prefix commands (`bootstrap` ([R] `bootstrap`), `jackknife` ([R] `jackknife`) and `svy` ([SVY] `svy`)) can report exponentiated coefficients, such as hazard ratios or odds ratios, when the `eform()` option is used. To make this feature available in your own program, it must have the associated properties defined (for instance, `hr` for the hazard ratio or `or` for the odds ratio). See [P] **program properties** for details. The extended macro function `properties` will report on the properties of any ado-file: for instance,

```

local logitprop: properties logit

```

will provide a list of properties associated with the `logit` ([R] `logit`) command.

## 11.9 Documenting your program

Stata's development tools make it easy for you to both write a useful program and document it in the way Stata users expect: as readily accessible on-line help. Even if the program is solely for your use, producing a help file is straightforward and useful. You need not resort to scrutinizing the code to remember how the program is called if you document it now, and keep that documentation up to date as the program is modified or enhanced. Just create a text file, for example, `pctrange.sthlp`,<sup>13</sup> with

13. Before version 10.1, Stata's help files were suffixed `.hlp`. Unless you are writing a program that must be compatible with earlier versions of Stata, you should use the `.sthlp` suffix.

your favorite text editor.<sup>14</sup>

The best way to document a Stata program is to learn a bit of SMCL, Stata's Markup and Control Language. Writing the help file in SMCL allows you to produce on-line help indistinguishable from that of official commands and other user-written programs. It also wraps properly when you resize the Viewer, or use a different size font in that window. A bare-bones help file for our `pctrange` program can be constructed with the following SMCL code:

```
{smcl}
{* *! version 1.0.0 31jul2007}{...}
{cmd:help pctrange}
{hline}

{title:Title}
{phang}
{bf: pctrange {c -} Calculate percentile ranges}

{title:Syntax}
{p 8 17 2}
{cmd:pctrange}
{it:varlist}
[
  [{cmd:if} {it:exp}]
  [{cmd:in} {it:range}]
  [
    {cmd:.,}
    {cmdab:noPRINT}
    {cmdab:FOR:mat()}{it:string}{cmd:)}
    {cmdab:MAT:rix()}{it:string}{cmd:)}
  ]
]

{p 4 6 2}
{cmd:by} is allowed; see {manhelp by D}.{p_end}
{p 4 6 2}
{cmd:time series operators} are allowed; see {help varlist}.{p_end}

{title:Description}

{pstd}{cmd:pctrange} computes four percentile ranges of the specified
variable(s): the 75-25 (interquartile) range, the 90-10, 95-05 and 99-01
ranges as well as the conventional range. These ranges are returned as scalars.
If multiple variables are included in the {it:varlist},
the results are returned as a matrix.

{title:Options}

{phang}{opt noprint} specifies that the results are to be returned
but not printed.

{phang}{opt format(string)} specifies the format to be used
in displaying the matrix of percentile ranges for multiple variables.

{phang}{opt mat(string)} specifies the name of the Stata matrix
```

---

14. See `ssc describe texteditors`.

to be created for multiple variables.

```
{title:Examples}

{phang}{stata "sysuse auto" : . sysuse auto}{p_end}
{phang}{stata "pctrange mpg" : . pctrange mpg}{p_end}
{phang}{stata "pctrange price mpg turn, format(%9.2f)" :. pctrange price mpg turn, format(%9.2f)}{p_end}

{title:Author}
{phang}Christopher F. Baum, Boston College{break}
baum@bc.edu{p_end}

{title:Also see}

{psee}
On-line: help for {help summarize}, {help pctile}
```

As you can see, the left and right braces (`{,}`) are the key markup characters in SMCL, playing the role of the angle brackets (`<, >`) in HTML web-page markup. There are many similarities between SMCL and HTML (and  $\text{\LaTeX}$ , for that matter).<sup>15</sup> As in  $\text{\LaTeX}$ , blank lines in SMCL influence vertical spacing, but in SMCL multiple blank lines are taken literally. The formatted help for `pctrange` may now be viewed:

```
help pctrange
-----
Title
  pctrange -- Calculate percentile ranges

Syntax
  pctrange varlist [if exp] [in range] [ , noPRINT FORmat(string)
  MATrix(string) ]

  by is allowed; see [D] by.
  time series operators are allowed; see varlist.

Description
  pctrange computes four percentile ranges of the specified variable(s):
  the 75-25 (interquartile) range, the 90-10, 95-05 and 99-01 ranges as
  well as the conventional range. These ranges are returned as scalars. If
  multiple variables are included in the varlist, the results are returned
  as a matrix.

Options
  noprint specifies that the results are to be returned but not printed.
  format(string) specifies the format to be used in displaying the matrix
  of percentile ranges for multiple variables.
  mat(string) specifies the name of the Stata matrix to be created for
  multiple variables.

Examples
  . sysuse auto
  . pctrange mpg
  . pctrange price mpg turn, format(%9.2f)

Author
  Christopher F Baum, Boston College
```

15. Mechanical translation of SMCL logfiles into HTML is quite reliably performed by the `log2html` package of Baum, Cox and William Rising, available from [R] `ssc`.

baum@bc.edu

Also see

On-line: help for summarize, pctlile

For full details on the construction of SMCL help files (and SMCL output in general), see [P] `smcl` and [U] **18.11.6 Writing online help**.

## 11.10 egen function programs

As we discussed in Section 3.4, the `egen` ([D] `egen`) (Extended Generate) command is open-ended, in that any Stata user may define an additional `egen` function by writing a specialized ado-file program. The name of the program (and of the file in which it resides) must start with `_g`: that is, `_gcrunch.ado` will define the `crunch()` function for `egen`.

To illustrate `egen` functions, let us create a function to generate one of the `pctrange` values, the 90–10 percentile range. The program follows the same pattern as our stand-alone command `pctrange` with one important difference. In an `egen` function, you must deal with the new variable to be created. The syntax for `egen` is:

```
egen [type] newvar = fcn(arguments) [if] [in] [, options]
```

The `egen` command, like `generate`, may specify a data type. The `syntax` command indicates that a *newvarname* must be provided, followed by an equals sign and an *fcn*, or function, with *arguments*. `egen` functions may also handle *if exp* and *in range* qualifiers and options.

The computation for our `egen` function is the same as that of `pctrange`, using `summarize` with the `detail` option. On the last line of the function, we `generate` the new variable, of the appropriate type if specified,<sup>16</sup> under the control of the ‘`touse`’ temporary indicator variable, limiting the sample as specified.

```
. type _gpct9010.ado
*! _gpct9010 v1.0.0 CFBaum 11aug2008
  program _gpct9010
    version 10.1
    syntax newvarname =/exp [if] [in]
    tempvar touse
    mark `touse' `if' `in'
    quietly summarize `exp' if `touse', detail
    quietly generate `typlist' `varlist' = r(p90) - r(p10) if `touse'
  end
```

This function works perfectly well, but it creates a new variable containing a single scalar

16. When *newvarname* or *newvarlist* is specified on `syntax`, the macro *typlist* is filled with the data type(s) to be used for the new variable(s).

value. As noted earlier, that is a very profligate use of Stata's memory (especially for large `_N`) and often can be avoided by retrieving the single scalar which is conveniently stored by our `pctrange` command. To be useful, we would like the `egen` function to be *byable*, so that it could compute the appropriate percentile range statistics for a number of groups defined in the data.

The changes to the code are relatively minor. We add an options clause to the `syntax` statement, as `egen` will pass the `by` prefix variables as a *by option* to our program. Rather than using `summarize`, we use `egen`'s own `pctile()` function, which is documented as allowing the *by prefix*, and pass the options to this function. The revised function reads:

```
. type _gpct9010.ado
*! _gpct9010 v1.0.1 CFBaum 11aug2008
    program _gpct9010
        version 10.1
        syntax newvarname =/exp [if] [in] [, *]
        tempvar touse p90 p10
        mark `touse' `if' `in'
        quietly {
            egen double `p90' = pctile(`exp') if `touse', `options' p(90)
            egen double `p10' = pctile(`exp') if `touse', `options' p(10)
            generate `typlist' `varlist' = `p90' - `p10' if `touse'
        }
    end
```

These changes permit the function to produce a separate percentile range for each group of observations defined by the `by`-list. To illustrate, we use `auto.dta`:

```
. sysuse auto, clear
(1978 Automobile Data)
. bysort rep78 foreign: egen pctrange = pct9010(price)
```

Now, if we want to compute a summary statistic (such as the percentile range) for each observation classified in a particular subset of the sample, we may use the `pct9010()` function to do so.

## 11.11 Writing an e-class program

The ado-file programs we have discussed in earlier sections are all *r*-class programs: that is, they provide results in the `return list`.<sup>17</sup> Many statistical procedures involve estimating a model (rather than computing one or more statistics) and are thus termed *estimation commands*, or *e*-class commands. One of Stata's great strengths derives from the common nature of its estimation commands, which follow a common syntax, leave behind the same objects, and generally support the same postestimation tools such as `test` ([R] `test`), `lincom` ([R] `lincom`), `mfx` ([R] `mfx`) to compute marginal effects and

17. With one exception: an `egen` program such as `_gpct9010` cannot return results in the `return list`.

`predict` ([R] `predict`) to compute predicted values, residuals and similar quantities. Although `e`-class commands are somewhat more complicated than `r`-class commands, it is reasonably simple for you to implement an estimation command as an ado-file. Many of the programming concepts discussed in earlier sections are equally useful in `e`-class commands. The additional features needed generally relate to postestimation capabilities.

As spelled out in [U] **18.9 Accessing results calculated by estimation commands** there are a number of conventions that an `e`-class command must follow:

1. The command must save its results in `e()`, accessed by `ereturn list`, rather than `r()`.
2. It should save its name in `e(cmd)`.
3. It should save the contents of the command line in `e(cmdline)`.
4. It should save the number of observations in `e(N)` and identify the estimation sample by setting the indicator variable (or “function”) `e(sample)`.
5. It must save the entire coefficient vector as Stata matrix `e(b)` and the variance-covariance matrix of the estimated parameters as Stata matrix `e(V)`.

Correct capitalization of these result names is important. The coefficient vector is saved as a  $1 \times k$  row vector for single-equation estimation commands, with additional rows added for multiple-equation estimators. The variance-covariance matrix is saved as a  $k \times k$  symmetric matrix. The presence of `e(b)` and `e(V)` in standardized locations enables Stata’s postestimation commands (including those you write) to work properly. Estimation commands may set other `e()` scalars, macros or matrices.

Whereas a `r`-class program such as `ptrange` uses the `return` ([P] `return`) command to return its results in `r()`, an `e`-class program uses the `ereturn` command. The command `ereturn name = exp` returns a scalar value, while `ereturn local name value` and `ereturn matrix name matname` return a macro and a Stata matrix, respectively. Note that you do not use `ereturn` for the coefficient vector or estimated variance-covariance matrix, as we now discuss.

The `ereturn post` command *posts* the estimates of `b` and `V` to their official locations. In order to return the coefficient vector and its variance-covariance matrix, you need to create the coefficient vector, say ‘`beta`’ and its variance-covariance matrix, say ‘`vce`’, and pass them back in the following fashion. We also can define the estimation sample flagged by the sample indicator temporary variable ‘`touse`’:

```
ereturn post 'beta' 'vce', esample('touse')
```

You may now save anything else in `e()`, using the `ereturn scalar`, `ereturn local` or `ereturn matrix` commands as described above. It is best to use the commonly-employed names for various quantities. For instance, `e(df_m)` and `e(df_r)` are commonly used to denote the numerator (model) and denominator (residual) degrees of freedom. `e(F)` commonly refers to the test against the null (constant-only) model for

non-asymptotic results, while `e(chi2)` is used for an asymptotic estimator. `e(r2)` or `e(r2_p)` refer to the  $R^2$  or pseudo- $R^2$ , respectively. Although you are free to choose other names for your `ereturn` values, it is most helpful if they match those used in common Stata commands. See [U] 18.10.2 Saving results in `e()` for more details.

### 11.11.1 Defining subprograms

If a user-written Stata command is to be executed, the file defining that command must be on the `adopath`<sup>18</sup>. However, a single `ado`-file can contain more than one program. The subsequent programs are *local* in the sense that they cannot be called independently. So, for instance, `one.ado` could contain

```

program one
...
end
program two
...
end
program three
...
end

```

Presumably the `one` command calls the `two` and `three` programs in the course of its execution. Those subprogram names are not visible to other commands, but may only be used by `one`. Using subprograms allows you to isolate sections of your program that are used repeatedly, or separate sections that perform quite distinct tasks within your command. We make use of this facility in Section 11.13.

## 11.12 Certifying your program

All computer programs have the potential to misbehave. Some will crash when presented with certain input values; some will never stop running; some will generate output that turns out to be incorrect. If you are writing your own Stata programs, how can you guard against these types of misbehavior, and be reasonably satisfied with your program's reliability? You may use the same tools that StataCorp developers use to *certify* official Stata's reliability by constructing and running a *certification script*.

In the very first issue of the *Stata Journal*, chief software developer William Gould formally discussed Stata's certification tools (Gould (2001)) and illustrated how they could be used to certify the performance of a user-written Stata program. Stata's `assert` ([D] `assert`) command, discussed in Section 5.2 in the context of data validation, is the key component of a certification script. The result of a computation is compared with a known value, or with the result of another routine known to be correct.

Gould describes the certification test script as a collection of do-files, executed in

---

18. Or the program must be loaded into memory from a do-file or entered interactively. We do not consider those possibilities.

turn by a master do-file. If no errors are detected by any of the do-files, the script will run to completion. However, at the first error, the do-file will abort. To illustrate, he presents a fragment of a typical test script (*op.cit.*, p. 37):

```

cscript summarize
which summarize
use auto
summarize mpg
assert r(N) == 74 & r(sum_w) == 74 & r(min) == 12 & r(max) == 41 & r(sum) == 1576
assert reldif(r(mean), 21.29729729729730) < 1e-14
assert reldif(r(Var), 33.47204738985561) < 1e-14
assert r(sd) == sqrt(r(Var))
summarize mpg if foreign
assert r(N) == 22 & r(sum_w) == 22 & r(min) == 14 & r(max) == 41 & r(sum) == 545
...

```

The `assert` commands in this fragment of the script all ensure that results left behind in the `return list` from `summarize` match known values and are internally consistent (for instance, that the computed standard deviation `r(sd)` is the square root of the computed variance `r(Var)`). Note the use of the `reldif()` function to compare a constant with the computed value. As mentioned in Section 2.4 in the context of finite-precision arithmetic, we cannot perform exact comparisons against non-integer values (see Gould (2006b) and Cox (2006a)).

The certification script should not only test against known values, but test that error messages are correctly produced when they should be. For instance, in the `auto` dataset, applying `summarize` outside of the defined observation range should produce an error 198:

```
summarize price in 75/99
```

How may we test this statement, given that its execution will cause an error and stop the do-file? With the `rcof` command. Coupled with the `noisily` prefix, we may use

```
rcof "noisily summarize price in 75/99" == 198
```

to ensure that an error (with the proper error code) is produced. If no error is produced, or if an error with another error code is produced, the certification script will fail. You may also test for appropriate syntax:

```
rcof "noisily summarize mpg, detail meanonly" != 0
```

tests whether the `summarize` command properly rejects the combination of the `detail` and `meanonly` options, which should be mutually exclusive.

As another example of certification practices, Baum, Schaffer and Stillman's `ivreg2` routine for instrumental variables estimation is an extension of Stata's earlier `ivreg` command, and parallels the current `ivregress` command. We trust that Stata's developers have fully certified the behavior of official `ivregress` and its predecessor `ivreg`, as well as that of `regress` and `newey` (`ivreg2` can estimate ordinary least squares (OLS) and "Newey–West" regressions). Therefore, we have constructed a certification script for `ivreg2`, available as an ancillary do-file of the `ivreg2` package, which conducts a

number of tests to ensure that the computed values are correct. Many of those tests rely on comparing the detailed results generated by `ivreg2` with those from `ivregress`, `ivreg`, `regress` and `newey`. See `ssc describe ivreg2`, Chapter 8 of Baum (2006a), Baum et al. (2003) and Baum et al. (2007).

In summary: best practices in Stata programming involve setting up a certification script for your program. The script should evolve, as every flaw in the program that is corrected should translate into an additional check against that condition. Every time the program is enhanced by adding features, additional certification tests should be added to ensure that those features work properly under all conditions, including conditions that may seem implausible. Just as the documentation of a program is as important as the code, validation of the program's reliability should be automated and redone whenever changes are made to the code.

## 11.13 programs for ml, nl, nlsur, simulate, bootstrap and jackknife

The ado-file programming techniques discussed in earlier sections carry over to those Stata commands and prefix operators which involve writing a program. For instance, maximum likelihood estimation, performed with the `ml` (`[R] ml`) command, requires that you write a likelihood function evaluator.<sup>19</sup> This is a quite formulaic program that calculates either one term of the log-likelihood function or its total over the estimation sample. In this context, you need only follow the template established for the particular form of `ml` you choose to specify the parameters to be estimated and the way in which they enter the log-likelihood function (LLF). Stata's `ml` routines support four *methods* of coding the LLF: the *linear form* (`lf`) method and methods `d0`, `d1` and `d2`. The linear form is the easiest to work with, but requires that the statistical model meets the *linear form restrictions* (see `[R] ml`). Methods `d0`, `d1` and `d2` require coding the LLF, the LLF and its first derivatives or the LLF and its first and second derivatives, respectively.

For example, here is a LLF linear-form evaluator for a linear regression model with normally distributed errors:

```
. type mynormal_lf.ado
*! mynormal_lf v1.0.0 CFBaum 11aug2008
program mynormal_lf
    version 10.1
    args lnf mu sigma
    quietly replace `lnf' = ln( normalden( $ML_y1, `mu', `sigma' ) )
end
```

In this program we use the `args` (`[P] args`) command<sup>20</sup> to retrieve the three items which

19. An essential reference for maximum likelihood programming in Stata is Gould et al. (2006).

20. In the `ml` context, we only need a subset of the capabilities of the `syntax` command. The `args`

are passed to the LLF evaluator: a variable `lnf` whose values are to be computed in the routine and the two parameters to be estimated, the conditional mean of the dependent variable (referred to as `$ML_y1`), `mu` and its variance `sigma`. The linear-form restrictions imply that we need not explicitly work with the elements of the conditional mean  $X\hat{\beta}$ . To invoke the LLF evaluator using the `auto.dta` dataset, we can use the command

```
ml model lf mynormal_lf (mpg = weight displacement) /sigma
```

which estimates the regression of `mpg` on `weight` and `displacement` with a constant term under the assumption of homoskedasticity (a constant error variance, estimated as `sigma`). The flexibility of this approach is evident if we considered a heteroskedastic regression model in which  $\sigma_i = \gamma_0 + \gamma_1 \text{price}_i$ .<sup>21</sup> We could estimate that model with the command

```
ml model lf mynormal_lf (mpg = weight displacement turn) (price)
```

where the second ‘equation’ refers to the specification of the  $\sigma_i$  term. The `ado`-file need not be modified, even though we have changed the list of regressors and made a different assumption on the distribution of the errors.

### Writing a ml-based command

The `ado`-file above can be used interactively with the `ml` command. What if you wanted to create a new Stata estimation command that implemented this particular maximum likelihood estimator? You merely need to write an additional `ado`-file, `mynormal.ado`:

```
. type mynormal.ado
*! mynormal v1.0.0 CFBaum 11aug2008
program mynormal
    version 10.1
    if replay() {
        if ("`e(cmd)'" != "mynormal") error 301
        Replay `0'
    }
    else Estimate `0'
end
program Replay
    syntax [, Level(cilevel) ]
    ml display, level(`level')
end
program Estimate, eclass sortpreserve
    syntax varlist [if] [in] [, vce(passthru) Level(cilevel) * ]
    mlopts mlopts, `options'
    gettoken lhs rhs: varlist
    marksample touse
    ml model lf mynormal_lf (mu: `lhs' = `rhs') /sigma ///
    if `touse', `vce' `mlopts' maximize
    ereturn local cmd "mynormal"
    Replay, level(`level')
```

command is better suited for use in a function evaluator program. Its syntax when used with `ml` is defined by that command; see [R] `ml`.

21. For a discussion of homoskedasticity and heteroskedasticity, see Baum (2006a), Chapter 6.

```
end
```

The `mynormal` program is a wrapper for two subprograms: `Replay` and `Estimate`, as discussed in Section 11.11.1. The `Replay` program permits our `mynormal` command to emulate all Stata estimation commands in supporting the *replay* feature. After you use a standard estimation command, you may always replay the estimation results if you have not issued another estimation command in the interim by merely giving the estimation command's name (for example, `regress`). The `mynormal` program checks to see that the previous estimation command was indeed `mynormal` before executing `Replay`.

The `Estimate` command does the work of setting the stage to call `ml` in its *non-interactive* mode, as signalled by the `maximize` option. We use the `sortpreserve` option to specify that the sort order of the dataset should be preserved and restored after our program has ended. The `syntax` command parses the variable list given to `mynormal` into the left-hand side (dependent) and right-hand side (covariates). In this example, only the homoskedastic case of a fixed parameter `/sigma` is supported. The `mlopts` command allows you to specify one or more of the maximum likelihood options (see [P] `mlopts` and Gould et al. (2006), pp. 180–183).

To illustrate `mynormal`, we use `auto.dta`:

```
. mynormal price mpg weight turn
initial:      log likelihood =      -<inf> (could not be evaluated)
feasible:    log likelihood = -814.40522
rescale:     log likelihood = -731.80124
rescale eq:  log likelihood = -701.88231
Iteration 0: log likelihood = -701.88231
Iteration 1: log likelihood = -693.55438
Iteration 2: log likelihood = -678.01692
Iteration 3: log likelihood = -677.74653
Iteration 4: log likelihood = -677.74638
Iteration 5: log likelihood = -677.74638

                                Number of obs =          74
                                Wald chi2(3)  =          46.26
                                Prob > chi2   =          0.0000

Log likelihood = -677.74638
```

price	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
<b>mu</b>					
mpg	-72.86501	79.0677	-0.92	0.357	-227.8348 82.10482
weight	3.524339	.7947479	4.43	0.000	1.966661 5.082016
turn	-395.1902	119.2837	-3.31	0.001	-628.9819 -161.3985
_cons	12744.24	4629.664	2.75	0.006	3670.269 21818.22
<b>sigma</b>					
_cons	2298.005	188.8948	12.17	0.000	1927.778 2668.232

We may use the replay feature, change the level of significance reported for confidence intervals, and invoke `test` ([R] `test`), just as we could with any Stata estimation com-

mand:

```
. mynormal, level(90)
```

	Number of obs	=	74		
	Wald chi2(3)	=	46.26		
	Prob > chi2	=	0.0000		

```
Log likelihood = -677.74638
```

	price	Coef.	Std. Err.	z	P> z	[90% Conf. Interval]
mu	mpg	-72.86501	79.06771	-0.92	0.357	-202.9198 57.18979
	weight	3.524339	.7947481	4.43	0.000	2.217094 4.831583
	turn	-395.1902	119.2837	-3.31	0.001	-591.3944 -198.986
	_cons	12744.24	4629.665	2.75	0.006	5129.123 20359.37
sigma	_cons	2298.005	188.8949	12.17	0.000	1987.301 2608.709

```
. test weight = 5
```

( 1) [mu]weight = 5	chi2( 1) =	3.45	Prob > chi2 =	0.0633
---------------------	------------	------	---------------	--------

```
. predict double pricehat, xb
```

```
. summarize pricehat
```

Variable	Obs	Mean	Std. Dev.	Min	Max
price	74	6165.257	2949.496	3291	15906
pricehat	74	6165.257	1829.306	1988.606	10097.71

We also may use `predict` ([R] `predict`) to compute the fitted values from our maximum likelihood estimation and `summarize` to compare them with the original series.

### 11.13.1 Programs for the `nl` and `nlsur` commands

A similar set of issues arise when performing nonlinear least squares estimation for either a single equation (`nl`, [R] `nl`) or a set of equations (`nlsur`, [R] `nlsur`). Although these commands may be used interactively or in terms of “programmed substitutable expressions,” most serious use is likely to involve your writing a *function evaluator program*. That program will compute the dependent variable(s) as a function of the parameters and variables specified.

The techniques used for a maximum likelihood function evaluator, as described above, are quite similar to those used by `nl` and `nlsur` function evaluator programs. For instance, we might want to estimate a constant elasticity of substitution (CES) production function

$$\ln Q_i = \beta_0 - \frac{1}{\rho} \ln (\delta K_i^{-\rho} + (1 - \delta)L_i^{-\rho}) + \epsilon_i$$

which relates a firm’s output  $Q_i$  to its use of capital, or machinery  $K_i$  and labor  $L_i$  (see

Greene (2008), p. 119). The parameters in this highly nonlinear relationship are  $\beta_0$ ,  $\rho$  and  $\delta$ .

We store the function evaluator program `nlces.ado`, as `nl` requires a program name that starts with the letters `nl`. As described in [R] `nl`, the `syntax` statement must specify a `varlist`, allow for an `if exp`, and an option `at(name)`. The parameters to be estimated are passed to your program in the row vector `at`. In our CES example, the `varlist` must contain exactly three variables, which are extracted from the `varlist` by the `args` ([P] `args`) command. This command assigns its three arguments to the three variable names provided in the `varlist`. For ease of reference, we assign `tempnames` to the three parameters to be estimated. The `generate` and `replace` statements make use of the `if exp` clause. The function evaluator program must replace the observations of the dependent variable: in this case, the first variable passed to the program, referenced within as `logoutput`.

```
. type nlces.ado
*! nlces v1.0.0 CFBaum 11aug2008
program nlces
  version 10.1
  syntax varlist(numeric min=3 max=3) if, at(name)
  args logoutput K L
  tempname b0 rho delta
  tempvar kterm lterm
  scalar 'b0' = 'at'[1, 1]
  scalar 'rho' = 'at'[1, 2]
  scalar 'delta' = 'at'[1, 3]
  gen double 'kterm' = 'delta' * 'K'^( -('rho' ) ) 'if'
  gen double 'lterm' = (1 - 'delta') * 'L'^( -('rho' ) ) 'if'
  replace 'logoutput' = 'b0' - 1 / 'rho' * ln( 'kterm' + 'lterm' ) 'if'
end
```

We invoke the estimation process with the `nl` command using Stata's `production` dataset.<sup>22</sup> You specify the name of your likelihood function evaluator by including only the unique part of its name (that is, `ces`, not `nlces`), followed by `@`. The order in which the parameters appear in the `parameters()` and `initial()` options defines their order in the `at` vector.<sup>23</sup> The `initial()` option is not required, but is recommended.

```
. use production, clear
. nl ces @ loutput capital labor, parameters(b0 rho delta) ///
> initial(b0 0 rho 1 delta 0.5)
(obs = 100)

Iteration 0: residual SS = 29.38631
Iteration 1: residual SS = 29.36637
Iteration 2: residual SS = 29.36583
Iteration 3: residual SS = 29.36581
Iteration 4: residual SS = 29.36581
Iteration 5: residual SS = 29.36581
Iteration 6: residual SS = 29.36581
```

22. This dataset may be accessed with `webuse production`.

23. Alternatively, you may use the `nparameters(#)` option, and merely specify the number of parameters. They are then named `b1`, `b2`, `...`

Iteration 7: residual SS = 29.36581

Source	SS	df	MS			
Model	91.1449924	2	45.5724962	Number of obs =	100	
Residual	29.3658055	97	.302740263	R-squared =	0.7563	
Total	120.510798	99	1.21728079	Adj R-squared =	0.7513	
				Root MSE =	.5502184	
				Res. dev. =	161.2538	

lnoutput	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
/b0	3.792158	.099682	38.04	0.000	3.594316	3.989999
/rho	1.386993	.472584	2.93	0.004	.4490443	2.324941
/delta	.4823616	.0519791	9.28	0.000	.3791975	.5855258

Parameter b0 taken as constant term in model & ANOVA table

After execution, you have access to all of Stata's postestimation commands. For instance, the elasticity of substitution  $\sigma = 1/(1 + \rho)$  of the CES function is not directly estimated, but is rather a nonlinear function of the estimated parameters. We may use Stata's `nlcom` ([R] **nlcom**) command to generate point and interval estimates of  $\sigma$  using the *delta method*.<sup>24</sup>

```
. nlcom (sigma: 1 / ( 1 + [rho]_b[_cons] ))
      sigma: 1 / ( 1 + [rho]_b[_cons] )
```

lnoutput	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
sigma	.4189372	.0829424	5.05	0.000	.2543194	.583555

This value, falling below unity in point and interval form, indicates that in the firms studied the two factors of production (capital and labor) are not very substitutable for one another.

The programming techniques illustrated here for `nl` carry over to the `nlshr` ([R] **nlshr**) command (new in Stata version 10), which allows you to apply nonlinear least squares to a system of non-simultaneous (or *seemingly unrelated*) equations. Likewise, you could write a *wrapper* for `nlces`, just as we illustrated above in the case of maximum likelihood, in order to create a new Stata command.

### 11.13.2 Programs for the simulate, bootstrap and jackknife commands

The `simulate` ([R] **simulate**), `bootstrap` ([R] **bootstrap**) and `jackknife` ([R] **jackknife**) commands may be used with many Stata commands, but often entail writing your own command to specify the quantities to be simulated, or the statistic for which

24. See [R] `predictnl`.

bootstrap or jackknife standard errors are required.<sup>25</sup>

`simulate` is used to perform Monte Carlo simulations of a random process. The command or program to be simulated is executed many times, or `reps()`. Each time it is executed, a new random draw is performed and one or more quantities calculated. Monte Carlo simulation is often used to analyze the properties of a particular estimator or test procedure. In this context, the command or program called by `simulate` will generate a new value of the estimator or test statistic in each replication, and return one or more quantities to the `simulate` command. `simulate` then constructs a new dataset in which each observation corresponds to one replication. That artificial dataset may then be used to compute various statistics of interest relating to the estimator or test statistic being studied.

As an example, we consider a simulation of the power of a standard  $t$ -test for sample mean under homoskedastic and groupwise-heteroskedastic errors.<sup>26</sup> The test statistic is computed under the former assumption: that the error distribution has a common variance  $\sigma^2$ . To set up a simulation experiment, we use Stata's `census2` dataset,<sup>27</sup> which contains 50 U.S. states' data on a number of demographic variables, as well as a region indicator that takes on integer values 1, 2, 3, 4 for four U.S. regions. We create a groupwise heteroskedastic error from the region indicator.

The simulation program, `mcsimul.ado`, takes a *varname* of an existing variable that is to be used in the simulation experiment. Optionally, a value `mu(#)` may be provided to be used in the null hypothesis of the  $t$ -test. If no value is provided, a default value of 75 is used.<sup>28</sup>

The simulation program expects to find two variables, `zmu` and `zfactor`, defined for each observation. It creates two temporary random variables, `y1` and `y2`, as normally distributed with means of  $\bar{varname} + 0.20 zmu$  and  $\bar{varname} + 0.20 zfactor$  respectively. The simulation program performs  $t$ -tests with the null hypothesis that the mean of the variable is `mu`. We record the  $p$ -value with which that null may be rejected: that is, the significance level of the test. The two `return scalar` statements indicate that the program produces two return values: the  $p$ -values for the two `ttests`.

```
. type mcsimul.ado
*! mcsimul v1.0.0 CFBaum 11aug2008
program mcsimul, rclass
    version 10.1
    syntax varname(numeric) [, mu(real 75)]
    tempvar y1 y2

    generate `y1' = `varlist' + invnorm(uniform()) * 0.20 * zmu
    generate `y2' = `varlist' + invnorm(uniform()) * 0.20 * z_factor
```

25. This should not be confused with the calculation of bootstrap or jackknife standard errors in many Stata estimation commands via specification of the `vce()` option. We consider here computation of bootstrap (jackknife) standard errors for a statistic that cannot be computed by executing a single Stata command.

26. See the `robvar` command ([R] `sdtest`) and Baum (2006c).

27. This dataset can be accessed with `webuse census2`.

28. Hard-coding this value as a default value for a numeric option is done for pedagogical purposes.

```

ttest 'y1' = 'mu'
return scalar p1 = r(p)
ttest 'y2' = 'mu'
return scalar p2 = r(p)
end

```

We now must set up the simulation experiment and execute the `simulate` ([R] `simulate`) command. The `set seed` command will cause the pseudo-random number generator to generate the same sequence of values each time this program is executed, which is useful for debugging purposes. We generate the `z_factor` variable as  $10 \times \text{region}$  and compute the scalar `zmu` to have the same value as the mean of `z_factor`. We now can invoke `simulate`, storing the two return values in new variables `p1` and `p2`. The `saving()` option indicates that a new dataset, `mcsimul.dta`, should be produced, and `reps(1000)` defines the experiment's number of replications. The argument of the `simulate` prefix command is merely the name of the simulation program, `mcsimul`, followed by the required *varname*. We execute the simulation for the variable `drate`, the death rate for each state, expressed as the number of deaths per 10,000 population. It has a sample mean of 84.3 and a range from 40 to 107.<sup>29</sup> We use a hypothesized value of 80 in the `mu()` option.

```

. set seed 20070731
. use census2, clear
(1980 Census data by state)
. generate z_factor = 10 * region
. summarize z_factor, meanonly
. scalar zmu = r(mean)
. quietly simulate p1=r(p1) p2=r(p2), ///
> saving(mcsimul,replace) nodots reps(1000): mcsimul drate, mu(80)

```

Following the simulation, we may examine the resulting dataset.

```

. use mcsimul, clear
(simulate: mcsimul)
. generate R5pc_1 = (p1 < 0.05)
. generate R5pc_2 = (p2 < 0.05)
. summarize

```

Variable	Obs	Mean	Std. Dev.	Min	Max
p1	1000	.0484347	.044073	.0009723	.3428818
p2	1000	.0572194	.0607124	.0007912	.4788797
R5pc_1	1000	.642	.479652	0	1
R5pc_2	1000	.597	.4907462	0	1

As expected, the power of the test (which is based on the assumption of normally distributed, homoskedastic errors) varies when heteroskedastic errors are encountered,

29. Analysis of these state-level descriptive statistics should be performed using weights. For pedagogical purposes, we treat them as raw data.

with the average  $p$ -value almost one per cent larger in the latter case. The `R5pc_1` and `R5_pc2` series, which flag the  $p$ -values below 0.05, indicate that the heteroskedastic case actually demonstrates slightly lower power (597 out of 1000 rejections at five per cent, versus 642 for the homoskedastic case).

These same programming techniques apply to writing programs for the `bootstrap` or `jackknife` prefix operators. In contrast to Monte Carlo simulation, which is used to analyze an artificial dataset, bootstrap techniques (and the closely related jackknife) make use of the empirical distribution of the errors in an estimated model. This is performed by resampling with replacement from the existing estimation results for a specified number of replications. Most commonly, bootstrap standard errors are computed by specifying `vce(bootstrap)` on an estimation command. However, if you want to compute bootstrap standard errors for a quantity that cannot be directly estimated by an existing Stata command, you must write a program to implement the estimation procedure you wish to study. Like `simulate`, `bootstrap` and `jackknife` create new datasets with one observation for each replication.

## 11.14 Guidelines for Stata ado-file programming style

To highlight the importance of good programming style practices in writing `ado`-files, we present here an edited excerpt from Nicholas J. Cox's excellent essay on "Suggestions on Stata programming style" (Cox (2005f)). The remainder of this section is quoted from that essay, other parts of which appear above as Section 2.8.

### 11.14.1 Presentation

In this subsection, I give a list of basic guidelines for formal Stata programs.

1. Always include a comment containing the version number of your program, your name or initials, and the date the program was last modified above the `program` line, for example,

```

*! 1.0.0 Tom Swift 21jan2006
program myprog

```

(As said, this line is indeed just a comment line; it bears no relation to the Stata `version` command. However, `which myprog` will echo this comment line back to you whenever this `myprog` is visible to Stata along your `ado`-path. Both this comment and a `version` command should be used.)

2. Use sensible, intelligible names where possible for programs, variables, and macros.
3. Choose a name for your program that does not conflict with anything already existing. Suppose that you are contemplating *newname*. If typing either `which newname` or `which newname.class` gives you a result, StataCorp is already using the name. Similarly, if `ssc type newname.ado` gives you a result, a program with your name is already on SSC. No result from either does not guarantee that

the program is not in use elsewhere: `findit newname` may find such a program, although often it will also find much that is irrelevant to this point.

4. Brevity of names is also a virtue. However, no platform on which Stata is currently supported requires an 8-character limit. Tastes are in consequence slowly shifting: an intelligible long name for something used only occasionally would usually be considered preferable to something more cryptic.
5. Note that actual English words for program names are supposedly reserved for StataCorp.
6. Use the same names and abbreviations for command options that are in common use in official Stata's commands. Try to adopt the same conventions for options' syntax; for example, allow a *numlist* where similar commands use a *numlist*. Implement sensible defaults wherever possible.
7. Group `tempname`, `tempvar`, and `tempfile` declarations.
8. Use appropriate `display` styles for messages and other output. All error messages (and no others) should be displayed as `err`; that is, type `di as err`. In addition, attach a return code to each error message; `198` (syntax error) will often be fine.

### 11.14.2 Helpful Stata features

Stata has a number of features that makes programming easier. Examples of ways a programmer can use these features are as follows:

1. Stata is very tolerant through version control of out-of-date features, but that does not mean that you should be. To maximize effectiveness and impact and to minimize problems, write programs using the latest version of Stata and exploit its features.
2. Make yourself familiar with all the details of `syntax`. It can stop you from reinventing little wheels. Use wildcards for options to pass to other commands when appropriate.
3. Support `if exp` and `in range` where applicable. This is best done using `marksample touse` (or occasionally `mark` and `markout`). Have `touse` as a temporary variable if and only if `marksample` or a related command is used. See `help marksample`.
4. Make effective use of information available in `e()` and `r()`. If your program is to run in a context that implies that results or estimates are available (say, after `regress`), make use of the stored information from the prior command.
5. Where appropriate, ensure that your command returns the information that it computes and displays so that another user may employ it `quietly` and retrieve that information.
6. Ensure that programs that focus on time series or panel data work with time-series operators if at all possible. In short, exploit `tsset`.

7. Familiarize yourself with the built-in material revealed by `creturn list`. Scrolling right to the end will show several features that may be useful to you.
8. SMCL is the standard way to format Stata output.

### 11.14.3 Respect for datasets

In general, make no change to the data unless that is the direct purpose of your program or that is explicitly requested by the user.

1. Your program should not destroy the data in memory unless that is essential for what it does.
2. You should not create new permanent variables on the side unless notified or requested.
3. Do not use variables, matrices, scalars, or global macros whose names might already be in use. There is absolutely no need to guess at names that are unlikely to occur, as temporary names can always be used (type `help macro` for details on `tempvar`, `tempname`, and `tempfile`).
4. Do not change the variable type unless requested.
5. Do not change the sort order of data; use `sortpreserve`.

### 11.14.4 Speed and efficiency

Here is a list of basic ways to increase speed and efficiency:

1. `foreach` and `forvalues` are cleaner and faster than most `while` loops and much faster than the old `for` that still satisfies some devotees. Within programs, avoid `for` like the plague. (Note to new Mata users: this does not refer to Mata's `for`.)
2. Avoid `egen` within programs; it is usually slower than a direct attack.
3. Try to avoid looping over observations, which is very slow. Fortunately, it can usually be avoided.
4. Avoid `preserve` if possible. `preserve` is attractive to the programmer but can be expensive in time for the user with large data files. Programmers should learn to master `marksample`.
5. Specify the type of temporary variables to minimize memory overhead. If a `byte` variable can be used, specify `generate byte 'myvar'` rather than letting the default type be used, which would waste storage space.
6. Temporary variables will be automatically dropped at the end of a program, but also consider dropping them when they are no longer needed to minimize memory overhead and to reduce the chances of your program stopping because there is no room to add more variables.

### 11.14.5 Reminders

In this section, I describe a few general procedures that will improve one's code:

1. Remember to think about string variables as well as numeric variables. Does the task carried out by your program make sense for string variables? If so, will it work properly? If not, do you need to trap input of a string variable as an error, say, through `syntax`?
2. Remember to think about making your program support `varlist`: when this is natural. See `help byable`.
3. Remember to think about weights and implement them when appropriate.
4. The job is not finished until the `.sthlp` is done. Use SMCL to set up your help files. Old-style help files, while supported, are not documented, while help files not written in SMCL cannot take advantage of its paragraph mode, which allows lines to autowrap to fit the desired screen width. For an introduction to the SMCL required to write a basic help file, see [U] **18.11.6 Writing online help** or `help examplehelpfile`.

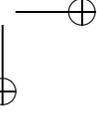
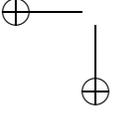
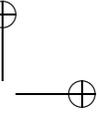
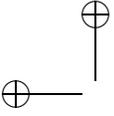
### 11.14.6 Style in the large

Style in the large is difficult to prescribe, but here are some vague generalities:

1. Before writing a program, check that it has not been written already! `findit` is the broadest search tool.
2. The best programs do just one thing well. There are exceptions, but what to a programmer is a Swiss army knife with a multitude of useful tools may look to many users like a confusingly complicated command.
3. Get a simple version working first before you start coding the all-singing, all-dancing version that you most desire.
4. Very large programs become increasingly difficult to understand, build, and maintain, roughly as some power of their length. Consider breaking such programs into subroutines or using a structure of command and subcommands.
5. More general code is often both shorter and more robust. Sometimes programmers write to solve the most awkward case, say, to automate a series of commands that would be too tedious or error-prone to enter interactively. Stepping back from the most awkward case to the more general one is often then easier than might be thought.
6. Do not be afraid to realize that at some point you may be best advised to throw it all away and start again from scratch.

### 11.14.7 Use the best tools

Find and use a text editor that you like and that supports programming directly. A good editor, for example, will be smart about indenting and will allow you to search for matching braces. Some editors even show syntax highlighting. For much more detailed comments on various text editors for Stata users, see `ssc describe texteditors`.



## 12 Cookbook: Ado-file programming

This cookbook chapter presents a number of recipes for Stata ado-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in an ado-file.

### 12.1 Retrieving results from rolling:

**The problem:** as posed by a question on Statalist, the `rolling:` prefix (see Section 7.2.4) will allow you to save the estimated coefficients (`_b`) and standard errors (`_se`) from a moving-window regression. What if you want to compute a quantity that depends on the full variance-covariance matrix of the regression (VCE)? Those quantities cannot be saved by `rolling:`. For instance, the regression

```
. regress y L(1/4).x
```

estimates the effects of the last four periods' values of `x` on `y`.<sup>1</sup> We might naturally be interested in the sum of the lag coefficients, as it provides the *steady-state* effect of `x` on `y`. This computation is readily performed with `lincom` ([R] **lincom**). If this regression is run over a moving window, how might we access the information needed to perform this computation?

A solution is available in the form of a *wrapper program* which may then be called by `rolling:`. We write our own `r-class` program, `myregress`, which returns the quantities of interest: the estimated sum of lag coefficients and its standard error. The program takes as arguments the *varlist* of the regression and two required options: `lagvar()`, the name of the distributed lag variable, and `nlags()`, the highest-order lag to be included in the `lincom`.<sup>2</sup> We build up the appropriate expression for the `lincom` command and return its results to the calling program.

```
. type myregress.ado
*! myregress v1.0.0 CFBaum 11aug2008
program myregress, rclass
version 10.1
syntax varlist(ts) [if] [in], LAGVar(string) NLAGs(integer)
regress `varlist' `if' `in'
```

---

1. See Section 2.4.3 for a discussion of Stata's time-series operators.

2. This logic assumes that the current value of the regressor is not included in the `lincom` computation. That could easily be modified by using `L(0/4)`.

```

local n11 = `nlags' - 1
forvalues i = 1/`n11' {
    local lv "`lv' L'i'.'lagvar' + "
}
local lv "`lv' L'nlags'.'lagvar'"
lincom `lv'
return scalar sum = `r(estimate)'
return scalar se = `r(se)'
end

```

As with any program to be used under the control of a prefix operator, it is a good idea to execute the program directly to test it to ensure that its results are those you could calculate directly with `lincom`.

```

. use wpi1, clear
. myregress wpi L(1/4).wpi t, lagvar(wpi) nlags(4)

```

Source	SS	df	MS			
Model	108199.912	5	21639.9823	Number of obs =	120	
Residual	59.2997117	114	.520172909	F( 5, 114) =	41601.52	
Total	108259.211	119	909.741272	Prob > F =	0.0000	
				R-squared =	0.9995	
				Adj R-squared =	0.9994	
				Root MSE =	.72123	

wpi	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
wpi						
L1.	1.43324	.0947574	15.13	0.000	1.245526	1.620954
L2.	-.3915563	.1648926	-2.37	0.019	-.7182073	-.0649053
L3.	.1669584	.1693717	0.99	0.326	-.1685657	.5024825
L4.	-.2276451	.0960385	-2.37	0.019	-.4178967	-.0373936
t	.0184368	.0071336	2.58	0.011	.0043052	.0325684
_cons	.2392324	.1641889	1.46	0.148	-.0860246	.5644894

```

( 1) L.wpi + L2.wpi + L3.wpi + L4.wpi = 0

```

wpi	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
(1)	.9809968	.0082232	119.30	0.000	.9647067	.9972869

```

. return list
scalars:
    r(se) = .0082232176260432
    r(sum) = .9809968042273991
. lincom L.wpi+L2.wpi+L3.wpi+L4.wpi
( 1) L.wpi + L2.wpi + L3.wpi + L4.wpi = 0

```

wpi	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
(1)	.9809968	.0082232	119.30	0.000	.9647067	.9972869

Having validated the wrapper program by comparing its results with those from `lincom`, we may now invoke it with `rolling`:

```

. rolling sum=r(sum) se=r(se) ,window(30) : ///
> myregress wpi L(1/4).wpi t, lagvar(wpi) nlags(4)
(running myregress on estimation sample)
Rolling replications (95)
-----| 1 -----| 2 -----| 3 -----| 4 -----| 5
..... 50
.....

```

We may graph the resulting series and its approximate 95% standard error bands with `twoway rarea` ([G] **graph twoway rarea**) and `tsline` ([TS] **tsline**):

```

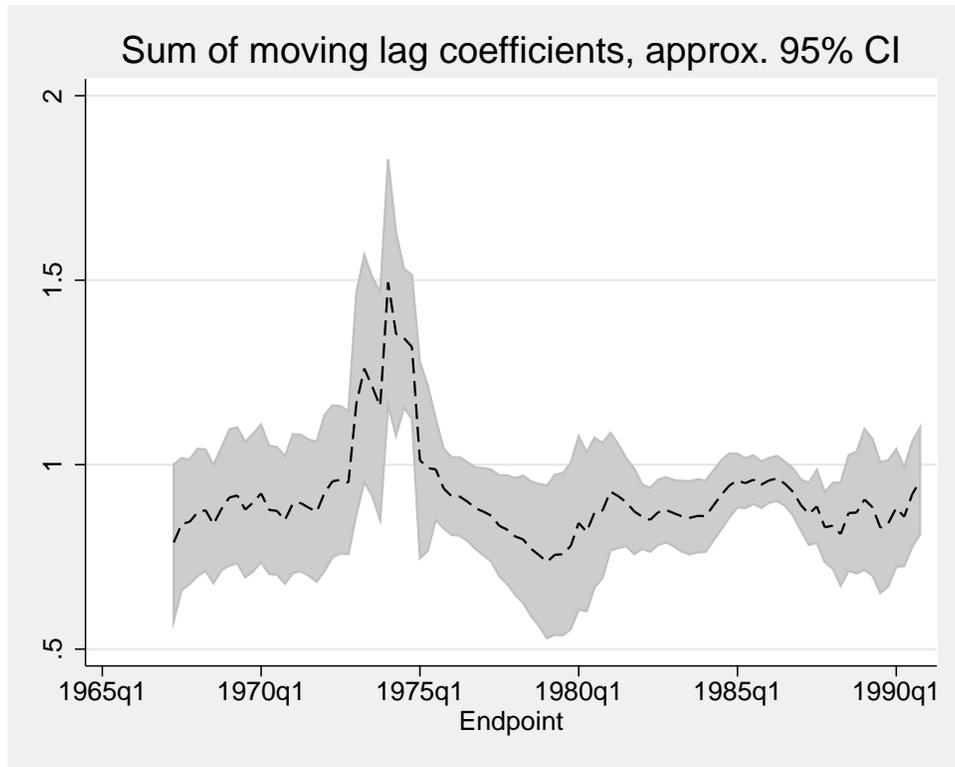
. tsset end, quarterly
      time variable: end, 1967q2 to 1990q4
              delta: 1 quarter

. label var end Endpoint

. g lo = sum - 1.96 * se
. g hi = sum + 1.96 * se

. twoway rarea lo hi end, color(gs12) title("Sum of moving lag coefficients, ap
> prox. 95% CI") ///
> || tsline sum, legend(off) scheme(s2mono)

```

Figure 12.1: Rolling `lincom` estimates.

## 12.2 Generalization of `egen` function `pct9010()` to support all pairs of quantiles

**The problem:** in Section 11.10, we developed a useful `egen` function that will produce a *percentile range* for a specified variable. It may operate under the control of a `by`-list, juxtaposing the percentile range for each subset of the data specified in the `by`-list with those observations. It is a one-trick pony, though, as the 90<sup>th</sup> and 10<sup>th</sup> percentiles are wired into the function.

It might be useful to take advantage of the `egen` `pctile()` function's ability to compute any percentiles of the specified variable. To achieve this, we modify `_gpct9010.ado` to the more general `_gpctrange.ado`. We add two options to the `egen` function, `lo()` and `hi()`. If not specified, those options take on 25 and 75, respectively, and compute the interquartile range. If specified, they must be checked for validity.

```
. type _gpctrange.ado
*! _gpctrange v1.0.0 CFBaum 11aug2008
```

## 12.2 Generalization of egen function pct9010() to support all pairs of quantiles 247

```

program _gpctrange
    version 10.1
    syntax newvarname =/exp [if] [in] [, LO(integer 25) HI(integer 75) *]

    if 'hi' > 99 | 'lo' < 1 {
        display as error "Percentiles 'lo' 'hi' must be between 1 and 9
    > 9."
        error 198
    }
    if 'hi' <= 'lo' {
        display as error "Percentiles 'lo' 'hi' must be in ascending or
    > der."
        error 198
    }
    tempvar touse phi plo
    mark 'touse' 'if' 'in'
    quietly {
        egen double 'phi' = pctile('exp') if 'touse', 'options' p('hi')
        egen double 'plo' = pctile('exp') if 'touse', 'options' p('lo')
        generate 'typlist' 'varlist' = 'phi' - 'plo' if 'touse'
    }
end

```

The computations are then generalized by merely passing the contents of the `lo()` and `hi()` options to `egen pctile()`.<sup>3</sup>

```

. sysuse auto, clear
(1978 Automobile Data)
. bysort rep78: egen iqr = pctrange(price) if inrange(rep78, 3, 5)
(15 missing values generated)
. bysort rep78: egen p8020 = pctrange(price) if inrange(rep78, 3, 5), ///
> hi(80) lo(20)
(15 missing values generated)
. tabstat iqr if inrange(rep78, 3, 5), by(rep78)
Summary for variables: iqr
    by categories of: rep78 (Repair Record 1978)

```

rep78	mean
3	2108
4	2443
5	1915
Total	2174.22

```

. tabstat p8020 if inrange(rep78, 3, 5), by(rep78)
Summary for variables: p8020
    by categories of: rep78 (Repair Record 1978)

```

rep78	mean
3	6231.5
4	3328
5	1915

3. Although we have suggested avoiding the use of `egen` within ado-files, its `pctile()` function is not easily replicated in ado-file code.

Total	4540.915
-------	----------

This version of the `egen` function is much more generally useful, and more likely to find a place in your toolbox.

## 12.3 Constructing a certification script

**The problem:** you would like to establish that an ado-file you have written is providing the correct results, and that any further modifications to the program will not harm its reliability. The best way to do that is to use Stata's *certification script* procedures ([P] **cscript**). Our solution draws heavily on the excellent discussion of statistical software certification in Gould (2001).

We will develop a certification script for the last version of **pctrange**, the ado-file we developed in the previous chapter. That version of the program (as modified in Section 11.8) is:

```
. type pctrange.ado
*! pctrange v1.0.6 CFBaum 11aug2008
program pctrange, rclass byable(recall)
    version 10.1
    syntax varlist(min=1 numeric ts) [if] [in] [, noPRINT FORmat(passthru)
> MATrix(string)]
    marksample touse
    quietly count if 'touse'
    if 'r(N)' == 0 {
        error 2000
    }
    local nvar : word count 'varlist'
    if 'nvar' == 1 {
        local res range p7525 p9010 p9505 p9901
        tempname 'res'
        quietly summarize 'varlist' if 'touse', detail
        scalar 'range' = r(max) - r(min)
        scalar 'p7525' = r(p75) - r(p25)
        scalar 'p9010' = r(p90) - r(p10)
        scalar 'p9505' = r(p95) - r(p5)
        scalar 'p9901' = r(p99) - r(p1)
        if "'print'" != "noprint" {
            display as result _n "Percentile ranges for 'varlist',
> N = 'r(N)'"
                display as txt "75-25: " 'p7525'
                display as txt "90-10: " 'p9010'
                display as txt "95-05: " 'p9505'
                display as txt "99-01: " 'p9901'
                display as txt "Range: " 'range'
        }
        foreach r of local res {
            return scalar 'r' = 'r'
        }
        return scalar N = r(N)
    }
    else {
        tempname rmat
        matrix 'rmat' = J('nvar',5,..)
        local i 0
        foreach v of varlist 'varlist' {
            local ++i
            quietly summarize 'v' if 'touse', detail
            matrix 'rmat'['i',1] = r(max) - r(min)
            matrix 'rmat'['i',2] = r(p75) - r(p25)
        }
    }
end
```

```

        matrix `rmat' [`i',3] = r(p90) - r(p10)
        matrix `rmat' [`i',4] = r(p95) - r(p5)
        matrix `rmat' [`i',5] = r(p99) - r(p1)
        local rown "'rown' 'v'"
    }
matrix colnames `rmat' = Range P75-P25 P90-P10 P95-P05 P99-P01
matrix rownames `rmat' = `rown'
if "'print'" != "noprint" {
    local form ", noheader"
    if "'format'" != "" {
        local form "'form' 'format'"
    }
    matrix list `rmat' `form'
}
if "'matrix'" != "" {
    matrix `matrix' = `rmat'
}
return matrix rmat = `rmat'
}
return local varname `varlist'
end

```

Following Gould (*op. cit.*, 35), we create a directory in our current working directory called `/bench` to hold certification scripts, and a subdirectory for this script called `/pctrange`. In the `bench` directory, we create `testall.do`:

```

clear
discard
set more off
cd first
quietly log using pctrange, replace
do test1
quietly log close

```

We begin our certification process by copying `auto.dta` into the `pctrange` directory. As Gould suggests (*op. cit.*, 45), certification scripts should be self-contained, not referring to files outside the directory in which they reside.

A certification script should run to normal completion if no errors are encountered. A script that aborts provides an indication that one or more tests in the script have failed. We first want to test the syntax of the program, and verify that appropriate error messages are produced if the program is called incorrectly. We can trigger errors without aborting our do-file by using the `rcof` ([P] `rcof`) command. For instance, `pctrange` requires at least one numeric variable and cannot handle string variables. It makes no sense to call the program without some observations in the data. We can test these conditions with

```

. cd bench/pctrange
/Users/baum/doc/ITSP/dof.8824/bench/pctrange/
. do test1
. cscript "test script for ITSP:" pctrange
-----BEGIN test script for ITSP: pctrange
. use auto

```

```
(1978 Automobile Data)
. rcoef "pctrange" != 0
. rcoef "pctrange price make" != 0
. drop _all
. rcoef "pctrange price mpg" != 0
.
end of do-file
```

Let's now check that *if exp* and *in range* conditions are handled properly. To do this, we must compare the output of the program (as provided in `return list` using the `assert ([P] assert)` command and the matrix function `mreldif()`). We test for absolute equality of the matrices produced, as there should be no possibility for rounding error in the two methods of computing the same quantities if our program is working properly. Note that `pctrange` only produces matrix `r(rmat)` when more than one variable appears in its *varlist*. We create a new script, `test2`, which incorporates the tests applied above.

```
. cd bench/pctrange
/Users/baum/doc/ITSP/dof.8824/bench/pctrange/
. do test2
. cscript "test script for ITSP:" pctrange
-----BEGIN test script for ITSP: pctrange
. use auto
(1978 Automobile Data)
. rcoef "pctrange" != 0
. rcoef "pctrange price make" != 0
. drop _all
. rcoef "pctrange" != 0
. use auto
(1978 Automobile Data)
. quietly pctrange price mpg if foreign
. matrix check1 = r(rmat)
. keep if foreign
(52 observations deleted)
. quietly pctrange price mpg
. mat check2 = r(rmat)
. scalar checka = mreldif(check1, check2)
. assert checka == 0
. use auto, clear
(1978 Automobile Data)
. quietly pctrange price mpg in 22/55
. matrix check3 = r(rmat)
. keep in 22/55
(40 observations deleted)
. quietly pctrange price mpg
. mat check4 = r(rmat)
. scalar checkb = mreldif(check3, check4)
. assert checkb == 0
```

```

. use auto, clear
(1978 Automobile Data)
. generate t = _n
. tsset t
      time variable: t, 1 to 74
      delta: 1 unit
. generate dp = D.price
(1 missing value generated)
. generate lmpg = L.mpg
(1 missing value generated)
. quietly pctrange dp lmpg
. mat check5 = r(rmat)
. quietly pctrange D.price L.mpg
. mat check6 = r(rmat)
. scalar checkc = mreldif(check5, check6)
. assert checkc == 0
.
.
end of do-file

```

We have also included a check of the program's ability to handle time-series (**ts**) operators.

We now want to check some of the program's calculations against those produced by **summarize**, **detail**. We may do this with a single variable, in which case **pctrange** returns a set of scalars. We now use the scalar function **reldif()**, which allows us to check to see that computations from **summarize** results are appropriately close to those of **pctrange**. We do not check for equality due to the limitations of finite-precision arithmetic given that we are comparing the results of two different commands. The value of  $10^{-13}$  is chosen to ensure that the two computed measures are sufficiently close. A larger value might have to be used on a different computing platform.

```

. cd bench/pctrange
/Users/baum/doc/ITSP/dof.8824/bench/pctrange/
. do test3
. cscript "test script for ITSP:" pctrange
-----BEGIN test script for ITSP: pctrange
. // (earlier tests omitted)
. use auto, clear
(1978 Automobile Data)
. quietly pctrange price
. scalar enn = r(N)
. scalar p9901 = r(p9901)
. scalar p9505 = r(p9505)
. scalar p9010 = r(p9010)
. scalar p7525 = r(p7525)
. scalar range = r(range)
. assert "'r(varname)'" == "price"

```

```
. quietly summarize price, detail
. assert reldif(r(p99) - r(p1), p9901) < 1e-13
. assert reldif(r(p95) - r(p5), p9505) < 1e-13
. assert reldif(r(p90) - r(p10), p9010) < 1e-13
. assert reldif(r(p75) - r(p25), p7525) < 1e-13
. assert reldif(r(max) - r(min), range) < 1e-13
.
end of do-file
```

Finally, we should check whether `pctrange` produces the same results under the control of a `by`-prefix. Like most Stata commands, `pctrange` only returns results from the last `by`-group. We add tests that verify that results from this `by`-group (where `foreign = 1`) are identical to those generated by limiting the sample to those observations.

```
. cd bench/pctrange
/Users/baum/doc/ITSP/dof.8824/bench/pctrange/
. do test4
. cscript "test script for ITSP:" pctrange
-----BEGIN test script for ITSP: pctrange
. // (earlier tests omitted)
. use auto, clear
(1978 Automobile Data)
. quietly by foreign: pctrange price mpg
. matrix check7 = r(rmat)
. keep if foreign
(52 observations deleted)
. quietly pctrange price mpg
. mat check8 = r(rmat)
. scalar checkd = mreldif(check7, check8)
. assert checkd == 0
.
end of do-file
```

We did not use `tempnames` or `tempvars` in these scripts due to their simplicity. For a more complicated certification process, those tools might be useful to prevent the possibility of name collisions.

A certification script is a work in progress. As Gould (*op. cit.*, p. 38) suggests, it need not be elegant, but it should be complete. As you think of additional conditions to be tested (or fix bugs in the ado-file), add them to the test script. The certification script should be run again every time a change is made to the code. If that change adds new features, tests should be added to the script putting them through their paces.

The `savedresults` command ([P] `savedresults`) allows you to compare the results of two commands' return values for both `r`-class and estimation (`e`-class) commands. This capability is very useful when you have a validated version of a command and a new version with additional features and you want to ensure that all of the saved results

produced by the new version match those of the old version.

If you are considering sharing your program with the Stata user community (for instance, by placing it in the SSC Archive ([R] `ssc`), or making it available from your website) you might want to include the certification script (and any datasets it references) as ancillary files in the package. Demonstrating that a user-written program passes a number of certification tests provides reassurance to other users that they can rely on the program's results.

## 12.4 Estimating means and variances using the `ml` command

**The problem:** a Stata user posed a question about the estimation of means and variances from subsamples of a normally distributed variable. He wanted to compute two nonlinear combinations of those estimates:

$$\beta = \frac{\sigma_1 - \sigma_2}{\sigma_1 + \sigma_2} \quad (12.1)$$

and

$$\alpha = 2\pi\sqrt{3} \left( \frac{\mu_1 - \mu_2}{\sigma_1 + \sigma_2} \right) \quad (12.2)$$

The user would also like to estimate the quantity  $\alpha$  given the assumption of a common variance,  $\sigma = \sigma_1 = \sigma_2$ .

This may readily be accomplished by `ml` as long as the user is willing to make a distributional assumption. We set up a variant of `mynormal_lf.ado`<sup>4</sup> that allows for separate means and variances, depending on the value of an indicator variable, which we access with global macro `subsample`:

```
. type meanvar.ado
*! meanvar v1.0.1 CFBaum 11aug2008
program meanvar
  version 10.1
  args lnf mu1 mu2 sigma1 sigma2
  qui replace `lnf' = ln(normalden($ML_y1, `mu1', `sigma1')) ///
    if $subsample == 0
  qui replace `lnf' = ln(normalden($ML_y1, `mu2', `sigma2')) ///
    if $subsample == 1
end
```

We now may set up the estimation problem. As we do not have the user's data, we use `auto.dta` and consider `foreign` as the binary indicator:

```
. sysuse auto, clear
(1978 Automobile Data)
. global subsample foreign
. generate byte iota = 1
. ml model lf meanvar (mu1: price = iota) (mu2: price = iota) /sigma1 /sigma2
note: iota dropped because of collinearity
note: iota dropped because of collinearity
. ml maximize, nolog
initial:    log likelihood =    -<inf> (could not be evaluated)
feasible:   log likelihood = -879.18213
rescale:    log likelihood = -705.93677
rescale eq: log likelihood = -701.24251

                                     Number of obs =          74
                                     Wald chi2(0)    =           .
                                     Prob > chi2     =           .

Log likelihood = -695.14898
```

---

4. See Section 11.13.

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mu1						
_cons	6072.423	425.3414	14.28	0.000	5238.769	6906.077
mu2						
_cons	6384.682	546.1422	11.69	0.000	5314.263	7455.101
sigma1						
_cons	3067.18	300.7618	10.20	0.000	2477.698	3656.662
sigma2						
_cons	2561.634	386.1808	6.63	0.000	1804.733	3318.534

```
. estimates store unconstr
```

For use below, we use `estimates store ([R] estimates)` to save the results of estimation under the name `unconstr`.

We can verify that these maximum likelihood estimates of the subsample means and variances are correct by estimating the subsamples with `ivreg2` (Baum et al. (2007)), available from the SSC Archive:

```
. ivreg2 price if !foreign
. ivreg2 price if foreign
```

Estimates of the desired quantities may be readily computed, in point and interval form, with `nlcom ([R] nlcom)`:

```
. nlcom ([sigma1]_b[_cons] - [sigma2]_b[_cons]) / ///
> ([sigma1]_b[_cons] + [sigma2]_b[_cons])
      _nl_1: ([sigma1]_b[_cons] - [sigma2]_b[_cons]) / ([sigma1]_b[_cons] + [
> sigma2]_b[_cons])
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
_nl_1	.089814	.089195	1.01	0.314	-.0850049	.2646329

```
.
. nlcom 2*_pi*sqrt(3) * (([mu1]_b[_cons] - [mu2]_b[_cons]) / ///
> ([sigma1]_b[_cons] + [sigma2]_b[_cons]))
      _nl_1: 2*_pi*sqrt(3) * (([mu1]_b[_cons] - [mu2]_b[_cons]) / ([sigma1]_b
> [_cons] + [sigma2]_b[_cons]))
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
_nl_1	-.6037236	1.339398	-0.45	0.652	-3.228896	2.021449

### 12.4.1 Applying equality constraints in ml estimation

The second task in the problem statement is the computation of  $\alpha$  subject to the constraint of equal variances in the two subsamples.<sup>5</sup> Define the `constraint` ([R] `constraint`), and include the `constraints()` option on `ml model`. As the output shows, the two `sigma` parameters are now forced to be equal. Given the nature of maximum likelihood estimation, this does not alter the point estimates of the `mu` parameters, but it alters their standard errors. We now can recompute the estimated quantity  $\alpha$ :

```
. constraint 1 [sigma1]_cons = [sigma2]_cons
. ml model lf meanvar (mu1: price = iota) (mu2: price = iota) /sigma1 /sigma2,
> ///
> constraints(1)
note: iota dropped because of collinearity
note: iota dropped because of collinearity
. ml maximize, nolog
initial:      log likelihood =      -<inf> (could not be evaluated)
feasible:     log likelihood = -910.93346
rescale:     log likelihood = -725.86354
rescale eq:  log likelihood = -708.1301
```

	Number of obs	=	74	
	Wald chi2(0)	=	.	
	Prob > chi2	=	.	

```
Log likelihood = -695.62494
( 1) [sigma1]_cons - [sigma2]_cons = 0
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mu1						
_cons	6072.423	405.766	14.97	0.000	5277.136	6867.71
mu2						
_cons	6384.682	623.8296	10.23	0.000	5161.998	7607.365
sigma1						
_cons	2926.02	240.5172	12.17	0.000	2454.615	3397.425
sigma2						
_cons	2926.02	240.5172	12.17	0.000	2454.615	3397.425

```
. estimates store constr
. nlcom 2*_pi*sqrt(3) * (([mu1]_b[_cons] - [mu2]_b[_cons]) / ///
> ([sigma1]_b[_cons] + [sigma2]_b[_cons]))
      _nl_1: 2*_pi*sqrt(3) * (([mu1]_b[_cons] - [mu2]_b[_cons]) / ([sigma1]_b
> [_cons] + [sigma2]_b[_cons]))
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
_nl_1	-.5806946	1.38475	-0.42	0.675	-3.294756	2.133366

5. In this form, the desired quantity could be calculated from a regression of `price` on the indicator variable. We use `ml` with `constraints` for pedagogical purposes.

We use `estimates store` to save the results of this constrained maximization under the name `constr`. As we have estimated an unconstrained and constrained form of the same model, we may use a likelihood ratio test (`lrtest`, [R] `lrtest`) to evaluate whether the constraints are rejected by the data:

```
. lrtest unconstr constr
Likelihood-ratio test          LR chi2(1) =      0.95
(Assumption: constr nested in unconstr)  Prob > chi2 =    0.3292
```

The large  $p$ -value on the  $\chi^2$  statistic indicates that the data do not reject the constraint of equal error variances for domestic and foreign automobiles.

## 12.5 Applying inequality constraints in ml estimation

**The problem:** certain parameters in a maximum likelihood estimation should obey inequality restrictions. For instance, the  $\sigma$  parameter should be strictly positive, as it is derived from the estimated variance of the error process. How can we ensure that these constraints are satisfied?

Consider the `mynormal_lf` program presented in Section 11.13. As Gould et al. (2006), p. 56 suggest, a more numerically stable form of the likelihood function for linear regression estimates  $\log \sigma$  rather than  $\sigma$  itself to allow the parameter to take on values on the entire real line. The likelihood function evaluator then becomes

```
. type mynormal_lf.ado
*! mynormal_lf v1.0.1 CFBaum 11aug2008
program mynormal_lf
  version 10.1
  args lnf mu lnsigma
  quietly replace `lnf' = ln( normalden( $ML_y1, `mu', exp(`lnsigma') ) )
end
```

As we still want to take advantage of the three-argument form of the `normalden()` function, we pass the parameter `exp('lnsigma')` to the function, which expects to receive  $\sigma$  itself as its third argument. But as the optimization takes place with respect to parameter `lnsigma`, difficulties with the zero boundary are avoided.

To apply the same logic to the ado-file version, `mynormal.ado`, we must consider one issue: when the `Replay` routine is invoked, the parameter displayed will be `lnsigma` rather than `sigma`. We can deal with this issue by using the `diparm()` option of `ml model`. We modify `mynormal.ado` accordingly:

```
. type mynormal.ado
*! mynormal v1.0.1 CFBaum 11aug2008
program mynormal
  version 10.1
  if replay() {
    if ("`e(cmd)'" != "mynormal") error 301
    Replay `0'
  }
  else Estimate `0'
end
program Replay
  syntax [, Level(cilevel) ]
  ml display, level('level')
end
program Estimate, eclass sortpreserve
  syntax varlist [if] [in] [, vce(passthru) Level(cilevel) * ]
  mlopts mlopts, 'options'
  gettoken lhs rhs: varlist
  marksample touse
  local diparm diparm(lnsigma, exp label("sigma"))
  ml model lf mynormal_lf (mu: `lhs' = `rhs') /lnsigma ///
  if `touse', `vce' `mlopts' maximize `diparm'
```

```

ereturn local cmd "mynormal"
ereturn scalar k_aux = 1
Replay, level('level')
end

```

Now, when the model is estimated, the ancillary parameter `lnsigma` is displayed and transformed into the original parameter space as `sigma`.

```

. sysuse auto, clear
(1978 Automobile Data)
. mynormal price mpg weight turn
initial:      log likelihood =      -<inf> (could not be evaluated)
feasible:    log likelihood = -811.54531
rescale:     log likelihood = -811.54531
rescale eq:  log likelihood = -808.73926
Iteration 0: log likelihood = -808.73926
Iteration 1: log likelihood = -729.21876 (not concave)
Iteration 2: log likelihood = -708.48511 (not concave)
Iteration 3: log likelihood = -702.39976
Iteration 4: log likelihood = -678.51799
Iteration 5: log likelihood = -677.74671
Iteration 6: log likelihood = -677.74638
Iteration 7: log likelihood = -677.74638

                                Number of obs =          74
                                Wald chi2(3)    =         46.26
                                Prob > chi2    =          0.0000
Log likelihood = -677.74638

```

price	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mpg	-72.86501	79.06769	-0.92	0.357	-227.8348	82.10481
weight	3.524339	.7947479	4.43	0.000	1.966661	5.082016
turn	-395.1902	119.2837	-3.31	0.001	-628.9819	-161.3985
_cons	12744.24	4629.664	2.75	0.006	3670.27	21818.22
/lnsigma	7.739796	.0821995	94.16	0.000	7.578688	7.900904
sigma	2298.004	188.8948			1956.062	2699.723

This same technique may be used to constrain a regression parameter to be strictly positive (or strictly negative).<sup>6</sup> Imagine that we believe that the first slope parameter in a particular regression model must be negative. We can no longer use the `lf` (linear form) method, but must switch to one of the more complicated methods `d0`, `d1` or `d2`. In the linear form method, your likelihood function evaluator only calculates one term of the likelihood function. Using the `d...` methods, you must calculate the total likelihood within your routine. In these methods, you must use the `mlevel` command (`[R] ml`) to evaluate the coefficient vector passed to the likelihood function evaluation, and the `mlsum` command to sum the likelihood over the available observations.<sup>7</sup> We

6. For an explanation of how this can be done in an OLS regression context, see Isabel Cañette's Stata FAQ, "How do I fit a linear regression with interval constraints in Stata?" <http://www.stata.com/support/faqs/stat/intconst.html>

7. See Gould et al. (2006) for full details.

start with the simple `mynormal_d0` routine from Gould et al. (2006), p. 98:

```
. type mynormal_lf_d0.ado
*! mynormal_lf_d0 v1.0.0 CFBaum 11aug2008
program mynormal_lf_d0
    version 10.1
    args todo b lnf
    tempvar mu
    tempname lnsigma
    mlevel 'mu' = 'b', eq(1)
    mlevel 'lnsigma' = 'b', eq(2) scalar
    quietly {
        mlsum 'lnf' = ln( normalden($ML_y1,'mu', exp('lnsigma')) )
    }
end
```

and invoke it with `ml model`:

```
. ml model d0 mynormal_lf_d0 (mu: price = mpg weight turn) /lnsigma, ///
> maximize nolog diparm(lnsigma, exp label("sigma"))
initial:      log likelihood =      -<inf> (could not be evaluated)
feasible:      log likelihood = -811.54531
rescale:      log likelihood = -811.54531
rescale eq:   log likelihood = -808.73926
. ml display
```

	Number of obs	=	74		
	Wald chi2(3)	=	46.26		
	Prob > chi2	=	0.0000		

Log likelihood = -677.74638

	price	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mu	mpg	-72.86507	79.06768	-0.92	0.357	-227.8349	82.10474
	weight	3.524333	.7947475	4.43	0.000	1.966656	5.082009
	turn	-395.1891	119.2836	-3.31	0.001	-628.9807	-161.3974
	_cons	12744.22	4629.664	2.75	0.006	3670.244	21818.19
lnsigma	_cons	7.739795	.0821994	94.16	0.000	7.578688	7.900903
	sigma	2298.002	188.8945			1956.06	2699.72

We now break out the first slope coefficient from the linear combination and give it its own “equation”. To refer to the variable `mpg` within the likelihood function evaluator, we must use a global macro<sup>8</sup> to impose the constraint of negativity on the `mpg` coefficient, we need only specify that the mean equation (for `mu`) is adjusted by subtracting the exponential of the parameter `a`:

```
. type mynormal_lf_d0_c1.ado
*! mynormal_lf_d0_c1 v1.0.0 CFBaum 11aug2008
program mynormal_lf_d0_c1
```

8. See Section 3.7.



_nl_1	-72.86415	79.06769	-0.92	0.357	-227.834	82.10568
-------	-----------	----------	-------	-------	----------	----------

We have estimated  $-\exp(\beta_{mpg})$ ; `nlcom` back-transforms the estimated coefficient to  $\beta_{mpg}$  in point and interval form.

Variations on this technique are used throughout Stata's maximum likelihood estimation commands to ensure that coefficients take on appropriate values. For instance, the bivariate probit command ([R] **biprobit**) estimates a coefficient  $\rho$ , the correlation between two error processes. It must lie within  $(-1, +1)$ . Stata's **biprobit** routine estimates the hyperbolic arctangent (`atanh()`) of  $\rho$ , which constrains the parameter itself to lie within the appropriate interval when back-transformed. A similar transformation could be used to constrain a slope parameter to lie within a certain interval of the real line.

## 12.6 Generating a dataset containing the single longest spell for each unit in panel data

**The problem:** in panel (longitudinal) data, many datasets contain *unbalanced panels*, with differing numbers of observations for different units in the panel. Some estimators commonly employed in a panel-data context can work with unbalanced panels, but expect to find a single *spell* for each unit: that is, a time-series without gaps. Finding and retaining the single longest spell for each unit within the panel is quite straightforward in the case of a single variable. However, for our purposes, we want to apply this logic *listwise*, and delete shorter spells if *any* of the variables in a specified *varlist* are missing. The solution will entail creation of a new, smaller dataset in which only panel units with single spells are present.

To motivate this form of data organization, note that the Arellano–Bond dynamic panel data estimator and its descendants (see [TS] `xtabond` and the user-written `xtabond2`),<sup>9</sup> consider that each spell of observations represents a panel unit.

We present a solution to this problem here in the context of an ado-file, `onespell.ado`. Dealing with this problem—finding and retaining the single longest spell for each unit within the panel—is quite straightforward in the case of a single variable. However, we want to apply this logic *listwise*, and delete shorter spells if *any* of the variables in a specified *varlist* are missing.

The program builds upon Nicholas J. Cox’s excellent `tsspell` command.<sup>10</sup> The command examines a single variable, optionally given a logical condition that defines a spell,<sup>11</sup> and creates three new variables: `_spell`, indicating distinct spells (taking on successive integer values); `_seq`, giving the sequence of each observation in the spell (taking on successive integer values); and `_end`, indicating the end of spells. If applied to panel data rather than a single timeseries, the routine automatically performs these observations for each unit of a panel.

In this first part of the program, we define the syntax of the ado-file. The program accepts a *varlist* of any number of numeric variables, `if exp` and `in range` options, and requires that the user provide a filename in the `saving()` option in which the resulting edited dataset will be stored. Optionally, the user may specify a `replace` option (which, as is usual in Stata, must be spelled out). The `noisily` option is provided for debugging purposes. The `preserve ([P] preserve)` command allows us to modify the data and return to the original dataset.

The `tsset ([TS] tsset)` command allows us to retrieve the names of the panel variable and time variable. If the data are not `tsset`, the program will abort. The `tsfill ([TS] tsfill)` command fills any gaps in the time variable with missing observations. We then use `marksample touse` to apply any qualifiers on the set of observations and define a number of `tempvars`.

---

9. `findit xtabond2`.

10. `findit tsspell`.

11. See Sections 4.4 and 8.4.

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For ease of exposition, I do not list the entire ado-file here. Rather, the first piece of the code is displayed (as a text file), and the remainder (also as a text file) as a separate listing below a discussion of its workings.

```
. type onespell_part1.txt
*! onespell 1.1.1 CFBAum 13jan2005
* locate units with internal gaps in varlist and zap all but longest spell
program onespell, rclass
    version 10.1
    syntax varlist(numeric) [if] [in], Saving(string) [ REPLACE NOIsily]
    preserve
    quietly tsset
    local pv "r(panelvar)"
    local tv "r(timevar)"
    summarize 'pv', meanonly
    local n1 = r(N)
    tsfill
    marksample touse
    tempvar testgap spell seq end maxspell keepspell wantspell
    local sss = cond("'noisily'" != "", "noisily", "quietly")
```

The real work is performed in the second half of the program. The temporary variable `testgap` is generated with the `cond()` function to define each observation as either its value of the panel variable (`pv`) or missing. Cox's `tsspell` is then invoked on the `testgap` variable with the logical condition that the variable is non-missing. We explicitly name the three variables created by `tsspell` as temporary variables `spell`, `seq` and `end`.

In the first step of pruning the data, we note that any observation for which `spell = 0` may be discarded, along with any observations not defined in the `touse` restrictions. Now, for each panel unit, we consider how many spells exist. If `spell > 1`, there are gaps in the usable data. The longest spell for each panel unit is stored in temporary variable `maxspell`, produced by `egen max()` from the `seq` counter. Now, for each panel unit, we generate a temporary variable `keepspell`, identified by the longest observed spell (`maxspell`) for that unit. We then can calculate temporary variable `wantspell` with `egen max()`, which places the `keepspell` value in each observation of the desired spell. What if there are two (or more) spells of identical length? By convention, the latest spell is chosen by this logic.

We can now apply `keep` to retain only those observations, for each panel unit, associated with that unit's longest spell: those for which `wantspell` equals the `spell` number. The resulting data are then `saved` to the file specified in the `saving()` option, optionally employing `replace`, and the original data are `restored`.

```
. type onespell_part2.txt
    'sss' {
* testgap is panelvar if obs is usable, 0 otherwise
        generate 'testgap' = cond('touse', 'pv', .)
        tsspell 'testgap' if !missing('testgap'), spell('spell') seq('s
> eq') end('end')
```

```

        drop if 'spell' == 0 | 'touse' == 0
* if 'spell' > 1 for a unit, there are gaps in usable data
* calculate max length spell for each unit and identify
* that spell as the one to be retained
    egen 'maxspell' = max('seq'), by('pv')
    generate 'keepspell' = cond('seq'=='maxspell', 'spell', 0)
    egen 'wantspell' = max('keepspell'), by('pv')
* in case of ties, latest spell of max length is selected
    list 'pv' 'tv' 'spell' 'seq' 'maxspell' 'keepspell' 'wantspell'
> , seby('pv')
        summarize 'spell' 'wantspell'
        keep if 'wantspell' == 'spell'
        summarize 'pv', meanonly
        local n2 = r(N)
        drop \_.*
    }
    display _n "Observations removed: " 'n1'-'n2'
    save 'saving', 'replace'
    restore
end

```

To illustrate, we modify the `grunfeld` dataset. The original dataset is a balanced panel of 20 years' observations on 10 firms. We remove observations from different variables in firms 2, 3 and 5, creating two spells in firms 2 and 3 and three spells in firm 5. We then apply `onespell`:

```

. webuse grunfeld, clear
. quietly replace invest = . in 28
. quietly replace mvalue = . in 55
. quietly replace kstock = . in 87
. quietly replace kstock = . in 94
. onespell invest mvalue kstock, saving(grun1) replace
Observations removed: 28
file grun1.dta saved

```

A total of 28 observations are removed. The tabulation shows that firms 2, 3 and 5 now have longest spells of 12, 14 and 6 years, respectively.

```

. use grun1, clear
. tab company

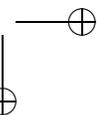
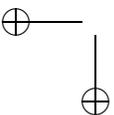
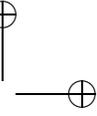
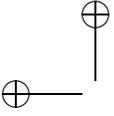
```

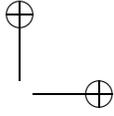
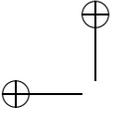
company	Freq.	Percent	Cum.
1	20	11.63	11.63
2	12	6.98	18.60
3	14	8.14	26.74
4	20	11.63	38.37
5	6	3.49	41.86
6	20	11.63	53.49
7	20	11.63	65.12
8	20	11.63	76.74
9	20	11.63	88.37
10	20	11.63	100.00

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```
Total |          172          100.00
```

Although this routine meets a specialized need, the logic that it employs may be useful in a number of circumstances for data management.





# 13 Mata functions for ado-file programming

## 13.1 Mata: first principles

Mata is a full-fledged programming language that operates in the Stata environment. You can start Stata, enter Mata with the `mata` command, and work interactively in that environment. You may even leave Mata with the `end` command, issue Stata commands, and return to Mata's workspace, which will be unchanged until you issue the command `mata: mata clear` or exit Stata. But Mata is useful in another context: that of non-interactive programming. You may write Mata functions, callable from Stata do-files or ado-files, that perform useful tasks. The functions may make use of Mata's facility with matrices and vectors or they may use other elements of Mata's environment. For instance, Mata can be used for file input and output (with functions much like those in the C programming language) and is an excellent environment for string processing. Unlike some matrix programming languages, Mata matrices can contain either numeric or string elements (but not both).

For matrix programming, Mata is a more useful environment than Stata's older `matrix` ([P] `matrix`) commands. All versions of Stata have limits on matrix size (for instance, 800 rows or columns in Stata/IC), and these limits can be quite constraining. Creating a sizable matrix from Stata variables will at least double the amount of memory needed to work with those two representations of the data. In contrast, Mata can work with *views*, or what might be considered *virtual matrices*, containing Stata variables' data but not requiring additional storage beyond a trivial amount of overhead. The suite of matrix functions available in Mata is also much broader than that available in Stata's matrix language. Additionally, Mata explicitly supports complex arithmetic and datatypes.

Most importantly, Mata code is automatically compiled into *bytecode*.<sup>1</sup> If you write an ado-file program that involves many explicit loops (such as those referencing the subscripts of matrices), the commands within the loop must be interpreted each time through the loop. The equivalent Mata code is compiled once, "on-the-fly", so that subsequent passes through the code are executing machine instructions rather than reinterpreting your code. If you write a Mata function, you can store it in object module form or place it in a library of object modules. The net effect is a considerable speed advantage for many routines coded in Mata rather than in the ado-file language.

---

1. <http://en.wikipedia.org/wiki/Bytecode>.

The integration between Mata and Stata's elements (variables, local and global macros, scalars and matrices) is complete. Within Mata, you may access Stata's objects and alter them. When using Mata's view matrices, alterations to the Mata matrix automatically modify the Stata observations and variables that comprise the view matrix.

In this chapter, I discuss how you may use Mata functions as adjuncts to your ado-file programs. The techniques developed in earlier chapters remain useful. For instance, you still use Stata's `syntax` and `marksample` statements to parse a user's command and prepare the appropriate sample for Mata. After calling a Mata function, you will use Stata's `return` and `ereturn` facilities to return computed quantities to the user. The best candidates for translation to Mata code are the heavily computational aspects of your routine, particularly if their logic can be readily expressed in matrix algebra.

### 13.1.1 What you should learn from this chapter

- Understanding of Mata's operators, subscripts, loop functions and conditionals
- How the components of a Mata function are defined
- How to call a Mata function from an ado-file
- How to use Mata's `st_` functions to exchange data with Stata
- How to construct arrays of temporary objects in Mata
- How to use Mata structures
- How to create compiled Mata functions or a Mata function library
- How to use user-contributed Mata functions

## 13.2 Mata fundamentals

Before delving into writing Mata functions, we must understand Mata's elements of syntax and several of its operators. Note that Mata's command prompt is the colon (`:`) rather than Stata's full stop (`.`).

### 13.2.1 Operators

The comma (`,`) is Mata's *column-join* operator, so

```
: r1 = (1, 2, 3)
```

creates a three-element row vector. We could also construct this vector using the *row range operator* (`..`) as

```
: r1 = (1..3)
```

The backslash (`\`) is Mata's *row-join* operator, so

```
: c1 = (4 \ 5 \ 6)
```

creates a three-element column vector. We could also construct this vector using the *column range operator* (`::`) as

```
: c1 = (4::6)
```

We may combine the column-join and row-join operators:

```
: m1 = (1, 2, 3 \ 4, 5, 6 \ 7, 8, 9 )
```

creates a  $3 \times 3$  matrix. The matrix could also be constructed with the row-range operator:

```
: m1 = ((1..3) \ (4..6) \ (7..9))
```

The prime or apostrophe (`'`) is Mata's *transpose* operator, so

```
: r2 = (1 \ 2 \ 3 )'
```

is a row vector.<sup>2</sup> Numeric matrix elements can be real or complex, so `2 - 3i` refers to the complex number  $2 - 3 \times \sqrt{-1}$ . The comma and backslash operators can be used on vectors and matrices as well as scalars, so

```
: r3 = r1, c1'
```

will produce a six-element row vector, and

```
: c2 = r1' \ c1
```

which is a six-element column vector.

The standard algebraic operators plus (+), minus (-) and multiply (\*) work on scalars or matrices:

```
: g = r1' + c1
: h = r1 * c1
: j = c1 * r1
```

In this example `h` will be the  $1 \times 1$  dot product<sup>3</sup> or inner product of row vector `r1` and column vector `c1` while `j` is their  $3 \times 3$  outer product.<sup>4</sup>

Mata's algebraic operators, including the forward slash (/) for division, can also be used in element-by-element computations when preceded by a colon:

```
: k = r1' :* c1
```

will produce the three-element column vector, with elements as the product of the respective elements.

---

2. Note that the transpose operator applied to a complex matrix produces the *conjugate transpose*, so that  $(a + b i)' = (a - b i)$ .

3. [http://en.wikipedia.org/wiki/Dot\\_product](http://en.wikipedia.org/wiki/Dot_product).

4. [http://en.wikipedia.org/wiki/Outer\\_product](http://en.wikipedia.org/wiki/Outer_product).

Mata's *colon operator* is very powerful in that it will work on nonconformable objects as long as the expression can be interpreted sensibly. For example:

```
: r4 = ( 1, 2, 3 )
: m2 = ( 1, 2, 3 \ 4, 5, 6 \ 7, 8, 9 )
: m3 = r4 :+ m2
: m4 = m1 :/ r1
```

adds the row vector **r4** to each row of the  $3 \times 3$  matrix **m2** to form **m3**, then divides each row of matrix **m1** by the corresponding elements of row vector **r1** to form **m4**.

Mata's scalar functions will also operate on elements of matrices:

```
: m5 = sqrt(m4)
```

will take the element-by-element square root of the  $3 \times 3$  matrix **m4**, returning missing values where appropriate.

The matrix operator **A # B** produces the Kronecker or direct product of matrices **A** and **B**.<sup>5</sup>

### 13.2.2 Relational and logical operators

As in Stata, the equality relational operators are **a == b** and **a != b**. They will work whether or not **a** and **b** are conformable or even of the same type: **a** could be a vector and **b** a matrix. They return 0 or 1. Unary not **!** returns 1 if a scalar equals zero, 0 otherwise, and may be applied in a vector or matrix context, returning a vector or matrix of 0 and 1 values.

The remaining relational comparison operators (**>**, **>=**, **<**, **<=**) can only be used on objects that are conformable and of the same general type (numeric or string). They return 0 or 1. The logical operators and (**&**), or (**|**), as in Stata, can only be applied to real scalars. If preceded by the colon operator (**:**), they may be applied to matrices.

### 13.2.3 Subscripts

Subscripts in Mata use square brackets and may appear on either the left or the right of an algebraic expression. There are two forms: *list* subscripts and *range* subscripts.

With *list subscripts*, you can reference a single element of an array as **x[i, j]**. The **i** or **j** references can also be vectors, such as **x[i, jvec]**, where **jvec = (4, 6, 8)** references those three columns of **x**. Missingness (signalled by full stops **.**) references all rows or columns, so **x[i, .]** or **x[i,]** extracts row **i**, and **x[., .]** or **x[,]** references the whole matrix.

You may also use the row range and column range operators described above to avoid listing each consecutive element: **x[(1..4), .]** and **x[(1::4), .]** both reference the first four rows of **x**. The double-dot range creates a row vector, while the double-colon

5. [http://en.wikipedia.org/wiki/Kronecker\\_product](http://en.wikipedia.org/wiki/Kronecker_product).

range creates a column vector. Either may be used in a subscript expression. Ranges may also decrement, so `x[(3::1), .]` returns the first three rows of `x` in reverse order.

*Range subscripts* use the notation `[i j]`. They can reference single elements of matrices, but are not useful for that. More useful is the ability to say `x[i, j \ m, n j]`, which creates a submatrix starting at `x[i, j]` and ending at `x[m, n]`. The arguments may be specified as missing (full stop), so `x[1, 2 \ 4, .]` will specify the submatrix ending in the last column and `x[4, 4 \ ., .]` will discard the first three rows and columns of `x`. They also may be used on the left hand side of an expression, or to extract a submatrix:

```
: v = invsym(xx)[1, 2 \ ., .]
```

discards the first row and column of the inverse of `xx`.

You need not use range subscripts, as even the specification of a submatrix can be handled with list subscripts and range *operators*, but they are more convenient for submatrix extraction (and faster in terms of execution time). Mata's interpretation of expressions will involve much less computation where range subscripts are used effectively. As Gould (2007a), p. 115 suggests, "Never code `x[5::1000]` or `x[5..1000]`. Code `x[15 \ 1000]`. ... Never code `X[5::100, 3..20]`. Code `X[15, 3 \ 100, 20]`." These admonitions arise because range subscripts allow Stata to identify a submatrix to be accessed, and the contents of that submatrix can be accessed more efficiently when it is known that they are contiguous.

## 13.2.4 Populating matrix elements

The Mata standard function `J()` provides the same capability as its Stata counterpart: `J(nrows, ncols, value)` creates a matrix of `nrows`  $\times$  `ncols` with each element set to `value`. However, in an update of February 2008, this function was enhanced. It can now generate a matrix with a pattern in its rows or columns.<sup>6</sup> For example:

```
. version 10.1
. mata:
----- mata (type end to exit) -----
: m1 = J(7, 3, (0.25, 0.50, 0.75))
: m1
      1      2      3      4      5      6      7      8      9
1  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
2  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
3  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
4  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
5  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
6  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
7  [ .25  .5  .75  .25  .5  .75  .25  .5  .75
: end
```

6. See Cox (2008).

Notice in this example that the second argument, 3, does not define the number of columns in the result matrix, but the number of replicates or copies of the row vector to be produced.

Other Mata functions have similar functionality when a vector takes the place of a matrix. For instance, the `rnormal()` function takes four arguments:  $r$ ,  $c$ ,  $m$ ,  $s$ , where  $m$  and  $s$  can be scalars, vectors or matrices. `rnormal(5, 5, 0, 1)` returns a  $5 \times 5$  matrix of draws from the standard Normal distribution, defined by  $m=0$  and  $s=1$ . But those two arguments need not be scalars:

```
. mata:
----- mata (type end to exit) -----
: m2 = rnormal(3, 2, (1, 5, 10), 1)
: m2
      1          2          3          4          5
-----
1 | 1.127679588  6.993281523  9.201610313  1.44491133  6.018139269
2 | -.2659044268  4.640042947  9.496285076  .8234787212  9.089975386
3 | 2.395392041  5.429020732  10.68722028  1.254825584  5.144066489
-----
      6
1 | 11.28016579
2 | 11.25508169
3 | 10.70177392
-----
: end
-----
```

In this example, the function call produces a  $3 \times 6$  matrix of Normal draws, with the mean vector of (1, 5, 10) repeated twice, with a scalar  $s$  of 1.

### 13.2.5 Mata loop commands

Several constructs support loops in Mata. As in any matrix language, explicit loops should not be used where matrix operations can be substituted. The most common loop construct resembles that of the C programming language:

```
: for (starting_value; ending_value; incr) {
:   ...
: }
```

where the three elements define the starting value, an ending value or bound, and an increment or decrement. The increment (++) and decrement (--) operators<sup>7</sup> can be used to manage counters. Note that these operators are available in two forms: *pre-increment* and *post-increment*. The pre-increment operator `++i` performs the operation

7. See [M-2] `op_increment`.

before the evaluation of the expression in which it appears, while the post-increment operator `i++` performs the operation after the evaluation of the expression in which it appears. The pre-decrement and post-decrement operators are defined similarly. Thus, given a vector `x`,

```
: i = 1
: x[ ++i ] = 42
: i = 1
: x[ i++ ] = 42
```

yield different results; the former places the constant 42 in the second element of `x`, while the latter places the constant in the first element of `x`. After either command, the value of `i` is 2.

To apply the increment and decrement operators in the context of the `for` loop,

```
: for (i = 1; i <= 10; i++) {
:     printf("%g squared is %g \n", i, i^2)
: }
```

We could also write

```
: for (i = 10; i > 0 ; i = i - 2) {
:     printf("%g squared is %g \n", i, i^2)
: }
```

If only a single statement will be executed by the `for` loop, it may be included on the same line as the `for` command without enclosing curly braces (`{}`).

As an alternative to the `for` statement, you may also use `do` to specify a loop, which follows the syntax

```
: do {
:     ...
: } while (exp)
```

which will execute the statements at least once. As a third alternative, you may use `while`:

```
: while (exp) {
:     ...
: }
```

which could be used, for example, to loop until convergence with an `exp` of (`sse > 1.0e-5`).

## 13.2.6 Conditional statements

To execute certain Mata statements conditionally, you use `if` and `else`:

```
: if (exp) statement
```

or

```
: if (exp) statement1
```

```
: else statement2
```

or

```
: if (exp1) {
:   statements1
: }
: else if (exp2) {
:   statements2
: }
: else {
:   statements3
: }
```

You may also use the conditional `a ? b : c`, where `a` is a real scalar. If `a` evaluates to true (nonzero), the result is set to `b`, otherwise `c`.<sup>8,9</sup> For instance,

```
: if (k == 0) dof = n-1
: else      dof = n-k
```

can be written as

```
: dof = ( k==0 ? n-1 : n-k )
```

For compatibility with old-style Fortran, there is a `goto` statement which conditionally branches control to a statement elsewhere in the program:

```
: label: statement
: ...
: if (exp) goto label
```

The `goto` statement is generally not necessary, as such a construct can be rewritten in terms of `do`:

```
: do {
: ...
: } while (exp)
```

The `goto` statement is most useful when a program being translated from Fortran code.

### 13.3 Function components

Mata code that is to be called from an ado-file must be defined as a *Mata function* which is the equivalent of a Stata `program`. Unlike a Stata program, a Mata function has an explicit *return type* and set of *arguments*. A function may be of return type `void` if it does not need a `return` statement. Otherwise, a function may be typed in terms of two characteristics: the nature of its *elements*, or the *element type*, and their *organization type*. For instance,

```
: real scalar calcsun(real vector x)
```

8. This function plays the same role as Stata's `cond()` function; see Section 3.3.2.

9. Although the conditional operator only operates on real scalars, Ben Jann's generalization of it, `mm_cond()`, can operate on matrices. It is available in his `moremata` package (`findit moremata`).

defines the function `calcsun` as a **real scalar** function. Its element type is **real** and its organization is **scalar**, so that the function will return a real number. There are six element types: **real**, **complex**, **numeric**, **string**, **pointer** and **transmorphic**. **numeric** encompasses either **real** or **complex**. I discuss the **pointer** element type in Section 13.8. **transmorphic** allows for any of the other types: that is, a **transmorphic** object may be filled with any of the other element types.

There are five organization types: **matrix**, **vector**, **rowvector**, **colvector** and **scalar**. Strictly speaking, the latter four are special cases of the **matrix** type. In Stata's matrix language, all matrices have two subscripts, neither of which can be zero. In Mata, all but the **scalar** organization type may have zero rows and/or columns (see [M-2] **void**).

If you do not declare a function's element type or organization type, its return type is by default the **transmorphic matrix**. That return type may be transmuted into any type of object. Although function definitions are not always necessary, it is good programming practice to make them explicit in case you mistakenly attempt to return a different kind of object than that declared. Explicit declarations also serve to document the function and lead to more efficient code. More importantly, they help to prevent errors, because they ensure that the returned object is of the proper return type.

### 13.3.1 Arguments

The Mata function declaration includes an *argument list*. In the example above, there is a single argument: **real vector x**. To call this function you must provide one (and only one) argument, and that argument must be typed as a **real vector**, or an error will occur. Inside the `calcsun` function, the contents of the vector will be known as **x** regardless of their representation elsewhere in Mata. Items whose types are defined as arguments should not be included in declaration statements within the function.

The names of arguments are required and arguments are positional. That is, the order of arguments in the calling sequence must match that in the Mata function. It is good programming practice to specify the arguments' element type and organization explicitly, for then Mata will detect an error if the arguments' characteristics do not match. Explicit declarations also serve to document the function and lead to more efficient code. The list of arguments may include a vertical bar (|) which indicates that all following arguments are optional:

```
: function mynorm(real matrix A, | real scalar power)
```

may be called with one matrix or with a matrix followed by a scalar. The optional arguments will generally be given missing values in the function. It is possible for all the arguments of a function to be optional.

### 13.3.2 Variables

Within each Mata function, *variables* may be explicitly declared. Unlike some programming languages, Mata does not require you to declare variables before use unless `matastrict` is set as the default. However, it is good programming practice to explicitly declare variables, just as we suggested above that functions' arguments should be declared. Once variables are declared, they cannot be misused. For instance, variables declared as one of the numeric types cannot be used to store string contents, and vice versa.

Variables within a Mata function have *local scope*. They cannot be accessed outside that function, so that their names cannot conflict with other objects elsewhere in Mata.<sup>10</sup> As with functions, Mata variables may be declared with each of the six element types and five organization types: for example,

```
: real scalar sum
: complex matrix lambda
```

A number of *reserved words* may not be used as the names of Mata variables. They are listed in [M-2] **reswords**.

### 13.3.3 Returns

Unlike a Stata ado-file program, which may return any number of scalars, macros and matrices through the `return list` or `ereturn list`, a Mata function can only return one object in its `return` statement. If the function is to return multiple objects, you should use Mata's `st_...` functions to return scalars, macros, matrices or Stata variables, as we demonstrate below.<sup>11</sup>

## 13.4 Calling Mata functions

To illustrate using a Mata function within a Stata ado-file program, let's imagine that we did not have an easy way of computing the minimum and maximum of the elements of a Stata variable<sup>12</sup> and wanted to do so with Mata, returning the two scalar results to Stata. Let's define the Stata command `varextrema`:

```
. type varextrema.ado
*! varextrema v1.0.0 CFBaum 11aug2008
program varextrema, rclass
    version 10.1
```

10. You can use the `external` declaration to indicate that a variable in a Mata function has *global scope* and is visible within any other Mata function. This is the same distinction that exists between local and global macros in Stata's do- and ado-files. One use of external variables in Mata is to allow a function to remember something from one call to the next (for instance, whether the function has been initialized). See [M-5] `findexternal()` for more details.

11. Mata functions can also modify one or more of their arguments. I do not further discuss that method.

12. `summarize`, `meanonly` or `egen`'s `min()` and `max()` functions could be used for this purpose.

```

syntax varname(numeric) [if] [in]
marksample touse
mata: calcextrema( "'varlist'", "'touse'" )
display as txt " min ( 'varlist' ) = " as res r(min)
display as txt " max ( 'varlist' ) = " as res r(max)
return scalar min = r(min)
return scalar max = r(max)
end

```

The elements of this ado-file should be familiar to you with the exception of the `mata:` statement. This `r`-class program takes a single numeric variable as an argument and allows the sample to be limited by `if exp` and `in range` qualifiers as defined in Section 11.6. The `marksample touse` statement, also described in that section, creates a `tempvar` which marks the observations to be included in further computations.

We then invoke Mata. Instead of the simple command `mata`, which would place Mata into interactive mode, we tell Mata to execute a function named `calcextrema` with the syntax `mata: function()`. The `calcextrema` function takes two arguments. From the code above, they are the *name* of the Stata variable passed to `varsum` and the *name* of the `tempvar` 'touse'. Both arguments are of type string, as we are only passing the names of Stata variables, as strings, not their values. The file `varextrema.mata` contains the Mata code. For presentation purposes, we have placed the Mata code in a separate file. In practice, we would include the lines below in `varextrema.ado`, or place the line `include varextrema.mata` after the `end` statement in `varextrema.ado`.<sup>13</sup>

```

. type calcextrema.mata
version 10.1
mata:
mata set matastrict on
// calcextrema 1.0.0 CFBaum 11aug2008
void calcextrema(string scalar varname, ///
                 string scalar touse)
{
    real colvector x, cmm
    st_view(x, ., varname, touse)
    cmm = colminmax(x)
    st_numscalar("r(min)", cmm[1])
    st_numscalar("r(max)", cmm[2])
}
end

```

We give the `version 10.1` statement to define to Stata that it is to invoke Mata under *version control* for version 10.1. After invoking Mata's interpreter with `mata:`,<sup>14</sup> we use `mata set matastrict on` to invoke Mata's strict mode, which will catch various errors in our code as it requires that we explicitly declare all variables in the Mata function.

---

13. See [P] **include**.

14. Note the distinction between `mata` and `mata:` on Stata's command line. The former accepts Mata commands and stays in Mata mode regardless of errors. The latter accepts Mata commands but exits Mata at the first error (similar to the default behavior of a do-file). In programming Mata functions, you should always use `mata:` to ensure that an error will abort the ado-file.

If a variable's name is misspelled, it will be flagged in Mata's strict mode.

As we will be returning two scalars to Stata, we must either return them in a vector (using Mata's `return` statement) or use Stata's `st_` functions. We choose to do the latter and declare the function as return type `void`. Two arguments are defined: the `string` scalars named `varname` and `touse`. These names are arbitrary as they are local to the function. They are defined as arguments, and need not be defined again. We define two items: `real colvector` `x` which will hold the *view* of the Stata variable,<sup>15</sup> and a vector `cmm`. The `st_view()` function defines the column vector `x` as the contents of `varname`, with the optional fourth argument applying the `touse` indicator to reflect any `if` or `in` qualifiers. Thus, Mata's column vector `x` contains the subset of observations of `varname` for which `touse == 1`. The second argument of `st_view`, set to missing (`.`) in this example, indicates which observations are to be retrieved. When set to missing, all observations are specified. We are using the `touse` argument to perform that selection.

The `st_numscalar()` function can be used to retrieve or set a Stata `scalar`. In its two-argument form, it sets the value of its first argument to the value of its second argument. Mata's `colminmax()` function computes the column minima and maxima of a vector or matrix; when applied to a vector, it returns a two-element vector containing the minimum and maximum, respectively. We create the Stata scalars named `r(min)` and `r(max)` by defining them as elements of the vector `cmm`.

We may now return to the last lines of `varextrema.ado`. Back in Stata, the scalars `r(min)` and `r(max)` are now defined, and may be included in `display` (`[P] display`) statements. The `varextrema` command displays the variable name and the extrema of the selected elements and returns those scalars to the user in the `return list`:

```
. sysuse auto, clear
(1978 Automobile Data)

. varextrema price if foreign
min ( price ) = 3748
max ( price ) = 12990

. return list
scalars:
          r(max) = 12990
          r(min) = 3748
```

## 13.5 Mata's `st_` interface functions

The example above made use of two of Mata's *st\_ interface functions*: `st_view()` and `st_numscalar()`. These functions are among the most important Mata components if you are using Mata in conjunction with ado-file programming. They provide full access to any object accessible in Stata and support a seamless interchange of computations between Stata and Mata. They are usefully summarized in [M-4] **Stata interface functions**.

15. I discuss view matrices in Section 13.5.

### 13.5.1 Data access

The first category of `st_` interface functions provide access to data. The `st_nobs()` and `st_nvar()` functions return the scalars corresponding to the number of observations and variables in the current Stata dataset, respectively: the same information is provided by `describe` ([D] `describe`) as `r(N)` and `r(k)`. The functions `st_data()` and `st_view()` allow you to access any rectangular subset of Stata's numeric variables (including the entire dataset) within Mata. You may access string variables with `st_sdata()` and `st_sview()`.

Although both `st_data()` and `st_view()` provide access to Stata's numeric variables, they differ in important ways. The `st_data()` function *copies* the specified data into a Mata matrix, while `st_view()` creates a *view matrix*: a virtual construct that allows you to use *and update* the specified data. The *view matrix*, as it does not involve a copy of the data, has a trivial overhead in terms of memory requirements. In contrast, the Mata matrix created by `st_data()` can require from 1 to 8 times as much memory ([D] `memory`) as the underlying variables use.<sup>16</sup> For a large dataset, that can make a tremendous difference if a sizable chunk of the dataset is selected. Views do involve a minor computational overhead, but it is likely to be offset by the memory savings in most cases. If you do not use views but employ `st_data()` to access Stata variables within Mata, you may still return the contents of the Mata matrix to Stata using the `st_store()` function, as described below.

A major advantage of views must be handled with care: altering the contents of a view matrix actually *changes the values* of the underlying Stata variables. This may be exactly what you want to do, or it may not.<sup>17</sup> As we will see, a very useful technique to generate the contents of a set of Stata variables involves creating those variables (as missing) in Stata, then calling Mata, creating a view on those variables (call it matrix *V*) and defining the contents of that matrix:

```
V[. , .] = result of computation
```

It is essential in this instance that you specify *V* as shown. If you merely place *V* on the left hand side of the expression, it would create a *new* Mata matrix *V* and break the link to the existing contents of the view matrix. For a thorough discussion of these issues, see Gould (2005).

The view matrix makes it possible to change the values of Stata variables within Mata, but requires that you create those variables (as placeholders, at least) before invoking Mata. If you would like to generate results in Mata and return them to Stata, but the number of result variables may depend upon the computations, there is another way to approach the problem. In that case, you may want to use `st_addvar()`

16. This range exists because the underlying variables could all be stored as `doubles` in Stata, requiring eight bytes per observation. All Mata numeric matrices require eight bytes per observation. On the other hand, the Stata data could all be `byte` variables which would each require much more storage in Mata.

17. For instance, consider when you might employ `preserve` and `restore` (see Section 2.5) in ado-file programming to protect the current dataset's contents.

([M-4] **Stata interface functions**) to create new variables in the Stata dataset from within Mata. The function call

```
varnums = st_addvar(type, name)
```

allows you to specify the names of one or more new variables (*name* may be a quoted string or a vector of quoted string names), and for each new variable specify its *type*: for instance, "float", "int", "str5". The function returns the variable *numbers* in the row vector *varnums* and creates the new variables with missing contents. To fill them in, we could use `st_store()`:

```
newvarnum = st_addvar("int", "idnr")
st_store(., newvarnum, values)
```

where *values* is the name of a column vector computed in Mata. If you are working with string data, you would use `st_sstore()` instead.

We may also combine the view matrix and `st_addvar()` techniques:

```
st_view(z, ., st_addvar(("int", "float"), ("idnr", "bpmx")))
z[., .] = ...
```

which would create a view matrix, *z*, for two new variables, *idnr* and *bpmx*. We may then compute values for those variables within Mata and alter the contents of *z*, which will in turn fill in the new variables in Stata. For a thorough discussion of these techniques, see Gould (2006a).

There are situations where you may not choose to use views. For instance, if you are going to explicitly loop through observations in the dataset, and every use you will make of the view matrix involves scalar calculations, views provide no advantage. The variant `_st_data()`, which returns a single observation, may be used. You should also take care not to make copies of views in your Mata code, as they more than double the memory requirements of the underlying data.

Mata matrices must contain either all numeric or all string elements. Therefore, you cannot create a view that mixes these element types. If you loaded the `auto` dataset and created a view matrix of the entire dataset, it would have missing columns corresponding to string variables (in the case of `auto.dta`, only the first column, `make`). The functions `st_sview()`, `st_sdata()` and `st_sstore()` allow you to create view matrices or regular matrices of string variables or return the contents of a Mata string matrix to Stata, respectively. You must be careful to ensure that the rows of a numeric matrix and string matrix (created by `st_sview()` or `st_sdata()`) are properly aligned. In particular, you should use the same `touse` indicator to specify the observations that are to be transferred to Mata in each function call. An additional interface function is very useful in this regard: `st_subview()`. As [M-5] `st_subview()` discusses, this function can be used to ensure that missing values are handled properly across variables, or within a panel context.<sup>18</sup>

18. There are also specialized Mata functions available for the handling of panel data: see [M-5] `panelinfo` and [M-5] `panesubmatrix` and their illustration in Section 14.3.

## 13.5.2 Access to locals, globals, scalars and matrices

The interface functions `st_local()`, `st_global()`, `st_numscalar()`, `st_strscalar()` and `st_matrix()` allow you to access Stata's objects. In their single-argument form, they copy the object into Mata. For instance,

```
mylocal = st_local("macroname")
```

will return the contents of local `macroname` to the string scalar `mylocal`. Access to global macros, Stata's numeric scalars, string scalars and matrices works in the same manner. You may also access Stata's characteristics (see Section 9.7) and `r()`, `e()`, `s()` and `c()` results. The functions `st_rclear()`, `st_eclear()` and `st_sclear()` can be used to delete all entries in the first three of those lists. A useful summary of these interface routines is provided in [M-5] `st_global`.

Keep in mind that in Stata, local macros and global macros are strings, even if they contain a single number. Mata distinguishes between numeric scalars and string scalars. If you define a macro in Stata:

```
scalar year 2008
global theanswer 42
```

and want to access those objects in Mata, you must use

```
theyear = st_numscalar("year")
theanswer = strtoreal(st_global("theanswer"))
```

Unless the global is cast to real with `strtoreal()`, it cannot be used in a computation within Mata.

These same interface functions may be used to *set* or *replace* the contents of Stata objects. In the two-argument form,

```
st_local("macroname", newvalue)
```

will create a local macro of that name in the scope of the calling program, or replace the contents of an existing macro of that name, with contents of *newvalue*. In the code example above, we used `st_numscalar()` to create the Stata scalar `r(sum)` and define its value.

## 13.5.3 Access to Stata variables' attributes

Additional interface functions provide the ability to check Stata variables' types, rename Stata variables, and obtain (or set) variables' formats, variable labels, or value labels. You may add (or drop) observations (or variables) to or from the Stata dataset from within Mata, and create temporary variables or filenames.

The interface functions `st_varindex()` and `st_varname()` allow you to map Stata variables' names to and from variable *indices*, respectively. In some cases, you may need to make use of variable indices in Mata. This is a concept generally alien to Stata users: the *number* of the variable in the current dataset. We recognize that the order

of variables in the dataset matters when using a hyphenated *varlist* (see Section 3.2.1), but do not usually consider that “`rep78` is the 4<sup>th</sup> variable in `auto.dta`.” Unlike Stata matrices (see Section 3.10), whose rows and columns have both numbers and names, Mata matrices’ rows and columns are only numbered. In some cases, it is useful to write Mata code stepping through a number of variables by their *indices*, or positions within the Stata dataset.

## 13.6 Example: `st_` interface function usage

As a second example of ado-file programming using a Mata function, imagine that you would like to *center* a number of numeric variables on their means, creating a new set of transformed variables. Surprisingly, official Stata does not contain a command that performs this function. Ben Jann’s `center` command (`findit center`) plays this role and works in version 7 or higher, as it does not employ Mata. We can address this problem with an ado-file program:

```
. type centervars.ado
*! centervars 1.0.0 CFBaum 11aug2008
program centervars, rclass
    version 10.1
    syntax varlist(numeric) [if] [in], GENERate(string) [DOUBLE]
    marksample touse
    quietly count if `touse'
    if `r(N)' == 0 error 2000
    foreach v of local varlist {
        confirm new var `generate' `v'
    }
    foreach v of local varlist {
        qui generate `double' `generate' `v' = .
        local newvars "`newvars' `generate' `v'"
    }
    mata: centerv( "`varlist'", "`newvars'", "`touse'" )
end
```

The syntax of this wrapper program is quite simple. It is called with a numeric *varlist*, supports `if` and `in` qualifiers and has a mandatory `generate(string)` option specifying a *stub* for new variable names, along the same lines as `tabulate rep78, gen(repair)`.<sup>19</sup> The program ensures that a positive number of observations are available after the `marksample` command. We must do some work with these new variables. First of all, we must ensure that all of the names created by the option are valid Stata new variable names and not already in use. We do this with `confirm new var` ([P] `confirm`), which will return an error if that is not so. In a second loop over the *varlist*, we construct each name, create the variable of the specified type with `generate`, and build up the local macro `newvars` as the list of the new variable names.<sup>20</sup> We then call the Mata function with three arguments: the list of variables to be centered, the list of result variables and

19. See Section 7.2.2.

20. We use two loops to ensure that no new variables are created if any of the new variable names are faulty.

the `touse` indicator. The Mata function, stored in `centerv.mata`, reads as:

```
. type centerv.mata
version 10.1
mata:
mata set matastrict on
// centerv 1.0.0 CFBaum 11aug2008
void centerv( string scalar varlist, ///
             string scalar newvarlist,
             string scalar touse)
{
    real matrix X, Z
    st_view(X=., ., tokens(varlist), touse)
    st_view(Z=., ., tokens(newvarlist), touse)
    Z[., .] = X :- mean(X)
}
end
```

We use the `st_view()` interface function to define matrix `X` as containing the specified variables and observations, while matrix `Z` refers to the corresponding `newvars`. As the `varlist` and `newvarlist` arguments are lists of variable names, we must use the `tokens()` ([M-5] `tokens`) function to split it into its components for use in `st_view()`.<sup>21</sup>

Recalling that changes to `Z` will alter the underlying Stata variables' values, the following statement uses Mata's *colon operator* to subtract the row vector produced by `mean(X)` from each row of `X`.<sup>22</sup> This example of Mata's extended definition of conformability illustrates how the colon operator can be used to perform an operation that would be a bit tricky in terms of matrix algebra. We invoke the `centervars` command, using the stubs `c_` and `cf_` to prefix the new variables created:

```
. sysuse auto, clear
(1978 Automobile Data)
. centervars price mpg, gen(c_)
. centervars price mpg if foreign, gen(cf_) double
. summarize c*
```

Variable	Obs	Mean	Std. Dev.	Min	Max
c_price	74	-.0000154	2949.496	-2874.257	9740.743
c_mpg	74	-4.03e-08	5.785503	-9.297297	19.7027
cf_price	22	1.65e-13	2621.915	-2636.682	6605.318
cf_mpg	22	-6.46e-16	6.611187	-10.77273	16.22727

## 13.7 Example: matrix operations

In this section, we outline the construction of a Stata command that uses Mata to achieve a useful task with time-series data: constructing averages of  $p$  consecutive values of a

21. Mata's `tokens()` function performs the same function as Stata's `tokenize` command, discussed above.

22. Mata's `mean()` function generates column means from a matrix.

variable as consecutive observations. For instance, you may want to combine quarterly national income data with the average inflation rate during the quarter, with inflation reported monthly. Likewise, you may want to convert monthly data to annual format, quarterly data to annual format, or business-daily data to weekly data.<sup>23</sup> In some cases (for instance, for graphical or tabular presentation) we may want to retain the original (high-frequency) data and add the lower-frequency series to the dataset.

To address these tasks, we might consider using various `egen` functions. For instance, assuming that we have monthly data with variable `t` as the month counter,

```
. generate qtr = qofd(dofm(t))
. bysort qtr: egen avgx = mean(x)
```

would create the quarterly average of the monthly series `x`. However, that value will be repeated for each month of the quarter. We could easily remove all but one value per quarter with

```
. replace avgx = . if mod(t, 3) != 0
```

but that would intersperse the lower-frequency data values with missing values. Such a listing would be quite awkward for tabular or graphical presentation.

As a more straightforward solution, we design a Stata command, `avgper`, which takes a single variable and optional `if exp` or `in range` conditions along with a mandatory option `per()`, the number of periods to be averaged into a lower-frequency series. We could handle multiple variables or alternative transformations (for example, sums over the periods rather than averages) with an expanded version of this routine.

The Stata ado-file defines the program and then validates the `per()` argument. We require that the number of high-frequency observations is a multiple of `per`.

```
. type avgper.ado
capture program drop avgper
*! avgper 1.0.0 CFBaum 08oct2007
program avgper, rclass
    version 10.1
    syntax varlist(max=1 numeric) [in], per(integer)
    marksample touse
    quietly count if `touse'
    if `r(N)' == 0 {
        error 2000
    }
    * validate per versus selected sample
    if `per' <= 0 | `per' >= `r(N)' {
        display as error "per must be > 0 and < N of observations."
        error 198
    }
    if mod(`r(N)', `per' != 0) {
        display as error "N of observations must be a multiple of per."
    }
end
```

---

23. For the Stata date frequencies of monthly, quarterly or half-yearly, this problem has already been solved by the author's `tscollap` routine (Baum (2000)). However, that routine (like `collapse ([D] collapse)`) destroys the original higher-frequency data, requiring an additional `merge` step to emulate the Mata routine developed below.

```

        error 198
    }
    * validate the new varname
    local newvar = "'varlist'A'per'"
    quietly generate `newvar' = .
    * pass the varname and newvarname to Mata
    mata: avgper("'varlist'", "'newvar'", 'per', "'touse'")
end

```

We attempt to create a new variable named  $vnameAn$ , where  $vname$  is the specified variable and  $n$  is the value of `per()`. If that variable name is already in use, the routine exits with error. The variable is created with missing values as it is only a placeholder. With successful validation, we pass the arguments to the Mata function `avgper`.

After these checks have been passed, we turn to the heart of the computation. The solution to the problem is a type of reshape. The  $N$ -element column vector into which `vname` has been copied may be reshaped into a matrix `v3` with  $q$  rows and `per` columns.  $q = N / \text{per}$  is the number of averaged observations that will result from the computation. If we postmultiply the transpose of matrix `v3` by a `per`-element column vector of ones,  $\iota$ , we would compute the sum over the `per` values for each new observation. The average would be  $1/\text{per}$  times that vector. Thus, we define the column vector's elements as `divisor = 1/per`. The resulting column vector, `v3`, is our averaged series of length  $q$ . To illustrate, let  $x$  be the  $N$  elements of the Stata variable. Each `per` consecutive elements become a column of the reshaped matrix:

$$\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_{per} \\ \\ x_{per+1} \\ x_{per+2} \\ \vdots \\ x_{2per} \\ \\ x_{2per+1} \\ x_{2per+2} \\ \vdots \\ \vdots \\ x_N \end{pmatrix} \Rightarrow \begin{pmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,q} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,q} \\ \vdots & & \ddots & \vdots \\ x_{per,1} & x_{per,2} & \cdots & x_{per,q} \end{pmatrix}$$

We then transpose the reshaped matrix and postmultiply by a `per`-element column

vector to construct the per-period average:

$$\begin{pmatrix} x_{1,1} & x_{2,1} & \cdots & x_{per,1} \\ x_{1,2} & x_{2,2} & \cdots & x_{per,2} \\ \vdots & & \ddots & \vdots \\ x_{1,q} & x_{2,q} & \cdots & x_{per,q} \end{pmatrix} \begin{pmatrix} \frac{1}{per} \\ \frac{1}{per} \\ \vdots \\ \frac{1}{per} \end{pmatrix} = \begin{pmatrix} x_1^* \\ x_2^* \\ \vdots \\ x_q^* \end{pmatrix}$$

The column vector  $x^*$ , labelled as `v3` in the Mata function, contains the averages of each `per` elements of the original Stata variable. The Mata function to achieve this task is quite succinct.

```
. type avgper.mata
version 10.1
mata:
    void avgper(string scalar vname,
               string scalar newvname,
               real scalar per,
               string scalar touse)
    {
        real matrix v1, v2, v3
        st_view(v1=., ., vname, touse)
        st_view(v2=., ., newvname)
        v3 = colshape(v1', per) * J(per, 1, 1/per)
        v2[ (1::rows(v3)), ] = v3
    }
end
```

We make use of *view matrices* to access the contents of `vname` (the existing variable name specified in the `avgper` command) and to access `newvarname` in Mata, which is our newly-created ‘newvar’ in the Stata code. The `colshape()` function creates a matrix which is  $q \times \text{per}$ , where  $q$  is the number of low-frequency observations to be created. Postmultiplying that matrix by a `per`-element column vector of  $1/\text{per}$  produces the desired result of a  $q$ -element column vector. That object, `v3` in Mata, is then written to the first  $q$  rows of view matrix `v2`, which corresponds to the Stata variable ‘newvar’.

To test the `avgper` command, we use the *Time Series Manual* dataset `urates` which contains monthly unemployment rates for a number of U.S. states. We apply `avgper` to one variable, `tenn` (the Tennessee unemployment rate), using both `per(3)` and `per(12)` to calculate quarterly and annual averages, respectively.

```
. use urates, clear
. tsset
      time variable: t, 1978m1 to 2003m12
             delta: 1 month
. avgper tenn, per(3) // calculate quarterly averages
. avgper tenn, per(12) // calculate annual averages
. summarize tenn*
```

Variable	Obs	Mean	Std. Dev.	Min	Max
tenn	312	6.339744	2.075308	3.7	12.8
tennA3	104	6.339744	2.078555	3.766667	12.56667

```
tennA12 |      26   6.339744   2.078075   3.908333   11.83333
```

The `summarize` command shows that the original series and two new series have identical means, which they must. To display how the new variables appear in the Stata data matrix, we construct two date variables with the `tsmktime` command (Baum and Wiggins (2000)) and list the first twelve observations of Tennessee's data. As you can verify, the routine is computing the correct quarterly and annual averages.

```
. tsmktime quarter, start(1978q1) // create quarterly calendar var
   time variable: quarter, 1978q1 to 2055q4
   delta: 1 quarter
. tsmktime year, start(1978) // create annual calendar var
   time variable: year, 1978 to 2289
   delta: 1 year
. list t tenn quarter tennA3 year tennA12 in 1/12, sep(3)
```

	t	tenn	quarter	tennA3	year	tennA12
1.	1978m1	5.9	1978q1	5.966667	1978	5.8
2.	1978m2	5.9	1978q2	5.766667	1979	5.791667
3.	1978m3	6.1	1978q3	5.733333	1980	7.3
4.	1978m4	5.9	1978q4	5.733333	1981	9.083333
5.	1978m5	5.8	1979q1	5.733333	1982	11.83333
6.	1978m6	5.6	1979q2	5.7	1983	11.45833
7.	1978m7	5.7	1979q3	5.733333	1984	8.55
8.	1978m8	5.7	1979q4	6	1985	7.983334
9.	1978m9	5.8	1980q1	6.166667	1986	8.041667
10.	1978m10	5.9	1980q2	7.066667	1987	6.591667
11.	1978m11	5.7	1980q3	8	1988	5.775
12.	1978m12	5.6	1980q4	7.966667	1989	5.108333

How might we perform this transformation for a whole set of variables? Rather than generalizing `avgper` to handle multiple variables, we just use a `foreach` loop over the variables:

```
. foreach v of varlist tenn-arkansas {
2.     avgper 'v', per(3)
3. }
. summarize tenn-arkansasA3, sep(6)
```

Variable	Obs	Mean	Std. Dev.	Min	Max
tenn	312	6.339744	2.075308	3.7	12.8
missouri	312	5.78109	1.591313	2.9	10.6
kentucky	312	6.867949	2.029192	3.8	12.6
indiana	312	6.106731	2.413917	2.8	12.7
illinois	312	6.865064	1.965563	4.1	12.9
arkansas	312	6.833974	1.676967	4.2	10.5
tennA3	104	6.339744	2.078555	3.766667	12.56667

missouriA3	104	5.78109	1.590077	3	10.46667
kentuckyA3	104	6.867949	2.029395	3.9	12.36667
indianaA3	104	6.106731	2.416999	2.9	12.4
illinoisA3	104	6.865064	1.964652	4.2	12.76667
arkansasA3	104	6.833974	1.679908	4.266667	10.46667

By using Mata and a simple matrix expression, we have considerably simplified the computation of the lower-frequency series, and may apply the routine to any combination of data frequencies (for example, business-daily data to weekly) without concern for Stata's support of a particular timeseries frequency.

### 13.7.1 Extending the command

It is straightforward to generalize the `avgper` command to handle several algebraic operations. Rather than averaging the series over `per` observations, we might want to sum the series over those observations. Alternatively, we might want to construct a new low-frequency series composed of the first (or last) observations within each interval. This will require an option in the ado-file, which we now rename `agggreg.ado`, to permit the user to specify the desired operation. The Stata ado-file code is now:

```
. type aggreg.ado
*! aggreg 1.0.0 CFBaum 11aug2008
program aggreg, rclass
    version 10.1
    syntax varlist(max=1 numeric) [if] [in], per(integer) [func(string)]
    marksample touse
    quietly count if `touse'
    if `r(N)' == 0 {
        error 2000
    }
    * validate per versus selected sample
    if `per' <= 0 | `per' >= `r(N)' {
        display as error "per must be > 0 and < N of observations."
        error 198
    }
    if mod(`r(N)',`per' != 0) {
        display as error "N of observations must be a multiple of per."
        error 198
    }
    * validate func option; default is average (code A)
    local ops A S F L
    local opnames average sum first last
    if "`func'" == "" {
        local op "A"
    }
    else {
        local nop : list posof "`func'" in opnames
        if !`nop' {
            display as err "Error: func must be chosen from `opnames'"
            error 198
        }
        local op : word `nop' of `ops'
    }
}
```

```

* validate the new varname
    local newvar = "'varlist' 'op' 'per'"
    quietly generate `newvar' = .
* pass the varname and newvarname to Mata
    mata: aggreg("'varlist'", "'newvar'", `per', "'op'", "'touse'")
    end

```

We add the `func()` option, which takes the default of `average`. We add code to validate the other choices: `sum`, `first` and `last`. We use the macro list function `list posof` to determine whether the value of `func` is in the list of supported operations; if not, an error is generated. The chosen function, `op`, is designated by a letter from local `ops` and passed to the Mata routine.

```

. type aggreg.mata
version 10.1
mata: mata set matastrict on
mata:
// aggreg 1.0.0 CFBaum 11aug2008
void aggreg(string scalar vname,
            string scalar newvname,
            real scalar per,
            string scalar op,
            string scalar touse)
{
    real colvector mult, v1, v2
    real matrix v3
    if (op=="A") {
        mult = J(per, 1, 1/per)
    }
    else if (op=="S") {
        mult = J(per, 1, 1)
    }
    else if (op=="F") {
        mult = J(per, 1, 0)
        mult[1] = 1
    }
    else if (op=="L") {
        mult = J(per, 1, 0)
        mult[per] = 1
    }
    st_view(v1=., ., vname, touse)
    st_view(v2=., ., newvname)
    v3 = colshape(v1', per) * mult
    v2[(1::rows(v3)), ] = v3
}
end

```

In the Mata routine, we need only modify the Mata `avgper()` code by altering the `per`-element column vector that multiplies the reshaped data. As shown above, the average is computed by setting elements of that vector to `1/per`. We create a `colvector` named `mult`. For the average operation, we define it as before. For the sum, it is merely defined as  $\iota$ , a vector of ones. For the first (last) operation, it is defined as a null vector with 1 in the first (last) position. With that change, the Mata function `aggreg()` can perform

any of these four functions on the timeseries.

We may readily verify that this extended program generates the proper series for each of its four operations:

```
. use urates
. aggreg tenn, per(3) // calculate quarterly averages
. aggreg tenn, per(3) func(sum) // calculate quarterly sum
. aggreg tenn, per(3) func(first) // extract first month's value
. aggreg tenn, per(3) func(last) // extract first month's value
. tsmktime quarter, start(1978q1) // create quarterly calendar var
    time variable: quarter, 1978q1 to 2055q4
    delta: 1 quarter
. list t tenn quarter tennA3 tennS3 tennF3 tennL3 in 1/12, sep(3)
```

	t	tenn	quarter	tennA3	tennS3	tennF3	tennL3
1.	1978m1	5.9	1978q1	5.966667	17.9	5.9	6.1
2.	1978m2	5.9	1978q2	5.766667	17.3	5.9	5.6
3.	1978m3	6.1	1978q3	5.733333	17.2	5.7	5.8
4.	1978m4	5.9	1978q4	5.733333	17.2	5.9	5.6
5.	1978m5	5.8	1979q1	5.733333	17.2	5.8	5.7
6.	1978m6	5.6	1979q2	5.7	17.1	5.7	5.6
7.	1978m7	5.7	1979q3	5.733333	17.2	5.7	5.8
8.	1978m8	5.7	1979q4	6	18	5.9	6.1
9.	1978m9	5.8	1980q1	6.166667	18.5	6	6.3
10.	1978m10	5.9	1980q2	7.066667	21.2	6.7	7.5
11.	1978m11	5.7	1980q3	8	24	8	8
12.	1978m12	5.6	1980q4	7.966667	23.9	8	8

## 13.8 Creating arrays of temporary objects with pointers

In Stata's ado-file language, it is common to create a set of temporary objects: temporary variables, local macros, or matrices. Sometimes it is necessary to create a different number of temporary items each time we run the program. That is a simple task in Stata's ado-file language, as we have seen in several examples. In Mata, however, the solution is not immediately clear: we need to declare variables, but the number of variables is not fixed. In this section, we consider that problem, using an example from the econometric literature.

Why might we need such a facility? Consider a Stata program that accepts a positive integer argument of `lags()`, which could take on any number of values, and then computes a matrix from several Stata variables *for each lag*. In some applications, such as the computation of a heteroskedastic- and autocorrelation-consistent (HAC)

covariance matrix,<sup>24</sup> two temporary objects will suffice, as the logic of that computation accumulates the matrices computed for each lag. We create one matrix in which to compute each term in the series and a second to hold the accumulation. In other contexts, however, we might need to use the values contained in each of those matrices in some formula. In ado-file code, we might write:

```
forvalues i = 1/'lags' {
    tempname phi'i'
    matrix 'phi'i'' = exp
}
```

which would define and compute the contents of a sequence of temporary matrices `phi1`, `phi2`, ..., `phi'lags'`. What would we need to do to perform this same task in a Mata context?

The solution involves the use of the sixth element type in Mata: the *pointer*. A pointer, as defined in [M-2] **pointer**, is an object that contains the *address* of another object. Pointers are commonly used to put a collection of items under one name and to pass functions to functions. A pointer to matrix `X` contains the address, or location in the computer's memory, of `X`. We do not really care to know what that number might be. It suffices to know that if we *dereference* the pointer, we are referring to the contents of the underlying object to which it points.<sup>25</sup> The dereferencing operator in Mata is `*`, so that if `p` is a pointer variable, `*p` refers to the underlying object.

How do we create a pointer variable? With the operator `&`, which instructs Mata to store the *address* (rather than the *contents*) of its argument in a pointer variable:

```
: X = (1, 2 \ 3, 4)
: p = &X
```

creates a pointer variable `p` which contains the address of matrix `X`. If we then refer to the variable:

```
: Z = *p
```

matrix `Z` will now be set equal to matrix `X`. Likewise,

```
: r = (*p)[ 2, .]
```

will cause `r` to be created as a row vector equal to the second row of `X`. Note that we use parentheses around `*p` to clarify that we refer to the second row of the object defined by dereferencing the pointer. Also note that the contents of `p` itself are not very useful:<sup>26</sup>

```
: p
0x2823b10c
```

Why then are pointers an important programming tool? If pointer variables could

24. See `newey` ([TS] `newey`).

25. Note the similarity to Stata's macros: regardless of the name of the macro, when we dereference it, we access its contents.

26. You are unlikely to get this same value if you use the same sequence of commands, as it depends on the state of Stata's memory at a particular time.

only be real scalars, they would not be very useful. But like other Mata objects, pointer variables may be arrayed in vectors or matrices. That now gives us the tools necessary to deal with the problem laid out above. We would like to set up a set of matrices, `phi1`, `...`, `phi'lags'`, within Mata where the Mata function will be called with the argument of `lags`. Within Mata, we now know how many matrices are to be created, and for ease of computation we want them to be named sequentially as `phi1`, `phi2`, `...`. We need to set up an *array of pointers* that will contain the addresses of each of these matrices. As with other Mata objects, we may fully declare the type of object we create, and it is recommended that you do so:<sup>27</sup>

```
: pointer(real matrix) rowvector ap
: ap = J(1, nlag, NULL)
```

We declare a vector of pointers, named `ap`, to real matrices. We then declare the vector as having `nlag` elements, each `NULL`. The keyword `NULL` is the equivalent of a missing value for a pointer variable. It indicates that it currently points to nothing. Having set up this array, we may now fill in each of its elements:

```
: for(i = 1; i <= nlag; i++) {
:     ap[i] = &(matrix expression)
: }
```

Within the loop, we compute some matrix expression, enclose it in parentheses, and store its *address* in the  $i^{\text{th}}$  element of the `ap` array. This matrix is *anonymous* in that it is not given a name; we merely record its address in the appropriate pointer variable. When we want to make use of that matrix, we refer to it as `*ap[i]`.

With the same technique, we could define a two-dimensional array of pointers such as

```
: pointer(real vector) matrix p2
```

which might be useful for associating a vector of coordinates with each point on a two-dimensional grid. Any other element type may be specified as the target of pointers, including pointers themselves:

```
: mata:
: void point2point(real scalar bar1, real scalar bar2)
: {
:     pointer(pointer(real matrix) rowvector) rowvector pp
:     pp = J(1, bar2, NULL)
```

This function declares an array of pointers, `pp`, of length `bar2`. Each element of `pp` points to a rowvector of pointers to real matrices. We could create those real matrices as anonymous, `bar1` in number for each element of `pp`, with the code:

```
: for(j = 1; j <= bar2; j++) {
:     pp[j] = &(J(1, bar1, NULL))
:     for(i = 1; i <= bar1; i++) {
:         (*pp[j])[i] = &(J(i, j, i*j + j^2) )
:     }
```

---

27. See [M-2] **Pointers**.

```
: }
```

Within the loop over  $j$ , we define the  $j^{\text{th}}$  element of the `pp` pointer array as the address of an anonymous rowvector of length `bar1`. Within the loop over  $i$ , we define the contents of each element of that anonymous rowvector as the address of a matrix. The matrix takes on different dimensions based on the values of  $i$  and  $j$ , illustrating that an array of pointers to objects need not refer to objects of the same dimension (only the same type, in this case, given our declaration). At this point, we have filled in the lowest-level objects, the real matrices themselves, and have established a hierarchy of pointers that address each of those objects.

We may now examine the contents of these arrays with the statements

```
: for(k = 1; k <= bar2; k++) {
:     for(l = 1; l <= bar1; l++) {
:         printf("j=%5.2f, i=%5.2f\n", k, l)
:         *(*pp[k])[l]
:     }
: }
: }
: end
```

As there are two levels of pointers in the data structure, we must dereference twice with the `*` operator: once to recover the value held in `pp[k]`, giving us the  $k^{\text{th}}$  vector of anonymous objects, and a second time (working outward) to retrieve the  $\ell^{\text{th}}$  element of that vector, which is the matrix stored at that location. If we execute the function with `bar1 = 2`, `bar2 = 3`, we are specifying that there should be three elements in the `pp` array, each of which points to a two-element vector. Each of those elements points to a real matrix:

```
. type gbpval.mata
version 10.1
mata:
real scalar function gbpval(real scalar dollar)
{
    real scalar usdpergbp
    usdpergbp = 2.08
    return( dollar / usdpergbp )
}
end
```

Pointer variables also may be used to refer to functions, permitting a routine to specify that alternative functions may be invoked depending on user input. We present additional examples of the usefulness of pointer variables in the following Cookbook chapter.

## 13.9 Structures

An additional useful tool available to the Mata programmer is the *structure*. For an extended discussion of Mata structures, see Gould (2007b). Structures may not be used

interactively. Structures allow you to organize several scalars, vectors and matrices (potentially of different types) and pass them to other routines as a single structure. For instance, we might consider a linear regression routine that would return a structure consisting of the coefficient vector  $\mathbf{e}(\mathbf{b})$ , the covariance matrix  $\mathbf{e}(\mathbf{V})$ , and several scalars such as `R-squared`, `N`, `k` and `Root MSE`. Rather than referring to each of those quantities individually, we could group them into a structure and pass the structure. This would make it easy to write a number of computational routines—each of which would produce a structure—and a single output routine that would display the contents of that structure, with minimal overhead.

As an example, consider a routine that generates graphical elements in the form of vectors in 2-space. Each vector has an origin at a (*x-coord*, *y-coord*) pair, a *length* and an *angle*, where 0 and 360 refer to east, 90 to north, and so on. Let us also imagine that each vector has a *color* associated with it when it is to be graphed. Mata structures are defined *outside* of functions, and must be defined *before* any reference appears to them:

```
. type myvecstr.mata
mata: mata clear
mata: mata set matastrict on
version 10.1
mata:
struct mypoint {
    real vector coords
}
struct myvecstr {
    struct mypoint scalar pt
    real scalar length, angle
    string scalar color
}
end
```

The `myvecstr` structure contains an instance of the `mypoint` structure, so we must define the latter first. Structure `mypoint` merely contains a real vector of undefined length. Structure `myvecstr` includes an instance of `mypoint` named `pt` as well as two real scalars (`length`, `angle`) and a string scalar `color`.

We may now define a function that makes use of the structure. It will take five arguments, and reference an instance of the `myvecstr` structure named `v`. As the (`xcoord`, `ycoord`) arguments are to be stored as a vector in `mypoint`, we place them in `v.pt.coords`. Note that the `v` and `pt` references refer to instances of the structure, while `coords` refers to the definition of `mypoint`'s contents. We also store the function's `len`, `ang`, `color` arguments in the `v` structure. We may then pass the entire `v` structure to a subroutine function `myvecsub`.

```
. type makevec.mata
version 10.1
mata:
function makevec(real scalar xcoord,
                real scalar ycoord,
                real scalar len,
```

```

        real scalar ang,
        string scalar color)
    {
        struct myvecstr scalar v
        v.pt.coords = (xcoord, ycoord)
        v.length = len
        v.angle = ang
        v.color = color
        myvecsub(v)
    }
end

```

The `myvecsub` function takes the structure as an argument named `e`, as it can access the elements of the structure. Likewise, a function defined as type `struct` can return a structure to the calling function. `myvecsub` extracts the x- and y-coordinates from the elements of the `e.pt.coords` vector and uses them to compute the `dist_from_origin` scalar.

```

. type myvecsub.mata
version 10.1
mata:
function myvecsub(struct myvecstr scalar e)
{
    real scalar dist_from_origin, xx, yy, ll, ang
    string scalar clr
    xx = e.pt.coords[1]
    yy = e.pt.coords[2]
    dist_from_origin = sqrt(xx^2 + yy^2)
    printf("\n The %s vector begins %7.2f units from the origin at (%f, %f)
> ", ///
        e.color, dist_from_origin, xx, yy)
    printf("\n It is %7.2f units long, at an angle of %5.2f degrees\n", e.l
> engh, e.angle)
}
end

```

We can now execute the function:

```

. mata:
----- mata (type end to exit) -----
: makevec(42, 30, 12, 45, "red")
The red vector begins  51.61 units from the origin at (42, 30)
It is  12.00 units long, at an angle of 45.00 degrees
: end
-----

```

Some additional things to note about structures: first, structures are compiled into functions of the same name, so the examples above have created functions `mypoint()` and `myvecstr()`. If you are saving your Mata functions in compiled form, these functions should be saved as well. Also, although an instance of a structure is named (as is `v` in `makevec()` above), you cannot examine the structure's contents using its name

(as you can with Mata scalars, vectors and matrices). A reference to the structure's name will only print its address in memory. If you want to examine the contents of a structure, use the `liststruct()` function.

Structures have many uses in Mata. You can program without them, but they will often make it much easier to write complicated code. For instance, you can test two structures for equality, which will be satisfied if and only if their members are equal. You can create vectors or matrices of structures, and use pointers to structures. For full details of the capabilities of Mata structures, see [M-2] **Structures** and the excellent discussion in Gould (2007b).

## 13.10 Additional Mata features

### 13.10.1 Macros in Mata functions

Stata's local macros (see Section 3.6) can be used to advantage in Mata functions, but with a very important caveat. Macro *evaluation* takes place in Mata as it does in Stata commands with one significant difference. When a Mata function is first defined, it is *compiled* into bytecode. In that compilation process, the values of any local (or global) macros are substituted for their names: the macros are *evaluated*. However, once the function is compiled, those values are *hard-coded* into the Mata function, just as any other definition would be. For example,

```
. type gbpval.mata
version 10.1
mata:
real scalar function gbpval(real scalar dollar)
{
    real scalar usdpergbp
    usdpergbp = 2.08
    return( dollar / usdpergbp )
}
end
```

would define a function which converts US dollars to British pounds sterling at a fixed exchange rate of US\$2.08 per pound sterling. Rather than placing that constant in the Mata function, we could write

```
. type gbpval2.mata
local usdpergbp 2.08
mata:
real scalar function gbpval2(real scalar dollar)
{
    return( dollar / 'usdpergbp' )
}
end
```

We can invoke the function with

```
. mata: gbpval2(100)
      48.07692308
```

What happens if we change the local macro?

```
. local usdpergbp 2.06
. mata: gbpval2(100)
      48.07692308
```

Why does Mata ignore the new value of the macro? Unlike Stata commands, which would use the current value of the local macro, the macro's value has been compiled into the `gbpval2` function, and can only be changed by recompiling that function. This is an important distinction, and explains why you cannot use local macros as counters within Mata functions as you can in ado-files or do-files.

Local macros in Mata functions serve to define objects, either numeric values or string values, that should be constants within the function. One useful task that they can serve is the replacement of a lengthy string—such as the URL of a filename on the internet—with a symbol. The value of that symbol is the URL. If the filename changes, you need only update the local macro's definition rather than change it in several places in the Mata function. Local macros may also be used to good advantage to define abbreviations for commonly used words or phrases. For instance, we may use the abbreviation `RS` to avoid repeatedly typing `real scalar`:

```
. type gbpval3.mata
version 10.1
local RS real scalar
mata:
'RS' function gbpval3('RS' dollar)
{
    'RS' usdpergbp
    usdpergbp = 2.08
    return( dollar / usdpergbp )
}
end
```

In summary, local macros can be used in Mata functions, but you must take care to remember that they are only expanded when the function is first compiled by Mata.

## 13.10.2 Compiling Mata functions

We have illustrated Mata functions in conjunction with ado-files by placing the Mata code *in-line*, that is, within the ado-file. If placed in-line, the Mata code will be compiled “just-in-time” the first time that the ado-file is called in your Stata session. Subsequent calls to the ado-file will not require compilation of the Mata function (or functions). An exchange on Statalist<sup>28</sup> suggests that if the Mata functions amount to fewer than 2,000 lines of code, incorporating them in-line will be quite acceptable in terms of performance.

28. <http://stata.com/statalist/archive/2005-08/msg00358.html>

There is one disadvantage of the in-line strategy, though. What if you have multiple ado-files that all reference the same Mata function, but may be called independently? Then you should consider saving a *compiled* version of the function which can then be accessed by all ado-files. Copying the Mata code into each ado-file works as a short-term solution, but will create persistent problems if you update the Mata functions and fail to remember to update each ado-file. As a better solution, you should place the Mata functions into a separate `.mata` file and create a `.mo` object file. Say that you write Mata function `crunch`, and store the code defining that function in `crunch.mata`. You may then issue the Mata command

```
: mata mosave crunch(), [ , dir(path) replace ]
```

This will create the object file `crunch.mo`, by default in the current working directory. That has its disadvantages (as described in Section 2.2.2). You may want to specify the option `dir(PERSONAL)` or `dir(PLUS)` on the `mata mosave` command, which will write the `.mo` file to those directories, respectively. The routine will then be found by a calling ado-file regardless of your current working directory. To implement creation of the object file for the function, you could include the `mata mosave` line in the `.mata` file. For example, `crunch.mata` might contain

```
version 10.1
mata:
real scalar crunch(...)
{
...
}
end
mata: mata mosave crunch(), dir(PERSONAL) replace
```

You could then define the function and create the object file with the Stata command

```
. do crunch.mata
```

which would create `crunch.mo` in your `PERSONAL` directory.

### 13.10.3 Building and maintaining an object library

Creating a separate `.mo` file for each Mata function in your `PERSONAL` directory will make those functions available to any ado-file. But if you have developed a large number of Mata functions, or want to provide those functions to other users in a convenient way, you should know about *Mata function libraries*. A function library, or `.mlib`, can hold up to 500 compiled functions. You create a function library with the Mata command

```
: mata mlib create libname [ , dir(path) replace ]
```

By convention, function libraries' names should start with the letter `l`. As with `mata mosave`, it is important to locate the library on the `adopath`, which you may do with the `dir()` option.

To include a Mata function in the library, you must first compile it by loading it into Mata's memory. Following the strategy above, you could rewrite the last line of

`crunch.mata` to be

```
mata: mata mlib add libname fcnname()
```

where *libname* refers to your existing library and *fcnname* is the Mata function name or names. Using wildcards, you may add a number of functions with a single command (for example, by referring to `cr*`), you specify all functions with names starting with `cr`. The trailing parens are required. Then, the Stata command `do crunch.mata` will compile the function and store it in the library.

One limitation exists, though. With `mata mlib add` you may add new functions to a library. However, you cannot update functions stored in the library. If you must remove a function, or replace it with a newer version, you must delete and recreate the library and load all of its previous contents. Accordingly, it is a very good idea to avoid altering a library with interactive commands, but instead write do-files that create and load all functions in the library as suggested in the last section of [M-2] **mata mlib**.

When you start Stata and first enter the Mata environment, Mata searches the standard `adopath` for all available Mata libraries. If you make changes to a library during a Stata session or download a package that contains a Mata library, those libraries' contents will not be immediately available. You must then refresh Mata's list of available libraries with the command

```
: mata mlib index
```

which will trigger the automatic search for Mata libraries on your machine.<sup>29</sup>

You should also note that Mata compiled functions (`.mo` files) and object libraries (`.mlib` files) are not backward-compatible. A function compiled in Stata 10, or a library constructed under Stata 10, cannot be used by Stata 9.x even though Mata was available in that version of Stata. To generate an object library usable in both Stata 9 and Stata 10 (and later versions), you must compile the functions and produce the library in Stata 9. As a number of functions and capabilities were added to Mata in Stata 10, you may not be able to execute the same Mata code in Stata 9.x.

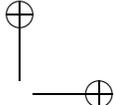
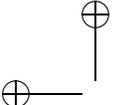
### 13.10.4 A useful collection of Mata routines

Presently, the largest and most useful collection of user-written Mata routines is Ben Jann's `moremata` package, available from the SSC Archive. The package contains a function library, `lmoremata`, as well as full documentation of all included routines (in the same style as Mata's on-line function descriptions). Very importantly, the package also contains the full source code for each Mata routine, accessible with `viewsource` ([P] `viewsource`). You should note that Mata authors need not distribute the Mata code for their routines. Unlike ado-file code, which is accessible by its very nature, Mata functions may be distributed in object code (or function library) form.

Routines in `moremata` currently include kernel functions; statistical functions for

29. Quitting and restarting Stata will have the same effect, but is not necessary.

quantiles, ranks, frequencies, means, variances and correlations; functions for sampling; density and distribution functions; root finders; matrix utility and manipulation functions; string functions; and input-output functions. Many of these functions provide functionality as yet missing from official Mata, and ease the task of various programming chores. Once you have downloaded the package from the SSC Archive, be sure to issue the command `mata mlib index` to ensure that its components may immediately be located by Mata.



## 14 Cookbook: Mata function programming

This cookbook chapter presents a number of recipes for Stata do-file programmers using the programming features described in the previous chapter. Each recipe poses a problem and a worked solution. Although you may not encounter this precise problem, you may be able to recognize its similarities to a task that you would like to automate in an ado-file and Mata function.

### 14.1 Reversing the rows or columns of a Stata matrix

**The problem:** Mata's built-in function list contains many useful matrix operations, but I recently came upon one I needed: the ability to *flip* a matrix along its row or column dimensions.<sup>1</sup> Either of these operations can readily be done as a Mata statement, but I'd rather not remember the syntax—nor remember what it is meant to do when I reread the code. So I wrote a simple Mata function to perform this task and wrapped it in an ado-file.<sup>2</sup>

To define the Stata command, the program `flipmat` takes the name of an existing Stata matrix. Optionally, you may specify `horiz` to reverse the order of the matrix's columns. By default, the command reverses the order of the matrix's rows. We use the `name` option of the `syntax` (`[P] syntax`) command, an abbreviation for `namelist`. The `name` option specifies that a single name must be provided. The `confirm` (`[P] confirm`) command comes in handy to ensure that the name provided is indeed that of a matrix. The command operates on the matrix in place, updating its contents.

```
. type flipmat.ado
capture program drop flipmat
*! flipmat 1.0.0 CFBaum 08oct2007
program flipmat
    version 10.1
    syntax name, [HORIZ]
    confirm matrix `namelist'
    mata: mf_flipmat("`namelist'", "`horiz'")
end
. set more off
```

---

1. This recipe is adapted from Stata Tip 37 (Baum (2006b)).  
2. My thanks to Mata's chief architect, Bill Gould, for improvements he suggested which make the code more general.

We now consider the Mata code. The basic logic is a single line: we replace matrix `X` with its own contents, with rows (columns) in reverse order depending on `horiz`. One complication: unlike Mata matrices, Stata matrices have row and column *stripes* which may contain two components labelling each row or column. For estimation results, for instance, the stripe element may include both an equation name and a variable name.<sup>3</sup> We do not want to wipe out these contents in the process, so we use `st_matrixrowstripe()` and `st_matrixcolstripe()` functions to preserve the contents of the stripes, and reorder them in line with the functioning of `flipmat`.

```
. type mf_flipmat.mata
version 10.1
mata:
void function mf_flipmat(string scalar name, string scalar horiz)
{
    real matrix X, rs, cs
    X = st_matrix(name)
    rs = st_matrixrowstripe(name)
    cs = st_matrixcolstripe(name)
    if (horiz == "") {
        X = (rows(X)>1 ? X[rows(X)..1, .] : X)
        rs = (rows(rs)>1 ? rs[rows(rs)..1, .] : rs)
    }
    else {
        X = (cols(X)>1 ? X[:, cols(X)..1] : X)
        cs = (rows(cs)>1 ? cs[rows(cs)..1, .] : cs)
    }
    st_matrix(name, X)
    st_matrixcolstripe(name, cs)
    st_matrixrowstripe(name, rs)
}
end
mata: mata mosave mf_flipmat(), dir(PERSONAL) replace
```

We follow the advice of Section 13.10.2 and store the compiled Mata function as a `.mo` file in our `PERSONAL` directory.

As an example, imagine that you have a set of course grades for homework (`hw`), midterm (`mt`), final exam (`final` and total points `total` stored in a matrix `grades`, with the rows identifying the students' ID numbers.

```
. mat list grades, noheader
      hw   mt  final  total
121   6    8    21    35
958   8    9    23    40
196   7   17    24    48
190   8   13    38    59
921  17   24    66   107
 33  17   31    76   124
806  19   29    80   128
```

---

3. See [M-4] `mf_st_matrix`.

514	21	51	71	143
526	22	40	96	158
340	26	59	105	190
101	30	49	119	198
661	30	62	124	216
856	32	66	128	226
581	34	57	135	226
276	34	64	133	231
287	33	64	137	234
703	35	63	136	234
210	37	78	134	249
81	37	79	142	258
366	40	82	160	282
705	42	85	167	294
66	43	85	173	301
424	45	87	177	309
964	47	86	190	323
345	54	106	223	383

The matrix is currently stored in ascending order of total points scored. If you'd like to reverse that,

```
. flipmat grades
. mat list grades, noheader
```

	hw	mt	final	total
345	54	106	223	383
964	47	86	190	323
424	45	87	177	309
66	43	85	173	301
705	42	85	167	294
366	40	82	160	282
81	37	79	142	258
210	37	78	134	249
703	35	63	136	234
287	33	64	137	234
276	34	64	133	231
581	34	57	135	226
856	32	66	128	226
661	30	62	124	216
101	30	49	119	198
340	26	59	105	190
526	22	40	96	158
514	21	51	71	143
806	19	29	80	128
33	17	31	76	124
921	17	24	66	107
190	8	13	38	59
196	7	17	24	48
958	8	9	23	40
121	6	8	21	35

and to display with the total points as the first column,

```
. flipmat grades, horiz
. mat list grades, noheader
```

	total	final	mt	hw
345	383	223	106	54
964	323	190	86	47
424	309	177	87	45
66	301	173	85	43
705	294	167	85	42
366	282	160	82	40
81	258	142	79	37
210	249	134	78	37
703	234	136	63	35
287	234	137	64	33
276	231	133	64	34
581	226	135	57	34
856	226	128	66	32
661	216	124	62	30
101	198	119	49	30
340	190	105	59	26
526	158	96	40	22
514	143	71	51	21
806	128	80	29	19
33	124	76	31	17
921	107	66	24	17
190	59	38	13	8
196	48	24	17	7
958	40	23	9	8
121	35	21	8	6

Finally, we note that this Mata routine works only with a Stata matrix, and a Stata matrix can only contain numeric (or missing) values. However, the technique used will operate on any Mata matrix, including complex and string matrices. An example of its application to a Mata string matrix is given in Baum (2006b).

## 14.2 Shuffling the elements of a string variable

**The problem:** you want to randomly shuffle the characters in each observation of a Stata string variable.

Mata's `jumble()` function fits the bill, using a very simple ado-file program to call it:

```
. type shufstr.ado
*! shufstr 1.0.0 CFBaum 11aug2008
program shufstr
  version 10.1
  syntax varlist(string max=1)
  mata: shufstr("`varlist'")
end
```

The program takes a single string variable as an argument and passes its name to our Mata function, `shufstr()`. The Mata code is equally simple:

```
. type shufstr.mata
version 10.1
mata: mata set matastrict on
mata: mata clear
// shufstr 1.0.0 CFBaum 11aug2008
mata:
  void function shufstr(string vector vname)
  {
    string matrix S
    real scalar i
    st_sview(S, ., vname)
    for(i = 1; i <= rows(S); i++) {
      S[i, .] = char(jumble(ascii(S[i, .]))')')
    }
  }
end
mata: mata mosave shufstr(), dir(PERSONAL) replace
```

We create a view matrix containing the string variable and define each row in turn as the `jumble()` of its characters. As `jumble()` is designed to shuffle the rows of a matrix,<sup>4</sup> we translate the string into a vector of ASCII codes<sup>5</sup> using the `ascii()` function. This is the simplest way in Mata to split a string into its characters. The `char()` function translates the vector of shuffled ASCII codes back to a single character string.

To illustrate, we extract the second word of variable `make` in `auto.dta` for the first 15 automobiles, and shuffle that word:

```
. sysuse auto
(1978 Automobile Data)
```

4. As [M-5] `sort()` indicates, `jumble(1::52)` would shuffle a deck of cards.

5. The ASCII character codes express each character as a integer between 1 and 255. For instance, the ASCII code for `b` is 42.

```

. generate model = ""
(74 missing values generated)
. quietly describe
. forvalues i = 1/'=r(N)' {
2.     local temp = make['i']
3.     local model: word 2 of 'temp'
4.     qui replace model = "'model'" in 'i'
5. }
. keep in 1/15
(59 observations deleted)
. keep make model price
. generate shufmod = model
. set seed 20080906
. shufstr(shufmod)
. list, sep(0) noobs

```

make	price	model	shufmod
AMC Concord	4,099	Concord	oCndocr
AMC Pacer	4,749	Pacer	cPera
AMC Spirit	3,799	Spirit	rStpii
Buick Century	4,816	Century	Cnetury
Buick Electra	7,827	Electra	eaElrtc
Buick LeSabre	5,788	LeSabre	ebaeSLr
Buick Opel	4,453	Opel	e0lp
Buick Regal	5,189	Regal	Raleg
Buick Riviera	10,372	Riviera	Reivira
Buick Skylark	4,082	Skylark	yakkrlS
Cad. Deville	11,385	Deville	Deielvl
Cad. Eldorado	14,500	Eldorado	oEldaord
Cad. Seville	15,906	Seville	leSeliv
Chev. Chevette	3,299	Chevette	eCethevt
Chev. Impala	5,705	Impala	amplaI

## 14.3 Firm-level correlations with multiple indices with Mata

**The problem:** we revisit the problem posed in Section 10.1, in which a user with firm-level panel data would like to compute the correlations between firm returns and a set of index fund returns, and determine which of those correlations is the highest for each firm. In the earlier presentation, we solved this problem with do-file code and Stata matrices. Here, we consider how it might be done more efficiently with Mata.

We first set up an ado-file to make the problem more general by allowing different variable names to be specified for the index fund returns, firm returns and firm identifier. The program, `maxindcorr`, takes a *varlist* of the names of index fund returns and three required options: `ret()`, the name of the firm returns variable, `firmed()`, the firm identifier variable, and `gen()`, a name which is used as a *stub* for four new variable names. These four variables will contain, for each firm, the firm's ID, its mean return, the number of quotes available and the number of the index fund with which the highest correlation appears. If the `gen()` option is given as `foo`, the variables created will be `foofirmed`, `foomu`, `foon` and `foomax`. After setting up a trading day calendar, we are ready to pass control to the Mata function `indcorr()`.<sup>6</sup>

```
. type maxindcorr.ado
*! maxindcorr 1.0.0 CFBaum 11aug2008
program maxindcorr
    version 10.1
    syntax varlist(numeric), RET(varname numeric) FIRMID(varname) GEN(string)

    * validate new variable names
    confirm new variable `gen'`firmed'
    confirm new variable `gen'`max'
    confirm new variable `gen'`mu'
    confirm new variable `gen'`n'

    tempvar trday

    * establish trading day calendar using firmed variable
    bysort `firmed': gen `trday' = _n
    qui tsset `firmed' `trday'
    qui generate `gen'`max' = .
    qui generate `gen'`mu' = .
    qui generate `gen'`n' = .
    qui generate `gen'`firmed' = .
    qui levelsof `firmed'
    local firms `r(levels)'
    local nf : word count `r(levels)'
    forv i = 1/'nf' {
        local fid : word `i' of `firms'
        qui replace `gen'`firmed' = `fid' in `i'
    }

    * create varlist of indices..ret
    local vl "`varlist' `ret'"

    * pass to Mata routine
    mata: indcorr("`firmed'", "`vl'", "`gen'")
end
```

---

6. The quietly prefix could be used on a block of statements rather than the individual statements below. However, that will suppress the listing of the statements in the block, which we avoid for pedagogical reasons here.

The Mata routine sets up views for the firm identifier (`ind`) and the data matrix (`pdata`). We then use the `panelsetup()` function to tell Mata that these are panel data, indexed by the firm identifier: the first column of `pdata`. The resulting matrix `info` merely contains, for each panel, the beginning and ending observation numbers of its elements. We then create views for the three new variables to be created.

These panel data are in the long format,<sup>7</sup> with `nf` firms' time-series observations. The heart of the routine is a loop over the `nf` panels found in `eye`. The `panelsubmatrix()` function extracts the appropriate rows of `eye` for the  $i^{\text{th}}$  panel, and Mata's `correlation()` function produces the correlation matrix. As the firm return variable is the last column of `eye`, all but the last element of the last row of `eye` are the correlations of interest. In the do-file code of Section 10.1, we stored those correlations in a matrix. As we only want to keep track of the maximum correlation, we use `maxindex()` to locate that element and store it directly in the result variable: the view `highcorr`. Likewise, we invoke `panelsubmatrix()` to compute the firm's mean return (with `mean()`) and number of quotes, and store those in the result variables.

```
. type indcorr.mata
mata: mata clear
version 10.1
mata: mata set matastrict on
mata:
// indcorr 1.0.0 CFBaum 11aug2008
void function indcorr(string scalar ind,
                    string scalar vn,
                    string scalar newvar)
{
    real matrix pdata, info, highcorr, sigma, z, enn, w
    real vector muret, ret
    real scalar nf, nv, nv1, i, imax
    string scalar mu, maxc, enname
    st_view(ind, ., ind)
    st_view(pdata, ., tokens(vn))
    info = panelsetup(ind, 1)
    nf = rows(info)
    nv = cols(pdata)
    nv1 = nv-1
    maxc = newvar + "max"
    st_view(highcorr, 1::nf, maxc)
    mu = newvar + "mu"
    st_view(muret, 1::nf, mu)
    enname = newvar + "n"
    st_view(enn, 1::nf, enname)
    // compute correlations between index columns and last column (ret)
    for(i = 1; i <= nf; i++) {
        sigma = correlation(panelsubmatrix(pdata, i, info))
        ret = sigma[nv, 1::nv1]
        maxindex(ret, 1, imax, w)
        highcorr[i] = imax
    }
    // calculate mean return and number of quotes for this panel
    z = panelsubmatrix(pdata[.,nv], i, info)
```

---

7. See Section 5.5.

```

        muret[i] = mean(z)
        enn[i] = rows(z)
    }
end
mata: mata mosave indcorr(), dir(PERSONAL) replace

```

We can now invoke the routine on the data used in Section 10.1:

```

. use ch14.3, clear
.
. maxindcorr index1-index9, ret(ret) firm(permno) gen(set1)
. summarize set1*

```

Variable	Obs	Mean	Std. Dev.	Min	Max
set1max	291	4.917526	2.665243	1	9
set1mu	291	-.0005513	.0061444	-.0775419	.0080105
set1n	291	1071.261	369.9875	8	1259
set1permno	291	58499.78	26550.12	10051	92655

```

. gsort -set1mu
. label def ind 1 Kappa 2 Lambda 3 Nu 4 Xi 5 Tau 6 Upsilon 7 Phi 8 Chi 9 Psi
. label values set1max ind
. list set1permno set1mu set1n set1max in 1/50, noobs sep(0)

```

set1pe-o	set1mu	set1n	set1max
23317	.0080105	8	Nu
53196	.0037981	465	Tau
67345	.0033149	459	Upsilon
90879	.0028613	1001	Psi
80439	.0027118	1259	Chi
64629	.0026724	1259	Upsilon
87165	.0025065	1259	Chi
76177	.002376	531	Nu
85073	.0023348	945	Chi
24441	.0023073	1259	Lambda
81063	.0022981	489	Chi
37284	.0021567	1259	Nu
14593	.0019581	1259	Kappa
80778	.0019196	941	Chi
68347	.0019122	85	Kappa
84827	.0018903	1259	Chi
84107	.0017555	987	Chi
22250	.0017191	1259	Lambda
76139	.0017182	1259	Phi
23819	.0016474	1259	Lambda
66384	.0016361	1259	Upsilon
38156	.001558	1259	Nu
88845	.0015497	1259	Lambda
85631	.0015028	1259	Chi
84788	.0015013	1259	Chi
77077	.0014899	1006	Phi
48653	.0014851	1259	Xi
92284	.0014393	1259	Psi
81877	.0014366	454	Chi

81178	.0014339	1186	Chi
81282	.0014084	1259	Phi
80114	.0014042	1259	Chi
56937	.0014028	1259	Tau
75819	.0013873	1259	Xi
22293	.0013792	1259	Chi
10085	.0013747	1072	Kappa
76712	.0013615	1259	Nu
77713	.0013607	127	Phi
12265	.0012653	858	Kappa
76779	.0012513	648	Lambda
83422	.0012314	1259	Chi
76224	.0012159	1259	Phi
47888	.0012045	1259	Xi
86569	.0011911	1259	Chi
77803	.0011858	1173	Phi
82272	.0011574	1259	Kappa
83976	.0011543	1259	Kappa
75510	.0011498	1259	Phi
15720	.0011436	1259	Lambda
90352	.0011411	1259	Psi

This more general routine illustrates how an ado-file and Mata subroutine may be used to provide a more efficient solution which can immediately be applied to a similar problem. Another consideration: the do-file routine of Section 10.1 may run afoul of Stata's `matsize` limits (`help limits`). There are no such limitations in Mata. Memory requirements could be reduced in `indcorr()` by using `panesubview()`, rather than `panesubmatrix()`. As those functions' documentation indicates, the latter is preferable if speed of execution is a greater concern than memory use.

## 14.4 Passing a function to a Mata function

**The problem:** you would like a Mata routine to apply a mathematical function, but would like to specify that function when you call the Mata routine rather than having every possible function coded in Mata. In sort, you would like to pass a function to a function, as described in [M-2] **ftof**.

We illustrate by modifying the **aggreg** routine presented in Section 13.7.1 (as this is a major change, we rename it **aggreg2**). We add one more optional argument to its syntax: **trans**(*function*), indicating that the original variable should be transformed before it is aggregated. The list of available transformations is defined in local macro **trops** as **abs exp log sqrt**. If no transformation is specified, the default identity transformation  $f(x) = x$  is applied.

Passing functions to functions makes use of *pointers*, as defined in Section 13.8. Before we set that up, one wrinkle must be addressed. As [M-2] **ftof** states, you cannot pass a *built-in* function to a function, and the mathematical functions are built-in. We get around this problem by defining our own trivial versions of each math function: for instance,

```
: function mf_abs(x) return(abs(x))
```

We now are ready to set up the passing mechanism. We parse the **trans**() option and define the name of the function to be passed in local macro **trfn**. The call to Mata function **aggreg2** includes an argument **&'trfn'()** which specifies the desired transformation in terms of a pointer to the function.

```
. type aggre2.ado
*! aggre2 1.0.0 CFBaum 11aug2008
program aggre2, rclass
    version 10.1
    syntax varname(numeric) [if] [in], per(integer) ///
        [func(string) trans(string)]
    marksample touse
    quietly count if `touse'
    if `r(N)' == 0 {
        error 2000
    }
    * validate per versus selected sample
    if `per' <= 0 | `per' >= `r(N)' {
        display as error "per must be > 0 and < N of observations."
        error 198
    }
    if mod(`r(N)',`per' != 0) {
        display as error "N of observations must be a multiple of per."
        error 198
    }
    * validate func option; default is average (code A)
    local ops A S F L
    local opnames average sum first last
    if "'func'" == "" {
        local op "A"
    }
    else {
```

```

        local nop : list posof "'func'" in opnames
        if !'nop' {
            display as err "Error: func must be chosen from 'opnames'"
            error 198
        }
        local op : word 'nop' of 'ops'
    }
* validate trans option; default is none (identity)
local trop abs exp log sqrt
if "'trans'" == "" {
    local trfn "mf_iden"
}
else {
    local ntr : list posof "'trans'" in trop
    if !'ntr' {
        display as err "Error: trans must be chosen from 'trop'"
        error 198
    }
    local trfn "mf_'trans'"
}
* validate the new varname
local newvar = "'varlist' 'op' 'trans' 'per'"
quietly generate 'newvar' = .
* pass the varname and newvarname to Mata
mata: aggreg2("'varlist'", "'newvar'", 'per', "'op'", ///
    &'trfn'(), "'touse'")
end

```

In the Mata function, the argument defining the name of the function is specified as

```
: pointer(real scalar function) scalar f
```

and invoked to transform the raw data in vector `v1` into vector `v1t`:

```
: v1t = (*f)(v1)
```

The Mata code reads:

```

. type aggreg2.mata
version 10.1
mata: mata clear
mata: mata set matastrict on
mata:
function mf_abs(x) return(abs(x))
function mf_exp(x) return(exp(x))
function mf_log(x) return(log(x))
function mf_sqrt(x) return(sqrt(x))
function mf_iden(x) return(x)
// aggreg2 1.0.0 CFBaum 11aug2008
void aggreg2(string scalar vname,
             string scalar newvname,
             real scalar per,
             string scalar op,
             pointer(real scalar function) scalar f,
             string scalar touse)
{
    real matrix v1, v1t, v2, v3

```

```

    real colvector mult
    if (op == "A") {
        mult = J(per, 1, 1/per)
    }
    else if (op == "S") {
        mult = J(per, 1, 1)
    }
    else if (op == "F") {
        mult = J(per, 1, 0)
        mult[1] = 1
    }
    else if (op == "L") {
        mult = J(per, 1, 0)
        mult[per] = 1
    }
    st_view(v1=., ., vname, touse)
    v1t = (*f)(v1)
    st_view(v2=., ., newvname)
    v3 = colshape(v1t', per) * mult
    v2[(1::rows(v3)),] = v3
}
end
mata: mata mosave aggreg2(), dir(PERSONAL) replace

```

We can now test our routine on the `urates` data used in Section 13.7.1 and verify that it is applying the correct transformations:

```

. use urates, clear
. aggreg2 tenn, per(3) trans(log) // calculate quarterly averages of log(tenn)
. aggreg2 tenn, per(3) func(sum) trans(sqrt) // calculate quarterly sum of sqrt
> (tenn)
. tsmktime quarter, start(1978q1) // create quarterly calendar var
    time variable: quarter, 1978q1 to 2055q4
    delta: 1 quarter
. list t tenn quarter tennAlog3 tennSsqrt3 in 1/12, sep(3)

```

	t	tenn	quarter	tennA1-3	tennSs-3
1.	1978m1	5.9	1978q1	1.786065	7.327801
2.	1978m2	5.9	1978q2	1.751859	7.203743
3.	1978m3	6.1	1978q3	1.746263	7.183253
4.	1978m4	5.9	1978q4	1.746062	7.182891
5.	1978m5	5.8	1979q1	1.746263	7.183253
6.	1978m6	5.6	1979q2	1.740364	7.162218
7.	1978m7	5.7	1979q3	1.746263	7.183253
8.	1978m8	5.7	1979q4	1.791667	7.348299
9.	1978m9	5.8	1980q1	1.818953	7.44945
10.	1978m10	5.9	1980q2	1.954307	7.9728
11.	1978m11	5.7	1980q3	2.079442	8.485281
12.	1978m12	5.6	1980q4	2.075249	8.467548

## 14.5 Using subviews in Mata

**The problem:** you make use of *view matrices* in Mata to avoid making copies of Stata's variables in Mata in your large dataset. You want to create subsets of those view matrices and minimize memory usage in doing so.

The solution involves the use of *subviews* in Mata. Like a view matrix, a subview is merely a reference to the specified components of another matrix. That matrix may be a view matrix or a regular matrix in Mata. In either case, you do not want to make a copy of the original matrix. You create subviews with Mata function `st_subview()`.

Let's say you want to form matrices within Mata for two sets of variables in your dataset. You could use `st_view` commands, specifying lists of variable names to be included:

```
. sysuse auto
(1978 Automobile Data)
. generate en = _n
. mata:
----- mata (type end to exit) -----
: st_view(Z1=., ., ("en", "price", "mpg", "turn"), 0)
: st_view(Z2=., ., ("en", "weight", "length", "rep78"), 0)
: Z1[ 6, .]
      1      2      3      4
1 | 6  5788  18  43
: Z2[ 6, .]
      1      2      3      4
1 | 8  3280  200  3
: end
-----
```

In this example, view matrices `Z1` and `Z2` do not have the same number of rows due to the presence of five missing values in `rep78`. The fourth argument to `st_view()` ensures that missing values in any of the variables cause those observations to be excluded. But what if the observations are no longer properly aligned after removing those with missing values? In this case, the matrices `Z1` and `Z2` will be misaligned in terms of the original observation numbers. As you can see, the sixth row of `Z1` contains the sixth observation of `auto.dta`, but the sixth row of `Z2` contains the eighth observation of this Stata dataset.

You can avoid this difficulty by building a single view matrix of all needed variables:

```
: st_view(Z, ., ("en", "price", "mpg", "turn", "weight", "length", "rep78"), 0)
```

and creating the desired subsets as subviews:

```
: st_subview(Z1, Z, ., (1, 2, 3, 4))
```

```
: st_subview(Z2, Z, ., (1, 5, 6, 7))
```

In this syntax, the row vector of indices specifies that columns 1, 2, 3 and 4 of  $Z$  are to be included in view matrix  $Z1$ , and that columns 1, 5, 6 and 7 of  $Z$  are to be included in view matrix  $Z2$ . The `st_view` matrix  $Z$  will exclude any observation with missing values on any of the variables, and the subview matrices  $Z1$  and  $Z2$  require no overhead (beyond a few bytes) as they are only references to the appropriate columns of  $Z$ . The subviews could even overlap, as above: the Stata variable `en` (the observation number) is included as the first column of each subview matrix.

There is also a specialized version of `subview()` for use with panel data: `panelsubview()`. See Section 14.3.

## 14.6 Storing and retrieving country-level data with Mata structures

**The problem:** you would like to store a collection of country-level data and be able to retrieve it by using Mata structures effectively.<sup>8</sup>

We set up a structure, `country`, which holds several string scalars, two numeric scalars and a vector of geographic coordinates for its capital city. Each element of the structure must be declared by type.

```
. type country.mata
version 10.1
mata: mata set matastrict on
mata:
// country 1.0.0 CFBaum 11aug2008
struct country {
    string scalar isocode
    string scalar name
    real scalar population
    real scalar gdppc
    string scalar capital
    real vector latlong
}
end
```

We now can define a Mata function, `loadcty`, which inserts data into the structure. It is defined as a `pointer` function so that it returns the address of that instance of the structure.

```
. type loadcty.mata
version 10.1
mata: mata set matastrict on
mata:
// loadcty 1.0.0 CFBaum 11aug2008
pointer(real scalar) loadcty(
    string scalar isocode,
    string scalar name,
    real scalar population,
    real scalar gdppc,
    string scalar capital,
    real scalar latitudeD,
    real scalar latitudeM,
    real scalar longitudeD,
    real scalar longitudeM )
{
    struct country scalar c
    c.isocode = isocode
    c.name = name
    c.population = population
    c.gdppc = gdppc
    c.capital = capital
    c.latlong = (latitudeD, latitudeM, longitudeD, longitudeM)
    return(&c)
}
```

8. See Section 13.9. For an extended discussion of Mata structures, see Gould (2007b).

```

}
end

```

To use the structure data, we define a Mata function `compcty` which compares a pair of countries, taking as arguments their respective structures. We would like to compute the airline distance between capital cities. This measure is often used in so-called gravity models of international trade. The computation is available in Stata from Bill Rising's `sphdist` command, available in the SSC Archive. His command expects four variables, giving latitude and longitude values for two locations,<sup>9</sup> and generates a new variable containing the computed distances. We only want to call this routine for a single observation, and receive a single value in return. We use Mata's `stata()` function to give the Stata command that runs `sphdist`, and `st_view()` to move data back and forth between Mata and Stata.

```

. type compcty.mata
version 10.1
mata: mata set matastrict on
mata:
// compcty 1.0.0 CFBaum 11aug2008
void compcty(struct country scalar a,
             struct country scalar b)
{
    real scalar poprat, gdprat, dist
    real matrix latlong
    printf("\nComparing %15s and %-15s\n\n", a.name, b.name)
    poprat = a.population / b.population
    printf("Ratio of population:      %9.2f\n", poprat)
    gdprat = a.gdppc / b.gdppc
    printf("Ratio of per capita GDP: %9.2f\n", gdprat)
    printf("\nCapital of %15s: %-15s\n Lat. %5.2f deg. Long. %5.2f deg.\n"
> , ///
           a.name, a.capital, a.latlong[1] + a.latlong[2] / 100, a.latlong[
> 3] + a.latlong[4] / 100)
    printf("\nCapital of %15s: %-15s\n Lat. %5.2f deg. Long. %5.2f deg.\n"
> , ///
           b.name, b.capital, b.latlong[1] + b.latlong[2] / 100, b.latlong[
> 3] + b.latlong[4] / 100)
    // store the latitude/longitude coordinates, reversing long. signs per sphdist
    > convention
    st_view(latlong=., ., ("lat1","long1","lat2","long2"))
    latlong[1, 1] = a.latlong[1] + a.latlong[2]/60
    latlong[1, 2] = -1 * (a.latlong[3] + a.latlong[4]/60)
    latlong[1, 3] = b.latlong[1] + b.latlong[2]/60
    latlong[1, 4] = -1 * (b.latlong[3] + b.latlong[4]/60)
    stata("capture drop __dist")
    // call Bill Rising's sphdist routine to compute the distance
    stata("sphdist, gen(__dist) lat1(lat1) lon1(long1) lat2(lat2) lon2(long
> 2)")
    st_view(dist=., ., ("__dist"))

```

9. The `sphdist` convention codes east longitude (east of Greenwich) as negative and west longitude as positive. Although it is an arbitrary convention, it is more common to code longitude in the same manner as time zones. For instance, for most of the year Boston is UCT−5, five hours behind London, and Berlin is UCT+1, one hour later than London. In the `compcty` routine, we reverse the sign of longitude values.

```

        printf("\nDistance between capitals: %9.2f km.\n",dist[1])
    }
end

```

We now can load the data structure with several countries' data.<sup>10</sup> Each invocation of the `loadcty()` function returns a pointer to that instance of the structure. We also set up the Stata variables `lat1`, `long1`, `lat2`, `long2` that will be accessed by `sphdist`.

```

. mata:
----- mata (type end to exit) -----
: addr1 = loadcty("US", "United States", 301.139947, 43800,"Washington DC", 38,
> 53, -77, -02)
: addr2 = loadcty("CA", "Canada", 33.390141, 35700, "Ottawa", 45, 24, -75, -43)
: addr3 = loadcty("TR", "Turkey", 71.158647, 9100, "Ankara", 39, 55, 32, 55)
: addr4 = loadcty("AR", "Argentina", 40.301927, 15200, "Buenos Aires", -34, -35
> , 58, 22)
: addr5 = loadcty("JP", "Japan", 127.433494, 33100, "Tokyo", 35, 40, 139, 45)
: end

. clear
. set obs 1
obs was 0, now 1
. generate lat1 = .
(1 missing value generated)
. generate long1 = .
(1 missing value generated)
. generate lat2 = .
(1 missing value generated)
. generate long2 = .
(1 missing value generated)

```

Now, we can invoke the `compcty()` function for any pair of countries that we have loaded into the data structure:

```

. mata:
----- mata (type end to exit) -----
: compcty(*addr1, *addr2)
Comparing   United States and Canada
Ratio of population:           9.02
Ratio of per capita GDP:       1.23
Capital of   United States: Washington DC
  Lat. 38.53 deg.  Long. -77.02 deg.
Capital of   Canada: Ottawa
  Lat. 45.24 deg.  Long. -75.43 deg.
Distance between capitals:     732.12 km.
: compcty(*addr1, *addr3)
Comparing   United States and Turkey

```

10. Population, per capita GDP (PPP) values and geographic coordinates are taken from the *CIA World Factbook*, <https://www.cia.gov/library/publications/the-world-factbook/>.

```

Ratio of population:          4.23
Ratio of per capita GDP:      4.81
Capital of   United States: Washington DC
  Lat. 38.53 deg. Long. -77.02 deg.
Capital of   Turkey: Ankara
  Lat. 39.55 deg. Long. 32.55 deg.
Distance between capitals:    8724.01 km.
: compcty(*addr3, *addr4)
Comparing    Turkey and Argentina
Ratio of population:          1.77
Ratio of per capita GDP:      0.60
Capital of   Turkey: Ankara
  Lat. 39.55 deg. Long. 32.55 deg.
Capital of   Argentina: Buenos Aires
  Lat. -34.35 deg. Long. 58.22 deg.
Distance between capitals:    8679.35 km.
: compcty(*addr1, *addr5)
Comparing    United States and Japan
Ratio of population:          2.36
Ratio of per capita GDP:      1.32
Capital of   United States: Washington DC
  Lat. 38.53 deg. Long. -77.02 deg.
Capital of   Japan: Tokyo
  Lat. 35.40 deg. Long. 139.45 deg.
Distance between capitals:    10897.34 km.
: end

```

---

Of course, the distance computation, a matter of spherical trigonometry implemented in `sphdist`, can be done directly in Mata. We construct a one-line function `deg2rad()` that converts a measurement in degrees into radians, and implement the trigonometric formulas from `sphdist` in a Mata function, `compcty2`:

```

. type compcty2.mata
version 10.1
mata:
real scalar deg2rad(real scalar deg)
{
    return(deg * pi() / 180)
}
void compcty2(struct country scalar a, struct country scalar b)
{
    real scalar poprat, gdprat, lat1, lat2, lon1, lon2, costhet, res
    printf("\nComparing %15s and %-15s\n\n", a.name, b.name)
    poprat = a.population / b.population
    printf("Ratio of population:      %9.2f\n", poprat)
    gdprat = a.gdppc / b.gdppc
    printf("Ratio of per capita GDP: %9.2f\n", gdprat)
    printf("\nCapital of %15s: %-15s\n Lat. %5.2f deg. Long. %5.2f deg.\n"
> , ///
        a.name, a.capital, a.latlong[1] + a.latlong[2] / 100, a.latlong

```

```

> [3] + a.latlong[4] /100)
    printf("\nCapital of %15s: %-15s\n Lat. %5.2f deg. Long. %5.2f deg.\n"
> , ///
        b.name, b.capital, b.latlong[1] + b.latlong[2] / 100, b.latlong[
> 3] + b.latlong[4] / 100)
// convert the latitude/longitude coordinates to radians
    lat1 = deg2rad(a.latlong[1] + a.latlong[2]/60)
    lon1 = deg2rad(a.latlong[3] + a.latlong[4]/60)
    lat2 = deg2rad(b.latlong[1] + b.latlong[2]/60)
    lon2 = deg2rad(b.latlong[3] + b.latlong[4]/60)
    costhet = sin(lat1) * sin(lat2) + cos(lat1) * cos(lat2) * cos(lon2 - lo
> n1)
    if (costhet == 1 | (lat1 == lat2 & lon1 == lon2)) {
        res = 0
    }
    else if (costhet == -1) {
        res = 20000
    }
    else {
        res = (pi() / 2 - atan(costhet / sqrt(1 - costhet^2))) * 20000
> / pi()
    }
    printf("\nDistance between capitals: %9.2f km.\n",res)
}
end

```

Selected results from the pure-Mata-based distance computation may be compared with those from the routine invoking `sphdist`:

```

. mata:
----- mata (type end to exit) -----
: compcty2(*addr1, *addr3)
Comparing United States and Turkey
Ratio of population: 4.23
Ratio of per capita GDP: 4.81
Capital of United States: Washington DC
Lat. 38.53 deg. Long. -77.02 deg.
Capital of Turkey: Ankara
Lat. 39.55 deg. Long. 32.55 deg.
Distance between capitals: 8724.01 km.
: compcty2(*addr3, *addr4)
Comparing Turkey and Argentina
Ratio of population: 1.77
Ratio of per capita GDP: 0.60
Capital of Turkey: Ankara
Lat. 39.55 deg. Long. 32.55 deg.
Capital of Argentina: Buenos Aires
Lat. -34.35 deg. Long. 58.22 deg.
Distance between capitals: 8679.35 km.
: end
-----

```

## 14.7 Locating nearest neighbors with Mata

**The problem:** a Stata user wanted to know how to find “nearest neighbors” in geographical terms: that is, which observations are spatially proximate to each observation in the dataset? This can be generalized to a broader problem: which observations are *closest* in terms of similarity of a number of variables? This might be recognized as a problem of calculating a propensity score (see Leuven and Sianesi’s `psmatch2` on the SSC Archive) but we would like to approach it from first principles with a Mata routine.

In response to the original posting in which the user had latitude and longitude coordinates for each observation, David M. Drukker proposed a Mata-based solution making use of the `minindex()` function.<sup>11</sup> We modify his solution below to allow a match to be defined in terms of a set of variables on which a close match will be defined. The quality of the match can then be evaluated by calculating the correlation between the original variable’s observations and its values of the identified “nearest neighbor.” That is, if we consider two units (patients, cities, firms, households) with similar values of  $x_1, \dots, x_m$ , how highly correlated are their values of  $y$ ?

Although the original example is geographical, the underlying task is found in many disciplines where a control group of observations is to be identified, each of which is the closest match to one of the observations of interest. For instance, in finance, you may have a sample of firms that underwent a takeover. For each firm, you would like to find a “similar” firm (based on several characteristics) that did not undergo a takeover. Those pairs of firms are nearest neighbors. In our application, we will compute the Euclidian distance (L2-norm) between the standardized values of pairs of observations.

To implement the solution, we first construct a Stata ado-file defining program `nneighbor` which takes a *varlist* of one or more measures that are to be used in the match.<sup>12</sup> In our application, we may use any number of variables as the basis for defining the nearest neighbor. The user must specify `y`, a response variable; `matchobs`, a variable to hold the observation numbers of the nearest neighbor; and `matchval`, a variable to hold the values of `y` belonging to the nearest neighbor.

After validating any *if exp* or *in range* conditions with `marksample`, the program confirms that the two new variable names are valid, then generates those variables with missing values. The latter step is necessary as we construct view matrices in the Mata function related to those variables, which must already exist. We then call the Mata function, `mf_nneighbor()`, and compute one statistic from its results: the correlation between the `y()` variable and the `matchvals()` variable, measuring the similarity of these `y()` values between the observations and their nearest neighbors.

```
. type nneighbor.ado
*! nneighbor 1.0.1 CFBaum 11aug2008
program nneighbor
    version 10.1
```

11. <http://stata.com/statalist/archive/2007-10/msg00365.html>

12. In the case above, that could be two variables: latitude and longitude, as in Section 14.6, where we measured distance between capital cities.

```

syntax varlist(numeric) [if] [in], ///
Y(varname numeric) MATCHOBS(string) MATCHVAL(string)

marksample touse
qui count if 'touse'
if r(N) == 0 {
    error 2000
}
// validate new variable names
confirm new variable 'matchobs'
confirm new variable 'matchval'
qui generate long 'matchobs' = .
qui generate 'matchval' = .
mata: mf_nneighbor("varlist", "matchobs", "y", ///
    "matchval", "touse")
summarize 'y' if 'touse', meanonly
display _n "Nearest neighbors for 'r(N)' observations of 'y'"
display "Based on L2-norm of standardized vars: 'varlist'"
display "Matched observation numbers: 'matchobs'"
display "Matched values: 'matchval'"
qui correlate 'y' 'matchval' if 'touse'
display "Correlation[ 'y', 'matchval' ] = " %5.4f 'r(rho)'
end

```

We now construct the Mata function. The function uses a view on the `varlist`, constructing view matrix `X`. As the scale of those variables affects the Euclidian distance (L2-norm) calculation, the variables are standardized in matrix `Z` using Ben Jann's `mm_meamcolvar()` function from the `moremata` package (see Section 13.10.4).<sup>13</sup> Views are then established for the `matchobs` variable (`C`), the response variable (`y`) and the `matchvals` variable (`ystar`).

For each observation and variable in the normalized *varlist*, the L2-norm of distances between that observation and the entire vector is computed as `d`. The heart of the function is the call to `minindex()`.<sup>14</sup> As David Drukker stated in his Statalist posting, this function is a fast, efficient calculator of the minimum values of a variable. Its fourth argument can deal with ties; for simplicity we do not handle ties here. We request the closest two values, in terms of the distance `d`, to each observation, recognizing that each observation is its own nearest neighbor. The observation numbers of the two nearest neighbors are stored in vector `ind`. Therefore, the observation number desired is the second element of the vector, and `y[ind[2]]` is the value of the nearest neighbor's response variable. Those elements are stored in `C[i]` and `ystar[i]`, respectively.

```

. type mf_nneighbor.mata
mata: mata clear
mata: mata set matastrict on
version 10.1
mata:
// mf_nneighbor 1.0.0 CFBaum 11aug2008
void function mf_nneighbor(string scalar matchvars,
    string scalar closest,
    string scalar response,

```

13. The `mm_meamcolvar()` function avoids the overhead of computing the full covariance matrix of `X`.

14. There is also a `maxindex()` function. See Section 14.3.

```

                                string scalar match,
                                string scalar touse)
{
    real matrix X, Z, mc, C, y, ystar
    real colvector ind
    real colvector w
    real colvector d
    real scalar n, k, i, j
    string rowvector vars, v
    st_view(X, ., tokens(matchvars), touse)
// standardize matchvars with mm_meancolvar from moremata
    mc = mm_meancolvar(X)
    Z = ( X :- mc[1, .] ) ./ sqrt( mc[2, .] )
    n = rows(X)
    k = cols(X)
    st_view(C, ., closest, touse)
    st_view(y, ., response, touse)
    st_view(ystar, ., match, touse)

// loop over observations
    for(i = 1; i <= n; i++) {
// loop over matchvars
        d = J(n, 1, 0)
        for(j = 1; j <= k; j++) {
            d = d + ( Z[., j] :- Z[i, j] ) :^2
        }
        minindex(d, 2, ind, w)
        C[i] = ind[2]
        ystar[i] = y[ind[2]]
    }
}
end
mata: mata mosave mf_nneighbor(), dir(PERSONAL) replace

```

We now can try out the routine. We employ the `usairquality` dataset used in earlier examples. It contains statistics for 41 U.S. cities' air quality (`so2`, or sulphur dioxide concentration) as well as several demographic factors. To test our routine, we first apply it to a single variable: population (`pop`). Examining the result, we can see that it is properly selecting the city with the closest population value as the nearest neighbor:

```

. use usairquality, clear
. sort pop
. nneighbor pop, y(so2) matchobs(mo1) matchval(mv1)
Nearest neighbors for 41 observations of so2
Based on L2-norm of standardized vars: pop
Matched observation numbers: mo1
Matched values: mv1
Correlation[ so2, mv1 ] = 0.0700
. list pop mo1 so2 mv1, sep(0)

```

	pop	mo1	so2	mv1
1.	71	2	31	36
2.	80	1	36	31
3.	116	4	46	13

4.	132	3	13	46
5.	158	6	56	28
6.	176	7	28	94
7.	179	6	94	28
8.	201	7	17	94
9.	244	10	11	8
10.	277	11	8	26
11.	299	12	26	31
12.	308	11	31	26
13.	335	14	10	14
14.	347	13	14	10
15.	361	14	9	14
16.	448	17	18	23
17.	453	16	23	18
18.	463	17	11	23
19.	497	20	24	14
20.	507	21	14	17
21.	515	22	17	61
22.	520	21	61	17
23.	529	24	14	29
24.	531	23	29	14
25.	540	24	26	29
26.	582	27	10	30
27.	593	26	30	10
28.	622	29	56	10
29.	624	28	10	56
30.	716	31	12	16
31.	717	30	16	12
32.	744	33	29	28
33.	746	32	28	29
34.	751	33	65	28
35.	757	34	29	65
36.	844	37	9	47
37.	905	36	47	9
38.	1233	39	10	35
39.	1513	38	35	10
40.	1950	39	69	35
41.	3369	40	110	69

We must note, however, that the response variable's values are very weakly correlated with those of the `matchvar`. Matching cities on the basis of one attribute does not seem to imply that they will have similar values of air pollution. We thus exercise the routine on two broader sets of attributes: one adding `temp` and `wind`, and the second adding `precip` and `days`, where `days` measures the mean number of days with poor air quality.

```
. nneighbor pop temp wind, y(so2) matchobs(mo3) matchval(mv3)
Nearest neighbors for 41 observations of so2
Based on L2-norm of standardized vars: pop temp wind
Matched observation numbers: mo3
Matched values: mv3
Correlation[ so2, mv3 ] = 0.1769

. nneighbor pop temp wind precip days, y(so2) matchobs(mo5) matchval(mv5)
Nearest neighbors for 41 observations of so2
Based on L2-norm of standardized vars: pop temp wind precip days
Matched observation numbers: mo5
```

```
Matched values: mv5  
Correlation[ so2, mv5 ] = 0.5286
```

We see that with the broader set of five attributes on which matching is based, there is a much higher correlation between the `so2` values for each city and those for its nearest neighbor.

## 14.8 Computing the SUR estimator for an unbalanced panel

**The problem:** Stata's seemingly unrelated regression (SUR) estimator (`sureg`, `[R] sureg`) estimates a set of equations, employing the matrix of residual correlations for each equation to produce a refined estimate of its parameter vector. The `sureg` estimator can be considered as a panel-data estimator that operates in the *wide form*. It is common for panel data to be *unbalanced*,<sup>15</sup> and Stata's `xt` (`[XT] xt`) commands handle unbalanced panels without difficulty. However, `sureg` discards any observation that is missing in *any* of its equations.<sup>16</sup> We would like to use `sureg` without losing these observations. If we use `correlate varlist` (`[R] correlate`), observations missing for *any* of the variables in the *varlist* will be dropped from the calculation. In contrast, the pairwise correlation command `pwcorr varlist` (`[R] pwcorr`) will compute correlations from all available observations for each pair of variables in turn. The logic of `sureg` is that of `correlate`; but the correlations of residuals employed by `sureg` may be, as in `pwcorr`, calculated on a pairwise basis, allowing the estimator to be applied to a set of equations which may cover different time periods (as long as there is meaningful overlap).

A question posed on Statalist raised this issue and questioned whether `sureg` could be used to work with an unbalanced panel. In this section, I illustrate how Mata may be used to handle this quite sophisticated estimation problem. I worked with the code of official Stata's `reg3` (`[R] reg3`) to extract the parsing commands that set up the problem,<sup>17</sup> and then wrote my own ado-file to perform the computations. It calls a Mata function that produces the estimates.

For brevity, I do not reproduce the parsing code taken from `reg3.ado`. The syntax of my program, `suregub`, is identical to that of `sureg` but does not support all of its options. The basic syntax is

```
suregub (depvar1 varlist1) (depvar2 varlist2) ... (depvarN varlistN)
```

When the parsing code has executed, it has populated a local macro `eqlist` of equations to be estimated and a set of local macros `ind1` ... `indN` which contains the right-hand-side variables for each of the  $N$  equations. We first generate the OLS residuals for each equation by running `regress` (`[R] regress`) and `predict, residual` (`[R] regress postestimation`). We find the maximum and minimum observation indices for each set of residuals with the `max()` and `min()` functions, respectively.

Temporary matrix `sigma` will contain the pairwise correlations of the equations' residuals. They are produced with calls to `correlate` (`[R] correlate`). We then invoke the Mata function `mm_suregub`, passing it the number of equations (`neq`), the list of equations (`eqlist`) and the computed `sigma` matrix. The remainder of `suregub.ado` is:

```
// generate residual series
```

---

15. See Section 5.3.

16. An alternative solution to this problem was provided (using Stata's `xtgee` command) by McDowell (2004).

17. Official Stata's `sureg.ado` is essentially a wrapper for `reg3.ado`.

```

local minn = .
local maxn = 0
forvalues i = 1/'neq' {
    local dv : word 'i' of 'eqlist'
    local eq'i' = "'dv' 'ind'i'"
    qui {
        regress 'dv' 'ind'i'
        tempvar touse'i' es eps'i'
        predict double 'eps'i' if e(sample), resid
        generate byte 'touse'i' = cond(e(sample), 1, .)
        summarize 'eps'i', meanonly
        local maxn = max('maxn', r(N))
        local minn = min('minn', r(N))
    }
}
tempname sigma
matrix 'sigma' = J('neq', 'neq', 0)
// generate pairwise correlation matrix of residuals;
// for comparison with sureg, use divisor N
local neq1 = 'neq' - 1
forvalues i = 1/'neq1' {
    forvalues j = 2/'neq' {
        qui correlate 'eps'i' 'eps'j', cov
        mat 'sigma'['i', 'i'] = r(Var_1) * (r(N) - 1) / (r(N))
        mat 'sigma'['j', 'j'] = r(Var_2) * (r(N) - 1) / (r(N))
        mat 'sigma'['i', 'j'] = r(cov_12) * (r(N) - 1) / (r(N))
        mat 'sigma'['j', 'i'] = 'sigma'['i', 'j']
    }
}
mata: mm_suregub('neq', "'eqlist'", "'sigma'")
display _newline "Seemingly unrelated regression for an unbalanced panel"
display _newline "Minimum observations per unit = 'minn'"
display _newline "Maximum observations per unit = 'maxn'"
mat b = r(b)
mat V = r(V)
ereturn clear
ereturn post b V
ereturn local cmd "suregub"
ereturn local minobs 'minn'
ereturn local maxobs 'maxn'
ereturn display
end

```

Following the Mata function's execution, we retrieve the estimated coefficient vector (returned as  $r(b)$ ) and covariance matrix (returned as  $r(V)$ ) to Stata matrices  $b$  and  $V$ , respectively. Those matrices are then *posted* to the `ereturn` values with `ereturn post` ([P] `ereturn`). The `ereturn display` command triggers the standard estimation output routine, which now presents the results of estimation from `mm_suregub()`.

The Mata function is more complicated than those we have seen in earlier examples. As introduced in Section 13.8, I employ pointers: in this case, rowvectors of pointers to real matrices. We also must work with the coefficient names and *matrix stripes*<sup>18</sup> attached to Stata matrices so that the display of estimation results will work properly. The first section of the function loops over equations, setting up the appropriate contents of the dependent variable (`yy[i]`) and the right-hand-side variables (`xx[i]`) for each

18. See Section 14.1.

equation in turn.<sup>19</sup>

In the second loop over equations, the elements of the full  $\mathbf{X}'\mathbf{X}$  matrix are computed as scalar multiples of an element of the inverse of `sigma` times the cross-product (`[M-5] cross()`) of the  $i^{\text{th}}$  and  $j^{\text{th}}$  equations' regressor matrices. The full  $\mathbf{y}'\mathbf{y}$  vector is built up from scalar multiples of an element of the inverse of `sigma` times the cross-product of the  $i^{\text{th}}$  equation's regressors and the  $j^{\text{th}}$  equation's values of `yy`. When these two matrices are assembled, the least squares solution is obtained with `invsym()`, and the appropriate matrix row and column stripes are defined for the result matrices `r(b)` and `r(V)`.

```
. type mm_suregub.mata
version 10.1
mata: mata clear
mata: mata set matastrict on
mata:
// mm_suregub 1.0.0 CFBaum 11aug2008
void mm_suregub(real scalar neq,
               string scalar eqlist,
               string scalar sigma)
{
    real matrix isigma, tt, eqq, iota, XX, YY, xi, xj, yj, vee
    real vector beta
    real scalar nrow, ncol, i, ii, i2, jj, j, j2
    string scalar lt, touse, le, eqname, eqv
    string vector v, vars, stripe
    pointer (real matrix) rowvector eq
    pointer (real matrix) rowvector xx
    pointer (real matrix) rowvector yy

    eq = xx = yy = J(1, neq, NULL)
    isigma = invsym(st_matrix(sigma))
    nrow = 0
    ncol = 0
    string rowvector coefname, eqn
    string matrix mstripe
// equation loop 1
    for(i = 1; i <= neq; i++) {
        lt = "touse" + strofreal(i)
        touse = st_local(lt)
        st_view(tt, ., touse)
        le = "eq" + strofreal(i)
        eqv = st_local(le)
        vars = tokens(eqv)
        v = vars[1, .]
// pull in full matrix, including missing values
        st_view(eqq, ., v)
        eq[i] = &(tt :* eqq)
// matrix eq[i] is [y|X] for ith eqn
        eqname = v[1]
        stripe = v[2::cols(v)], "_cons"
        coefname = coefname, stripe
        eqn = eqn, J(1, cols(v), eqname)
// form X, assuming constant term
        nrow = nrow + rows(*eq[i])
    }
}
```

19. A constant term is assumed to be present in each equation.

```

        iota = J(rows(*eq[i]), 1, 1)
        xx[i] = &((*eq[i])[1,2 \ .. ]), iota)
        ncol = ncol + cols(*xx[i])
// form y
        yy[i] = &(*eq[i])[.,1]
    }
    XX = J(ncol, ncol, 0)
    YY = J(ncol, 1, 0)
    ii = 0
// equation loop 2
    for(i=1; i<=neq; i++) {
        i2 = cols(*xx[i])
        xi = *xx[i]
        jj = 0
        for(j=1; j<=neq; j++) {
            xj = *xx[j]
            j2 = cols(*xx[j])
            yj = *yy[j]
            XX[l ii+1, jj+1 \ ii+i2, jj+j2 |] = isigma[i, j] :* cro
> ss(xi, xj)
            YY[l ii+1, 1 \ ii+i2, 1 |] = YY[l ii+1, 1 \ ii+i2, 1 |]
> + ///
            isigma[i, j] :* cross(xi,
> yj)
            jj = jj + j2
        }
        ii = ii + i2
    }
// compute SUR beta (X' [Sigma^-1 # I] X)^-1 (X' [Sigma^-1 # I] y)
    vee = invsym(XX)
    beta = vee * YY
    st_matrix("r(b)", beta')
    mstripe=eqn', coefname'
    st_matrixcolstripe("r(b)", mstripe)
    st_matrix("r(V)", vee)
    st_matrixrowstripe("r(V)", mstripe)
    st_matrixcolstripe("r(V)", mstripe)
}
end
mata: mata mosave mm_suregub(), dir(PERSONAL) replace

```

To validate the routine, we first apply it to a balanced panel, for which it should replicate standard `sureg` results if it has been programmed properly. As we have verified that `suregub` passes that test using the `grunfeld.dta` dataset, we modify that dataset to create an unbalanced panel:

```

. use grunfeld, clear
. drop in 75/80
(6 observations deleted)
. drop in 41/43
(3 observations deleted)
. drop in 18/20
(3 observations deleted)
. keep if company <= 4
(120 observations deleted)

```

```

. drop time
. reshape wide invest mvalue kstock, i(year) j(company)
(note: j = 1 2 3 4)
Data                long  ->  wide
-----
Number of obs.      68   ->   20
Number of variables  5   ->   13
j variable (4 values) company -> (dropped)
xij variables:
                    invest -> invest1 invest2 ... invest4
                    mvalue -> mvalue1 mvalue2 ... mvalue4
                    kstock -> kstock1 kstock2 ... kstock4

. list year invest*, sep(0)

```

	year	invest1	invest2	invest3	invest4
1.	1935	317.6	209.9	.	40.29
2.	1936	391.8	355.3	.	72.76
3.	1937	410.6	469.9	.	66.26
4.	1938	257.7	262.3	44.6	51.6
5.	1939	330.8	230.4	48.1	52.41
6.	1940	461.2	361.6	74.4	69.41
7.	1941	512	472.8	113	68.35
8.	1942	448	445.6	91.9	46.8
9.	1943	499.6	361.6	61.3	47.4
10.	1944	547.5	288.2	56.8	59.57
11.	1945	561.2	258.7	93.6	88.78
12.	1946	688.1	420.3	159.9	74.12
13.	1947	568.9	420.5	147.2	62.68
14.	1948	529.2	494.5	146.3	89.36
15.	1949	555.1	405.1	98.3	.
16.	1950	642.9	418.8	93.5	.
17.	1951	755.9	588.2	135.2	.
18.	1952	.	645.5	157.3	.
19.	1953	.	641	179.5	.
20.	1954	.	459.3	189.6	.

We may then invoke `suregub` to generate point and interval estimates:

```

. suregub (invest1 mvalue1 kstock1) (invest2 mvalue2 kstock2) ///
>         (invest3 mvalue3 kstock3) (invest4 mvalue4 kstock4)
Seemingly unrelated regressions for an unbalanced panel
Min obs per unit = 14
Max obs per unit = 20

```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
invest1						
mvalue1	.0787979	.0220396	3.58	0.000	.035601	.1219948
kstock1	.245538	.044413	5.53	0.000	.1584901	.3325858
_cons	64.69007	96.85787	0.67	0.504	-125.1479	254.528
invest2						
mvalue2	.1729584	.0640754	2.70	0.007	.047373	.2985439

kstock2	.4150819	.1279443	3.24	0.001	.1643156	.6658482
_cons	-53.8353	128.2932	-0.42	0.675	-305.2853	197.6147
<hr/>						
invest3						
mvalue3	.0522683	.0191105	2.74	0.006	.0148124	.0897243
kstock3	.1071995	.0287962	3.72	0.000	.0507599	.163639
_cons	-39.32897	37.37061	-1.05	0.293	-112.574	33.91607
<hr/>						
invest4						
mvalue4	.0632339	.0142336	4.44	0.000	.0353364	.0911313
kstock4	.1487322	.0825525	1.80	0.072	-.0130678	.3105321
_cons	12.50393	11.02009	1.13	0.257	-9.09504	34.1029
<hr/>						

A number of additional features could be added to `suregub` to more closely match the behavior of `sureg`. That effort is left to the ambitious reader. The full code for `suregub.ado` is available in the electronic supplement to this book.

## 14.9 A GMM-CUE estimator using Mata's `optimize()` functions (with Mark E. Schaffer)

**The problem:** We would like to implement the continuously-updated generalized method of moments estimator (GMM-CUE) of Hansen et al. (1996) in Mata.<sup>20</sup> This is an estimator of a linear instrumental variables model that requires numerical optimization for its solution. We have implemented this estimator for `ivreg2` in Stata's ado-file language using the maximum likelihood commands (`ml`, `[R] ml`). Although that is a workable solution, it can be very slow for large datasets with many regressors and instruments. In Stata version 10, a full-featured suite of optimization commands are available in Mata as `optimize()` (`[M-5] optimize`). We implement a simple IV-GMM estimator in Mata and use that as a model for implementing GMM-CUE.

The two-step GMM estimator for a linear instrumental variables regression model reduces to standard IV if we assume an *i.i.d.* error process, or if the equation is exactly identified with the number of instruments equal to the number of regressors.<sup>21</sup> The following ado-file, `mygmm2s.ado`, accepts a dependent variable and three additional optional variable lists: for endogenous variables, included instruments and excluded instruments. A constant is automatically included in the regression and in the instrument matrix. There is a single option, `robust`, which specifies whether we are assuming *i.i.d.* errors or allowing for arbitrary heteroskedasticity. The routine calls Mata function `m_mygmm2s()` and receives results back in the return list. Estimation results are assembled and `posted` to the official locations so that we may make use of Stata's `ereturn display` command and enable the use of post-estimation commands such as `test` and `lincom`.

```
. type mygmm2s.ado
*! mygmm2s 1.0.2 MES/CFB 11aug2008
program mygmm2s, eclass
    version 10.1
/*
Our standard syntax:
mygmm2s y, endog(varlist1) inexog(varlist2) exexog(varlist3) [robust]
where varlist1 contains endogenous regressors
      varlist2 contains exogenous regressors (included instruments)
      varlist3 contains excluded instruments
Without robust, efficient GMM is IV. With robust, efficient GMM is 2-step
efficient GMM, robust to arbitrary heteroskedasticity.
To accommodate time-series operators in the options, add the "ts"
*/
    syntax varname(ts) [if] [in] [, endog(varlist ts) inexog(varlist ts) //
> /
        exexog(varlist ts) robust ]
    local depvar `varlist'
/*
marksample handles the variables in `varlist' automatically, but not the
variables listed in the options `endog', `inexog' and so on. -markout- sets
`thouse' to 0 for any observations where the variables listed are missing.
```

20. The rationale for this estimator is presented in Baum et al. (2007), pp. 477–479.

21. See Baum et al. (2007), pp. 467–469.

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```

*/
    marksample touse
    markout 'touse' 'endog' 'inexog' 'exexog'
// These are the local macros that our Stata program will use
    tempname b V omega
// Call the Mata routine. All results will be waiting for us in "r()" macros af
> terwards.
    mata: m_mygmm2s("`depvar'", "`endog'", "`inexog'", ///
                   "`exexog'", "`touse'", "`robust'")
// Move the basic results from r() macros into Stata matrices.
    mat `b' = r(beta)
    mat `V' = r(V)
    mat `omega' = r(omega)
// Prepare row/col names.
// Our convention is that regressors are [endog included exog]
// and instruments are [excluded exog included exog]
// Constant is added by default and is the last column.
    local vnames `endog' `inexog' _cons
    matrix rnames `V' = `vnames'
    matrix colnames `V' = `vnames'
    matrix colnames `b' = `vnames'
    local vnames2 `exexog' `inexog' _cons
    matrix rnames `omega' = `vnames2'
    matrix colnames `omega' = `vnames2'
// We need the number of observations before we post our results.
    local N = r(N)
    ereturn post `b' `V', depname(`depvar') obs(`N') esample(`touse')
// Store remaining estimation results as e() macros accessible to the user.
    ereturn matrix omega `omega'
    ereturn local depvar = "`depvar'"
    ereturn scalar N = r(N)
    ereturn scalar j = r(j)
    ereturn scalar L = r(L)
    ereturn scalar K = r(K)
    if "`robust'" != "" {
        ereturn local vcetype "Robust"
    }
    display _newline "Two-step GMM results" _col(60) "Number of obs = " e(N)
> )
    ereturn display
    display "Sargan-Hansen J statistic: " %7.3f e(j)
    display "Chi-sq(" %3.0f e(L)-e(K) " ) P-val = " ///
           %5.4f chiprob(e(L)-e(K), e(j)) _newline
end

```

The Mata function receives the names of variables to be included in the regression and creates view matrices for  $Y$  (the dependent variable),  $X1$  (the endogenous variables),  $X2$  (the exogenous regressors or included instruments) and  $Z1$  (the excluded instruments). The `st_tsrevar()` ([M-5] `st_tsrevar()`) function is used to deal with Stata's time series operators in any of the variable lists.

```

. type m_mygmm2s.mata
mata:mata clear
version 10.1

```

```

mata: mata set matastrict on
mata:
// m_mygmm2s 1.0.0 MES/CFB 11aug2008
void m_mygmm2s(string scalar yname,
              string scalar endognames,
              string scalar inexognames,
              string scalar exexognames,
              string scalar touse,
              string scalar robust)
{
    real matrix Y, X1, X2, Z1, X, Z, QZZ, QZX, W, omega, V
    real vector cons, beta_iv, beta_gmm, e, gbar
    real scalar K, L, N, j

    // Use st_tsrevar in case any variables use Stata's time-series operators.
    st_view(Y, ., st_tsrevar(tokens(yname)), touse)
    st_view(X1, ., st_tsrevar(tokens(endognames)), touse)
    st_view(X2, ., st_tsrevar(tokens(inexognames)), touse)
    st_view(Z1, ., st_tsrevar(tokens(exexognames)), touse)

    // Our convention is that regressors are [endog included exog]
    // and instruments are [excluded exog included exog]
    // Constant is added by default and is the last column.
    cons = J(rows(X2), 1, 1)
    X2 = X2, cons
    X = X1, X2
    Z = Z1, X2

    K = cols(X)
    L = cols(Z)
    N = rows(Y)

    QZZ = 1/N * quadcross(Z, Z)
    QZX = 1/N * quadcross(Z, X)

    // First step of 2-step feasible efficient GMM: IV (2SLS). Weighting matrix
    // is inv of Z'Z (or QZZ).
    W = invsym(QZZ)
    beta_iv = (invsym(X'Z * W * Z'X) * X'Z * W * Z'Y)
    // By convention, Stata parameter vectors are row vectors
    beta_iv = beta_iv'

    // Use first-step residuals to calculate optimal weighting matrix for 2-step FE
    > GMM
    omega = m_myomega(beta_iv, Y, X, Z, robust)
    // Second step of 2-step feasible efficient GMM: IV (2SLS). Weighting matrix
    // is inv of Z'Z (or QZZ).
    W = invsym(omega)
    beta_gmm = (invsym(X'Z * W * Z'X) * X'Z * W * Z'Y)
    // By convention, Stata parameter vectors are row vectors
    beta_gmm = beta_gmm'

    // Sargan-Hansen J statistic: first we calculate the second-step residuals
    e = Y - X * beta_gmm'
    // Calculate gbar = 1/N * Z'*e
    gbar = 1/N * quadcross(Z, e)
    j = N * gbar' * W * gbar

    // Sandwich var-cov matrix (no finite-sample correction)
    // Reduces to classical var-cov matrix if Omega is not robust form.
    // But the GMM estimator is "root-N consistent", and technically we do
    // inference on sqrt(N)*beta. By convention we work with beta, so we adjust
    // the var-cov matrix instead:

```

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```

        V = 1/N * invsym(QZX' * W * QZX)
// Easiest way of returning results to Stata: as r-class macros.
    st_matrix("r(beta)", beta_gmm)
    st_matrix("r(V)", V)
    st_matrix("r(omega)", omega)
    st_numscalar("r(j)", j)
    st_numscalar("r(N)", N)
    st_numscalar("r(L)", L)
    st_numscalar("r(K)", K)
}
end
mata: mata mosave m_mygmm2s(), dir(PERSONAL) replace

```

This function in turn calls an additional Mata function, `m_myomega()`, to compute the appropriate covariance matrix. This is a **real matrix** function, as it will return its result, the real matrix `omega`, to the calling function. Because we will reuse the `m_myomega()` function in our GMM-CUE program, we place it in a separate file, `m_myomega.mata`, with instructions to compile it into a `.mo` file (see Section 13.10.3).

```

. type m_myomega.mata
mata: mata clear
version 10.1
mata: mata set matastrict on
mata:
// m_myomega 1.0.0 MES/CFB 11aug2008
real matrix m_myomega(real rowvector beta,
                     real colvector Y,
                     real matrix X,
                     real matrix Z,
                     string scalar robust)
{
    real matrix QZZ, omega
    real vector e, e2
    real scalar N, sigma2

// Calculate residuals from the coefficient estimates
    N = rows(Z)
    e = Y - X * beta'

    if (robust=="") {
// Compute classical, non-robust covariance matrix
        QZZ = 1/N * quadcross(Z, Z)
        sigma2 = 1/N * quadcross(e, e)
        omega = sigma2 * QZZ
    }
    else {
// Compute heteroskedasticity-consistent covariance matrix
        e2 = e:^2
        omega = 1/N * quadcross(Z, e2, Z)
    }
    _makesymmetric(omega)
    return (omega)
}
end
mata: mata mosave m_myomega(), dir(PERSONAL) replace

```

This gives us a working Mata implementation of an instrumental variables estimator and an IV-GMM estimator (accounting for arbitrary heteroskedasticity), and we can verify that its results match those of `ivregress` ([R] `ivregress`) or our own `ivreg2`.

To implement the GMM-CUE estimator,<sup>22</sup> we clone `mygmm2s.ado` to `mygmmcue.ado`. The ado-file code is very similar:

```
. type mygmmcue.ado
*! mygmmcue 1.0.2 MES/CFB 11aug2008
program mygmmcue, eclass
    version 10.1
    syntax varname(ts) [if] [in] [ , endog(varlist ts) ///
        inexog(varlist ts) exexog(varlist ts) robust ]
    local depvar `varlist'

    marksample touse
    markout `touse' `endog' `inexog' `exexog'
    tempname b V omega

    mata: m_mygmmcue("`depvar'", "`endog'", "`inexog'", ///
        "`exexog'", "`touse'", "`robust'")

    mat `b' = r(beta)
    mat `V' = r(V)
    mat `omega'=r(omega)
// Prepare row/col names
// Our convention is that regressors are [endog included exog]
// and instruments are [excluded exog included exog]
    local vnames `endog' `inexog' _cons
    matrix rownames `V' = `vnames'
    matrix colnames `V' = `vnames'
    matrix colnames `b' = `vnames'
    local vnames2 `exexog' `inexog' _cons
    matrix rownames `omega' = `vnames2'
    matrix colnames `omega' = `vnames2'

    local N = r(N)
    ereturn post `b' `V', depname(`depvar') obs(`N') esample(`touse')
    ereturn matrix omega `omega'
    ereturn local depvar = "`depvar'"
    ereturn scalar N = r(N)
    ereturn scalar j = r(j)
    ereturn scalar L = r(L)
    ereturn scalar K = r(K)

    if "`robust'" != "" ereturn local vcetype "Robust"
    display _newline "GMM-CUE estimates" _col(60) "Number of obs = " e(N)
    ereturn display
    display "Sargan-Hansen J statistic: " %7.3f e(j)
    display "Chi-sq(" %3.0f e(L)-e(K) " ) P-val = " ///
        %5.4f chiprob(e(L)-e(K), e(j)) _newline
end
```

We now consider how the Mata function must be modified to incorporate the numerical optimization routines. We must first make use of Mata's `external` ([M-2] `declarations`)

22. See Baum et al. (2007), pp. 477–480.

declaration to specify that the elements needed within our objective function evaluator are visible to that routine. We could also pass those arguments to the evaluation routine, but treating them as `external` requires less housekeeping.<sup>23</sup> As in the standard two-step GMM routine, we derive first-step estimates of the regression parameters from a standard GMM estimation.

We then use Mata's `optimize()` functions to set up the optimization problem. The `optimize_init()` call, as described in Gould (2007b), sets up a Mata *structure*, in our case named `S`, containing all elements of the problem.<sup>24</sup> In a call to `optimize_init_evaluator()`, we specify that the evaluation routine is a Mata function, `m_mycuecrit()`, by providing a *pointer* to the function (see Section 13.8). We call `optimize_init_which()` to indicate that we are minimizing (rather than maximizing) the objective function, and use `optimize_init_evaluatoretype()` that our evaluation routine is a type `d0` evaluator. Finally, we call `optimize_init_params()` to provide starting values for the parameters from the instrumental variables coefficient vector `beta_iv`. The `optimize()` function invokes the optimization routine, returning its results in the parameter rowvector `beta_cue`. The optimal value of the objective function is retrieved with `optimize_result_value()`.

```
. type m_mygmmcue.mata
mata: mata clear
version 10.1
mata: mata set matastrict on
mata:
// m_mygmmcue 1.0.0 MES/CFB 11aug2008
void m_mygmmcue(string scalar yname,
                string scalar endognames,
                string scalar inexognames,
                string scalar exexognames,
                string scalar touse,
                string scalar robust)
{
    real matrix X1, X2, Z1, QZZ, QZX, W, V
    real vector cons, beta_iv, beta_cue
    real scalar K, L, N, S, j

    // In order for the optimization objective function to find various variables
    // and data they have to be set as externals. This means subroutines can
    // find them without having to have them passed to the subroutines as arguments
    > .
    // robustflag is the robust argument recreated as an external Mata scalar.
    external Y, X, Z, e, omega, robustflag
    robustflag = robust
    st_view(Y, ., st_tsrevar(tokens(yname)), touse)
    st_view(X1, ., st_tsrevar(tokens(endognames)), touse)
    st_view(X2, ., st_tsrevar(tokens(inexognames)), touse)
    st_view(Z1, ., st_tsrevar(tokens(exexognames)), touse)

    // Our convention is that regressors are [endog      included exog]
    // and instruments are                  [excluded exog included exog]
```

23. As discussed in [M-5] `optimize()`, pp. 287–288, you may always pass up to nine extra arguments to evaluators. However, you must then keep track of those arguments and their order.

24. See Section 13.9.

```

// The constant is added by default and is the last column.
cons = J(rows(X2), 1, 1)
X2 = X2, cons
X = X1, X2
Z = Z1, X2
K = cols(X)
L = cols(Z)
N = rows(Y)
QZZ = 1/N * quadcross(Z, Z)
QZX = 1/N * quadcross(Z, X)

// First step of CUE GMM: IV (2SLS). Use beta_iv as the initial values for
// the numerical optimization.
W = invsym(QZZ)
beta_iv = invsym(X'Z * W * Z'X) * X'Z * W * Z'Y
// Stata convention is that parameter vectors are row vectors, and optimizers
// require this, so must conform to this in what follows.
beta_iv = beta_iv'

// What follows is how to set out an optimization in Stata. First, initialize
// the optimization structure in the variable S. Then tell Mata where the
// objective function is, that it's a minimization, that it's a "d0" type of
// objective function (no analytical derivatives or Hessians), and that the
// initial values for the parameter vector are in beta_iv. Finally, optimize.
S = optimize_init()
optimize_init_evaluator(S, &m_mycuecrit())
optimize_init_which(S, "min")
optimize_init_evaluatoretype(S, "d0")
optimize_init_params(S, beta_iv)
beta_cue = optimize(S)

// The last omega is the CUE omega, and the last evaluation of the GMM
// objective function is J.
W = invsym(omega)
j = optimize_result_value(S)
V = 1/N * invsym(QZX' * W * QZX)
st_matrix("r(beta)", beta_cue)
st_matrix("r(V)", V)
st_matrix("r(omega)", omega)
st_numscalar("r(j)", j)
st_numscalar("r(N)", N)
st_numscalar("r(L)", L)
st_numscalar("r(K)", K)
}
end
mata: mata mosave m_mygmmcue(), dir(PERSONAL) replace

```

Let us now examine the evaluation routine. Given values for the parameter vector `beta`, it computes a new value of the omega matrix ( $\Omega$ , the covariance matrix of orthogonality conditions) and a new set of residuals `e`, which are also a function of `beta`. The `j` statistic, which is the minimized value of the objective function, is then computed, depending on the updated residuals `e` and the weighting matrix  $W = \Omega^{-1}$ , a function of the updated estimates of `beta`.

```

. type m_mycuecrit.mata
mata: mata clear

```

14.9 A GMM-CUE estimator using Mata's optimize() functions (with Mark E. Schaffer)341

```

version 10.1
mata: mata set matastrict on
mata:
// GMM-CUE evaluator function.
// Handles only d0-type optimization; todo, g and H are just ignored.
// beta is the parameter set over which we optimize, and
// j is the objective function to minimize.
// m_mycuecrit 1.0.0 MES/CFB 11aug2008
void m_mycuecrit(todo, beta, j, g, H)
{
    external Y, X, Z, e, omega, robustflag
    real matrix W
    real vector gbar
    real scalar N

    omega = m_myomega(beta, Y, X, Z, robustflag)
    W = invsym(omega)
    N = rows(Z)
    e = Y - X * beta'

    // Calculate gbar=Z'*e/N
    gbar = 1/N * quadcross(Z,e)
    j = N * gbar' * W * gbar
}
end
mata: mata mosave m_mycuecrit(), dir(PERSONAL) replace

```

Our Mata-based GMM-CUE routine is now complete. To validate both the two-step GMM routine and its GMM-CUE counterpart, we write a simple certification script (see Section 11.12) for each routine. First, let's check to see that our two-step routine works for both *i.i.d.* and heteroskedastic errors:

```

. cscript mygmm2s adofile mygmm2s
-----BEGIN mygmm2s
-> which mygmm2s
./mygmm2s.ado
*! mygmm2s 1.0.2 MES/CFB 11aug2008
. set more off
.
. mata: mata clear
. program drop _all
. // use http://fmwww.bc.edu/ec-p/data/hayashi/griliches76.dta, clear
. use griliches76, clear
(Wages of Very Young Men, Zvi Griliches, J.Pol.Ec. 1976)
. quietly ivreg2 lw s expr tenure rns smsa (iq=med kww age mrt), gmm2s
. savedresults save ivhomo e()
. mygmm2s lw, endog(iq) inexog(s expr tenure rns smsa) ///
> exexog(med kww age mrt)

Two-step GMM results                                     Number of obs = 758
-----+-----+-----+-----+-----+-----+-----+-----
      lw |          Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----+-----+-----+-----+-----+-----+-----+-----
      iq |   -.0115468    .0052169   -2.21   0.027   -.0217717   -.001322
      s  |   .1373477    .0169631    8.10   0.000    .1041007    .1705947

```

expr	.0338041	.007268	4.65	0.000	.019559	.0480492
tenure	.040564	.0088553	4.58	0.000	.023208	.0579201
rns	-.1176984	.0353037	-3.33	0.001	-.1868924	-.0485043
smsa	.149983	.0314254	4.77	0.000	.0883903	.2115757
_cons	4.837875	.3448209	14.03	0.000	4.162038	5.513711

Sargan-Hansen J statistic: 61.137  
 Chi-sq( 3 ) P-val = 0.0000

```
. savedresults compare ivhomo e(), include(macros: depvar scalar: N j matrix: b
> V) ///
>          tol(1e-7) verbose
comparing macro e(depvar)
comparing scalar e(N)
comparing scalar e(j)
comparing matrix e(b)
comparing matrix e(V)

.
. quietly ivreg2 lw s expr tenure rns smsa (iq=med kww age mrt), gmm2s robust
. savedresults save ivrobust e()
. quietly mygmm2s lw, endog(iq) inexog(s expr tenure rns smsa) ///
>          exexog(med kww age mrt) robust
. savedresults compare ivrobust e(), include(macros: depvar scalar: N j matrix:
> b V) ///
>          tol(1e-7) verbose
comparing macro e(depvar)
comparing scalar e(N)
comparing scalar e(j)
comparing matrix e(b)
comparing matrix e(V)
```

Our `mygmm2s` routine returns the same results as `ivreg2` (Baum et al. (2007)) for the several objects included in the `savedresults compare` validation command.<sup>25</sup> Now we construct and run a similar script to validate the GMM-CUE routine:

```
. cscript mygmmcue adofile mygmmcue
-----BEGIN mygmmcue
-> which mygmmcue
./mygmmcue.ado
*! mygmmcue 1.0.2 MES/CFB 11aug2008
. set more off
. mata: mata clear
. program drop _all
. set rmsg on
r; t=0.00 9:39:34
. use griliches76, clear
(Wages of Very Young Men, Zvi Griliches, J.Pol.Ec. 1976)
r; t=0.00 9:39:34
.
. quietly ivreg2 lw s expr tenure rns smsa (iq=med kww age mrt), cue
r; t=7.18 9:39:41
. savedresults save ivreg2cue e()
```

25. These functions of `ivreg2` have been certified against official Stata's `ivregress`.

14.9 A GMM-CUE estimator using Mata's optimize() functions (with Mark E. Schaffer)343

```
r; t=0.00 9:39:41
. mygmmcue lw, endog(iq) inexog(s expr tenure rns smsa) ///
>      exexog(med kww age mrt)
Iteration 0: f(p) = 61.136598
Iteration 1: f(p) = 32.923655
Iteration 2: f(p) = 32.83694
Iteration 3: f(p) = 32.832195
Iteration 4: f(p) = 32.831616
Iteration 5: f(p) = 32.831615
```

GMM-CUE estimates Number of obs = 758

lw	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
iq	-.0755427	.0132447	-5.70	0.000	-.1015018	-.0495837
s	.3296909	.0430661	7.66	0.000	.245283	.4140989
expr	.0098901	.0184522	0.54	0.592	-.0262755	.0460558
tenure	.0679955	.0224819	3.02	0.002	.0239317	.1120594
rns	-.3040223	.0896296	-3.39	0.001	-.4796931	-.1283515
smsa	.2071594	.0797833	2.60	0.009	.050787	.3635318
_cons	8.907018	.8754361	10.17	0.000	7.191194	10.62284

```
Sargan-Hansen J statistic: 32.832
Chi-sq( 3 ) P-val = 0.0000
```

```
r; t=0.57 9:39:42
. savedresults compare ivreg2cue e(), include(macros: depvar scalar: N j matrix
> : b V) ///
>      tol(1e-4) verbose
comparing macro e(depvar)
comparing scalar e(N)
comparing scalar e(j)
comparing matrix e(b)
comparing matrix e(V)
r; t=0.01 9:39:42
```

```
. quietly ivreg2 lw s expr tenure rns smsa (iq=med kww age mrt), cue robust
r; t=13.46 9:39:55
. savedresults save ivreg2cue e()
r; t=0.00 9:39:55
```

```
. mygmmcue lw, endog(iq) inexog(s expr tenure rns smsa) ///
>      exexog(med kww age mrt) robust
Iteration 0: f(p) = 52.768916
Iteration 1: f(p) = 28.946591 (not concave)
Iteration 2: f(p) = 27.417939 (not concave)
Iteration 3: f(p) = 27.041838
Iteration 4: f(p) = 26.508996
Iteration 5: f(p) = 26.420853
Iteration 6: f(p) = 26.420648
Iteration 7: f(p) = 26.420637
Iteration 8: f(p) = 26.420637
```

GMM-CUE estimates Number of obs = 758

lw	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
iq	-.0770701	.0147825	-5.21	0.000	-.1060433	-.048097
s	.3348492	.0469881	7.13	0.000	.2427542	.4269441
expr	.0197632	.0199592	0.99	0.322	-.019356	.0588825

tenure	.0857848	.0242331	3.54	0.000	.0382888	.1332807
rns	-.3209864	.091536	-3.51	0.000	-.5003937	-.1415791
smsa	.255257	.0837255	3.05	0.002	.091158	.419356
_cons	8.943698	.9742228	9.18	0.000	7.034257	10.85314

Sargan-Hansen J statistic: 26.421  
 Chi-sq( 3 ) P-val = 0.0000

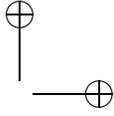
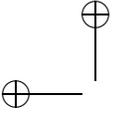
r; t=0.68 9:39:56

```
. savedresults compare ivreg2cue e(), include(macros: depvar scalar: N j matrix
> : b V) ///
```

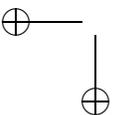
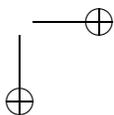
```
>          tol(1e-4) verbose
comparing macro e(depvar)
comparing scalar e(N)
comparing scalar e(j)
comparing matrix e(b)
comparing matrix e(V)
r; t=0.01 9:39:56
```

We find that the estimates produced by `mygmmcue` are reasonably close to those produced by the different optimization routine employed by `ivreg2`. As we sought to speed up the calculation of GMM-CUE estimates, we are pleased to see the timings displayed by `set rmsg on`. For the non-robust estimates, `ivreg2` took 6.07 seconds, while `mygmmcue` took 0.51 seconds: a twelve-fold speedup. For the robust CUE estimates, `ivreg2` required 12.69 seconds, compared to 0.64 seconds for `mygmmcue`: an amazing twenty times faster. Calculation of the robust covariance matrix using Mata's matrix operations is apparently much more efficient from a computational standpoint.

Although this Mata-based GMM-CUE routine for linear instrumental variables models is merely a first stab at taking advantage of Mata's efficiency, it is evident that the approach has great potential for the development of more readable and efficient code.



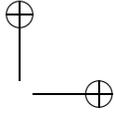
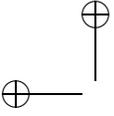
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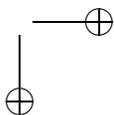
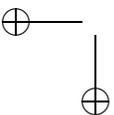
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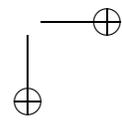
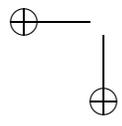
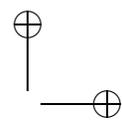
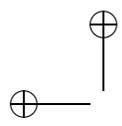
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