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Measuring Firms' R&D Effects on Technical Progress: Japan in the 1990s

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1. Introduction

One of the important public policy issues in science and technology is to ascertain if and how firms' investments in research and development (R&D) contribute to technical change (TC) at firm and industry levels. Griliches (1979) made the pioneering contribution to our understanding of economic growth by pointing out that accumulation of firms' investments in R&D and creation of knowledge will lead to TC, which in turn will increase total factor productivity growth (TFPG).[1] Griliches (1996, f.n. 11) subsequently pointed out the importance of explaining TC. In order to achieve this goal it is necessary to estimate firms' TC. In this paper we present a method based on index number theory for estimating TC and then apply it for estimating TC for firms in Japanese manufacturing industries in the 1990s.

Broadly speaking there are two approaches used in the literature for empirically measuring the contributions of R&D to technical progress. In the first approach, researchers assume that the firm's production environment is given by a Cobb-Douglas production function such as

(1-1) $y = e^{rt} K^{\alpha} L^{\beta} R^{\gamma}$

where y is firm's output, K, L and R are, respectively, the fixed capital stock, labor service input and the stock of knowledge (research) capital, r is the exogenously given rate of disembodied technical change over time (t), and α, β and γ are positive scalar share parameters, respectively, for fixed capital stock, labor input and knowledge capital stock.[2] In most empirical studies using this model it is typical to assume constant returns to scale with respect to capital stock and labor ($\alpha+\beta=1$). By taking natural log of the both sides of (1-1) we obtain a model specification which is linear in lny, lnK, lnL and lnR. (1-1) also implies (e.g. Griliches and Lichtenberg (1984)) that, for TFP defined by

(1-2) $T(t) = y / K^{\alpha} L^{\beta}$

TFPG is given by

(1-3) $[(dT(t))/dt / T(t)] = r + \gamma\, [dK(t) / K(t)]$

or

(1-4) $[(dT(t))/dt / T(t)] = r + \rho\, ((dK(t) / K(t)) / y(t)$

where $\rho = \partial y / \partial K$. For estimated TFPG ((dT(t))/dt / T(t)) and knowledge capital growth ((dK(t) / K(t)) regression equations using (1-3) and (1-4) provide estimates for γ (or ρ) which represents the contributions of R&D to total factor productivity growth. Interpreting estimated γ (or ρ) precisely, however, is not straightforward for the following reasons: whether or not the coefficient of the R&D stock variable should be included in the definition of the constant returns to scale (Griliches and Lichtenberg (1984)); the effects of scale economies are not explicitly modeled; the conceptual difficulty of TFP (1-2) which does not include one of the production inputs (R); and the double counting of firms' investment in R&D (Griliches (1980),

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[1] This is one of the basic notions underlying endogenous growth theory proposed in the literature (Romer (1990)).

[2] Materials and energy are other production inputs that are sometimes included in (I.1) in previous studies.

Schankerman (1981)). Another reason is that firms' R&D investment in practice takes the form of expenditures for procuring standard production inputs such as physical capital and labor services.

The second approach is to assume a production function with inputs such as fixed capital stock and labor but not knowledge capital stock. Firms' TFPG or TC is calculated for this production environment and then is regressed on the firms' R&D investment or other variables representing the firms' R&D activities. In this approach all physical investments (e.g. capital equipment and labor) procured by R&D projects are included in the included production inputs and TC represents only the part of TFPG which can not be explained by the simple growth of production inputs. This approach recognizes explicitly the potential role of firms' R&D investment in enhancing their technical change, as was proposed by Griliches (1979).

These two approaches to modeling R&D are complementary and are sometimes used (at least conceptually) interchangeably in the literature.[3] In this paper we use the modeling framework adopted in the second approach. We first present an empirical specification for estimating TC directly while controlling for the effects of economies of scale. We then apply the method to estimate TC for Japanese manufacturing firms and also measure the impacts of the firms' investments in R&D on their TC.

Japanese manufacturing firms' R&D investment and productivity

A number of previous studies have found statistically significant impacts of U.S. firms' investments in R&D on their output productivity measured in a variety of ways (e.g. Griliches (1986, 1994), Griliches and Lichtenberg (1984)). In particular Griliches and Lichtenberg (1984) showed that R&D had significant positive impacts on total factor productivity growth for firms using U.S. data up to the 1970s. Lichtenberg and Siegal (1991) and Griliches (1994) found similar impacts for R&D for the 1980s. Despite Japanese manufacturers' significant levels of R&D activities, relatively little empirical evidence seems available the literature on the impact of their R&D investments on TC (or more broadly on TFPG) (Kinukawa (2000). Exceptions to this include Griliches and Mairesse (1990) who did not find such relationships for Japan for the period 1974-80 and Odagiri and Iwata (1986) and Goto and Suzuki (1989) who found some evidence for such relationships for the periods 1966-82 and 1978-1983, respectively. In this paper we investigate empirically if such relationships existed for Japanese firms in the 1990s.

The primary objective of this paper is to test empirically the hypothesis proposed by Griliches (1979) that firms' investments in R&D contribute to increasing their TC using data for Japanese manufacturers for the period 1988-98.[4] TFPG primarily consists of TC and economies of scale the latter of which may systematically vary with firm characteristics. Our econometric specification has some advantages in testing the Griliches hypothesis at least for Japanese firms for which significant short-run economies of scale have been observed for the sample period.[5]

[3] For example, Griliches and Lichtenberg (1984, p.481) and Lichtenberg and Siegel (1991, eq.(1)) use empirical specifications in which total factor productivity growth is regressed on net change in R&D stock. Relatively little structural interpretations of the regression coefficient of net change in R&D stock appear to be possible.
[4] Previous empirical estimates for Japan including those cited above did not explicitly control for scale economies.
[5] For example, Nakajima, Nakamura and Yoshioka (1998), Nakajima, Nakamura, Nakamura and Yoshioka (2002) report statistically significant short-run economies of scale for Japanese manufacturing firms for the 1990s.

As discussed below estimating TC while controlling for scale economies typically suffers from sample multicollinearity problems.[6] In order to control for scale economies in our estimation task we will use an empirical framework which takes advantage of certain properties of index numbers.

In this paper we first estimate TC and scale elasticity (elasticity of scale) using data at both establishment and firm levels for each of 22 Japanese manufacturing industries. TFPG, which is the sum of TC and economies of scale, is also estimated. At the firm level TC measures not only technical progress that takes place at the establishment level but also managerial improvements brought about by such means as investing in information technologies, educating managerial personnel, and rationalizing the firms' overall workforce. Therefore studying technical change behavior at both the establishment and firm levels will shed light on the efficiency at the firm-level of productivity improvement beyond scale economies and technical progress at the establishment level. We then estimate the effects of firms' R&D on TC. We find some empirical evidence that Japanese firms' TC was improved by R&D investments during the 1990s. This is consistent with the Griliches hypothesis.

We also find some evidence that TC (and TFPG) for Japanese manufacturing industries declined significantly in the late 1980s, during the few years prior to the burst of the financial bubble in 1990. This suggests the existence of massive investments in inputs by Japanese manufacturers, where such capacity expansions were not accompanied by technical progress.

The organization of the rest of the paper is as follows. In the next Section 2 we present our empirical framework for estimating TC and economies of scale using Japanese data at the establishment and firm levels. In Section 3 we present and discuss our estimation results for TC and economies of scale. In Section 4 we present regression results measuring the relationship between firms' R&D investments and TC. Section 5 concludes.

2. Methodology for Estimating Technical Progress and Returns to Scale

It is important to control for returns to scale in estimating TC. Many previous studies, however, have reported difficulties in implementing estimation strategies which can control for estimating or controlling for returns of scale in a robust manner. Sample multicollinearity is the primary reason for such observed difficulties. A standard method to estimate these unknown parameters is to estimate a flexible cost function using cost share equations. However, estimating scale economies using a translog cost function, for example, requires the estimation of the cost function itself as well as the share equation system. Since output, its squares and its cross products with input prices are all in the cost function, multicollinearity can potentially cause serious estimation problems.

For example, in studying the efficiency of U.S. manufacturing industries, Caves and Barton (1990, p. 34) note that "The idea of an intensive examination of scale economies was dropped after the results for the twelve-industry panel were analyzed. The behavior of the estimated coefficients, especially in the translog functions, did not inspire confidence in our ability to determine the minimum efficiency scales...." Efficient estimation based on fully

[6] As discussed below, this is because regression equations for isolating scale economies by definition require either output or cost variables on the right-hand side and such variables are often highly correlated with time trends or price variables.

simultaneous estimation of all unknown parameters is also desirable but our own computational experiences as well as others' suggest it is not always possible to implement it where serious multicollinearity problems exist. For example, in a study to estimate scale economies and technical progress (approximated by time) using time series data and a translog production function, Chan and Mountain (1983, p. 665) state that ".... All these problems point towards the difficulty of distinguishing between scale economies and time at such an aggregate level." Banker, Charnes, Cooper and Maindiratta (1988, p. 40) also note that their procedure is likely to provide unreliable estimates for returns to scale if there is a collinearity problem in estimating flexible form production functions.

In this study we use an estimating framework that can accommodate a broad range of underlying production structures while limiting the number of unknown parameters to be estimated. Our estimation model contains only a few explanatory variables which are not highly collinear in cross sections and over time. Our method, which is parsimonious in terms of the number of unknown parameters to be estimated, incorporates flexible production functions and provides a statistically consistent means for estimating scale economies and technical progress.

We begin by considering the concept of returns to scale in the cross section, and then go on to allow for disembodied technical change over successive 2-year time periods.[7] Although the forms of returns to scale and technical progress that we allow for are simplistic, in the empirical application of our methodology, the estimation is carried out separately at both the establishment and firm levels for roughly two dozen industries and for success pairs of years over the 1980s and 1990s. This renders less serious the limitations of the methodology.

2.1 Returns to Scale

Our methodology presumes that panel data are available for one or more samples of production units (PUs, indexed for each sample by $i = 1,\ldots,I$) of some sort -- establishments and also firms in each of about two dozen industries in this study, and that the PUs have approximately the same production structure for successive pairs of years over some period of time $t = 1,\ldots,T$ where T is at least 2. In this study, output for each PU is measured as real sales (denoted by the scalar, y^{it}). On the input side, data are needed for the quantities for N inputs for each PU in each year (the column vectors $x^{i,t} = (x_1^{i,t},\ldots,x_N^{i,t})$), and we need unit prices for the inputs (the column vectors $w^{i,t} = (w_1^{i,t},\ldots,w_N^{i,t})$). Our establishment and firm level data are described more fully in section 3.

For now we ignore the time dimension (and omit the time superscript) so as to focus on the measure of returns to scale.

We assume that the structure of production can be described by a production function f which is homogeneous of degree k, where the constant term and the returns to scale and technical progress parameters are allowed to vary over industries and from one 2-year time internal to the next.

[7] The methodology here can be easily extended for the case where more than two time periods of cross-section data are available.

Thus, for the establishments or firms in each of our industry, 2-year data samples, we assume that the structure of production can be described in each year by a homogeneous of degree k production function denoted by

(2-1) $$y^i = f(x^i) .$$

It follows from the homogeneity assumption for the production function that if the input vector for the j^{th} PU equals λ times the input vector for PU i, then the level of output for the j^{th} PU is given by λ to the k^{th} power times the output quantity for PU i; i.e.,

(2-2) $$\begin{aligned} y^j &= f(x^j) \\ &= f(\lambda x^i) \\ &= \lambda^k f(x^i) \\ &= \lambda^k y^i. \end{aligned}$$

Taking natural logarithms (denoted by ln), from (2-2) we have

(2-3) $$\ln y^j - \ln y^i = k \ln \lambda .$$

Expression (2-3) can be solved for k, yielding

(2-4) $$k = (\ln y^j - \ln y^i) / \ln \lambda .$$

This is the elasticity of returns to scale with respect to output for the degree k homogenous production function f.

For a pair of PUs i and j that have the production structure described by (2-2), λ is the factor by which the input quantities for PU i must be inflated in order to move from the PU i to the PU j production surface. This is the definition of a Malmquist input quantity index for comparing the inputs of PU i with those of PU j using the technology of PU i. We denote this Malmquist input quantity index by $Q^{*i,j}_{M|i}$ where the superscripts indicate which PUs are being compared, the subscript M denotes that this is a Malmquist index (the notation M(t) will be used instead when we also wish to note the time period for the index) and the subscript i denotes that the comparison is based on the technology of PU i. Similarly, $(1/\lambda)$ is the factor by which the input quantities for PU j must be reduced in order to move from the PU j to the PU i production surface. This is the definition of a Malmquist input quantity index for comparing the inputs of PU j with those of PU i using the technology of PU j. We denote this Malmquist input quantity index by $Q^{*j,i}_{M|j}$. There is no obvious reason for preferring either $Q^{*i,j}_{M|i}$ or $Q^{*j,i}_{M|j}$. Thus, Caves, Christensen and Diewert (1982b) define the geometric average of these two Malmquist input indexes to be *the* Malmquist index for comparing the inputs of firms i and j, with this Malmquist input index denoted equivalently by $Q^{*i,j}_{M}$ or $Q^{*j,i}_{M}$. Thus, what we will refer to as the Malmquist input index is given by

(2-5)
$$Q_M^{*i,j} = (Q_{M|i}^{*i,j} Q_{M|j}^{*j,i})^{(1/2)} = Q_M^{*j,i}.$$

In the following we present our estimation method for two important classes of flexible production functions, translog and quadratic functions.

Case 1. Translog production function

In general, Malmquist indexes are theoretical constructs that cannot be evaluated using observable price data. However, Caves, Christensen and Diewert (1982b) provide theoretical results showing conditions under which the Malmquist input index equals the Törnqvist input quantity index (Theil (1965), Törnqvist (1936) and Fisher (1922)) denoted by $Q_T^{*i,j} (= Q_T^{*j,i})$.[8] One of the conditions under which this will be true is when the PUs have the same translog production function. Thus, f is translog, we have

(2-6)
$$\lambda = Q_M^{*i,j} = Q_T^{*i,j}$$

where

(2-7)
$$\ln Q_T^{*i,j} = (1/2)(s^i + s^j)'(\ln x^j - \ln x^i).$$

Under the additional assumption that the PUs minimize costs, then $s^i = (s_1^i, \ldots, s_N^i)$ and $s^j = (s_1^j, \ldots, s_N^j)$ are the cost share vectors for the n input factors for the two PUs. The input price vectors for the PUs i and j are denoted by $w^i = (w_1^i, \ldots, w_N^i)$ and $w^j = (w_1^j, \ldots, w_N^j)$, and the elements of the cost share vectors are given by

(2-8)
$$s_n^i = (w_n^i x_n^i)/(w^{i\prime} x^i) \quad \text{and} \quad s_n^j = (w_n^j x_n^j)/(w^{j\prime} x^j)$$

where a prime denotes a transpose.[9] Yoshioka, Nakajima and Nakamura (1994) and Nakajima, Nakamura and Yoshioka (1998) presented an alternative proof of (2-6) - (2-8). (See Appendix A.) The Törnqvist input quantity index defined in (2-7) can be evaluated from the data available to us for plants and for firms.

Suppose that the production function is a homogeneous of degree k translog function (Christensen, Jorgenson and Lau (1973)) given by

(2-9)
$$k^{-1} \ln f(x^i) = \beta_0 + \beta_1' \ln x^i + (1/2) \ln x^{i\prime} R \ln x^i.$$

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[8] Caves, Christensen and Diewert (1982a) also establish this result for the case where the two PUs have translog distance functions with different first order coefficients provided that the returns to scale are constant or decreasing (that is, provided that k=1 or k<1), but we cannot exclude the increasing returns to scale case of k>1 in this present study.

[9] Note that the PU specific price vectors are treated as being given exogenously and are assumed not to depend on the level of production for a PU, though they can very over the PUs.

In our setting the unknown parameters in (2-9) are β_0, a scalar, β_1, a column vector of coefficients with column sum 1, and k, a scalar representing the degree of homogeneity. R is a non-positive definite matrix with column sums equal to 0. The dimensions of β_1 and R conform to that of x^i.

For a given time period, if the technology of the PUs i and j can be represented by the translog production function given in (2-9), then under the assumptions that have been made and using (2-6), the returns to scale in the cross-section can be represented as

(2-10)
$$k = (\ln y^j - \ln y^i)/\ln Q_T^{*i,j}$$
$$= [\ln f(x^j) - \ln f(x^i)]/\ln Q_T^{*i,j}$$

where $\ln Q_T^{*i,j}$ is given by (2-7).

Case 2. Flexible quadratic production function

Suppose the underling homogeneous of degree k production has Diewert's (1976) flexible quadratic form as follows:

(2-11) $$y^i = f(x^i) = (x^{i\prime}\, A\, x^i)^{k/2}$$

By Euler's theorem we have $ky^i = \nabla f(x^i)'x^i$. Cost minimization implies that the input price vector w^i is proportional to $\nabla f(x^i)$, i.e. $w^i \propto \nabla f(x^i)$. Thus we have

(2-12) $$\nabla f(x^i)'/ ky^i = \nabla f(x^i)' (\nabla f(x^i)'x^i) = w^{i\prime}/ w^{i\prime}x^i$$

Using the Laspeyres input quantity index, $Q_L = (w^{i\prime}x^j / w^{i\prime}x^i)$, and the Paasche input quantity index, $Q_P = (w^{j\prime}x^j / w^{j\prime}x^i)$, we can write the Fisher (1922) ideal input quantity index as follows:

(2-13) $$Q_F = (Q_L Q_P)^{1/2} = ((w^{i\prime}x^j / w^{i\prime}x^i)(w^{j\prime}x^j / w^{j\prime}x^i))^{1/2}$$
$$= [(\nabla y^{i\prime}x^j / k\, y^i)(k\, y^j / (\nabla y^{j\prime}x^i))]^{1/2}$$
$$= [\{y^j (x^{i\prime} \nabla x^i) /y^i (x^{j\prime}\nabla x^j)\} \{ (y^{i\prime} \nabla x^j) /(x^{j\prime} \nabla x^i)\}]^{1/2}$$
$$= (y^i / y^j)^k,$$

where (2-11) and (2-12) have been used.[10]

Thus we have

(2-14) $$k = (\ln y^j - \ln y^i) / \ln Q_F$$

or

[10] Yoshioka, Nakajima and Nakamura (1994, pp.62-64) presented this proof.

(2-15) $\ln y^j - \ln y^i = k \ln Q_F$.

From (2-4) and (2-15) we have $\lambda = Q_F$ for the quadratic production case.

A more direct proof based on the Malmquist quantity index for the flexible quadratic production function case, which is similar to the proof given above for Case 1, is also possible and is given as follows.

Using results in Diewert (1992, p.239) we can show that, for the flexible quadratic production function,

(2-16) $$\lambda = Q_M^{*i,j} = Q_F^{*i,j}.$$

Thus it follows from (2-4) that

(2-17) $$\ln Q_F^{*i,j} = (\ln y^j - \ln y^i)/k.$$

We have shown that when the production functions have flexible translog or quadratic forms, the returns to scale parameter k can be described simply as the difference between the logs of output observed for two sample points divided by the log of the relevant input quantity index. We will use this fact below for devising econometric specifications which are parsimonious in the number of unknown parameters to be estimated.

2.2 Disembodied Technical Change

In this study, we do not allow for within-industry cross section differences in the rate of technical change (TC). In the time dimension, we allow for technical progress from one year to the next for the establishments or firms in an industry, but do not allow for returns to scale over time. More specifically, when modeling the production activities of PUs in the same industry over multiple time periods, we assume a production function that incorporates time as a separable variable:

(2-18) $$y^{i,t} = f(x^{i,t}, t) = \lambda^{-k} f(\lambda x^{i,t}, t).$$

In this equation, $y^{i,t}$ and $x^{i,t}$ are, respectively, the scalar output quantity and the production input vector for the i^{th} PU in period t, and where λ is a positive constant as before.

We assume that for one time period forward at a time, the technical progress of the PUs can be described, as a first order approximation, by

(2-19) $$\partial \ln y^{i,t} / \partial t = \partial \ln f(x^{i,t}, t) / \partial t = r$$

where r is a constant. With this assumption, (2-18) can be expressed as

(2-20) $$y^{i,t} = f(x^{i,t}) e^{rt},$$

so that we have

(2-21) $$k^{-1}\ln y^{i,t} = k^{-1}\ln f(x^{i,t}) + (k^{-1})rt .$$

In (2-18), $k^{-1}\ln f(x^{i,t})$ is assumed to obey the translog function given in (2-9).

3. Our Empirical Approach

3.1 A Basic Estimating Equation

We assume in the rest of this paper that the translog homogeneous of degree k production function characterizes the production environment for firms and establishments.
Suppose that the production for the PUs in an industry is described by

(3-1) $$\ln y^{i,t} = \ln f(x^{i,t}) + rt ,$$

as follows from (2-20). For some reference PU in some given time period s ($1 \le s \le T-1$), say A, from (3-1) we have

(3-2) $$\ln y^{A,s} = \ln f(x^{A,s}) + rs .$$

Now, consider any other PU in time period s, say i. From (3-1) we have

(3-3) $$\ln y^{i,s} = \ln f(x^{i,s}) + rs .$$

Subtracting (3-3) from (3-2) we have

(3-4) $$\ln y^{A,s} - \ln y^{i,s} = \ln f(x^{A,s}) - \ln f(x^{i,s}) .$$

Using (2-10), we have the result that

(3-5) $$\ln f(x^{A,s}) - \ln f(x^{i,s}) = k \ln Q^{*A,i}_{T(s)}$$

where the Törnqvist index on the right compares the inputs for the establishment or firm i with those for the reference plant or firm in period s.

For period s+1, the appropriate reference PU for our purposes is A in period s+1, but with the same input vector as in period s; that is, we use

(3-6) $$\begin{aligned} \ln y^{A,s+1} &= \ln f(x^{A,s}) + r(s+1) \\ &= \ln y^{A,s} + r. \end{aligned}$$

Thus for any given period s ($1 \le s \le T-1$), from (3-4) and (3-5) we see that the period s output for the i[th] PU is related to the period s output of the reference PU by

(3-7) $$\ln y^{i,s} = \ln y^{A,s} + k \ln Q^{*A,i}_{T(s)}.$$

And for period s+1 we have

(3-8) $$\begin{aligned} \ln y^{i,s+1} &= \ln y^{A,s+1} + k \ln Q^{*A,i}_{T(s+1)} \\ &= \ln y^{A,s} + r + k \ln Q^{*A,i}_{T(s+1)} \end{aligned}$$

where $\ln y^{A,s+1}$ is the hypothetical expected output of the reference PU in period s+1 given by (3-6).

Our basic estimating equation is obtained by combining (3-7) and (3-8) as

(3-9) $$\ln y^{i,t} = \beta_0 + \beta_1 D_{i,t} + \beta_2 \ln Q^{*i,A}_{T(t)} + u^{i,t},$$

where $\beta_0 = \ln f(x^{A,s}), \beta_1 = r, \beta_2 = k$ and where the time dummy is defined by

(3-10) $$\begin{aligned} D^{i,t} &= 1 \quad \text{if} \quad t = s+1 \\ &= 0 \quad \text{if} \quad t = s. \end{aligned}$$

The error term u has been added in (3-9) because it is assumed that the derived estimating equation holds with error for the observed data. In estimation, we treat the error term $u^{i,t}$ as randomly distributed in the annual cross sections with zero mean and constant variance σ_u^2 and over time (for t=s, s+1) as autocorrelated with ρ as the first order autocorrelation for the PUs in each of our industry and 2-year subsamples of data for plants and for firms.

There are only three unknown parameters to estimate in our econometric specification (3-9)[11].

In general, year dummy D_{it} and Translog input quantity chain index number q_{it} in (3-9) are not expected to be highly correlated.[12] This will allow us to empirically identify both r(S) and k(S) without the sample problem of multicollinearity. Since we allow the error term ε_{it} in (3-9) to obey a first-order autoregressive process, we estimate b_0, b_1 and b_2 using generalized least squares (GLS).

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[11] In estimating scale economies and technical change using aggregate time series, Chan and Mountain (1983), for example, both had to estimate 22 unknown parameters using 25 annual observations.

[12] For our particular data set used, the correlation coefficients calculated for the 22 manufacturing industries are quite small and range between .009 and .025.

To estimate (3-9), a reference PU must be selected or created, and then the values must be calculated for the Törnqvist index for comparing the input quantities of each of the estimation sample PUs with the input quantities for the reference PU.

In the case of our establishment data, for each of our industry- 2 year panel data samples, the smallest plant size group for the first of the two years is used as the reference production unit. We then computed Törnqvist indexes comparing the output of each of the other plants to the reference production unit.

For our firm data, we have followed the method proposed by Cave, Christensen and Diewert (1982a) to compute Törnqvist-type input index values.

Our data

We use two sets of data.

Establishment data

The Japanese Ministry of Economy, Trade and Industry (METI)[13] conducts annually the Census of Manufacturing by Industry. (20 manufacturing industries are involved.) For each year this Census consists of a cross section of establishments chosen based on the number of employees. Typical size groups (the numbers of employees) used are: (1) 30-49, (2) 50-99, (3) 100-199, (4) 200-299, (5) 300-499, (6) 500-999 and (7) 1000 and more. (The number of these groups and hence the definitions of size groups vary somewhat over time, however.) Henceforth "the size" refers to the size of establishment measured in terms of the number of employees. MITI publishes only average figures for each of the size groups by industry.

In the following these grouped data on establishments will be viewed as ordered cross-sectional observations ($i = 1, 2, ..., I$); that is, establishments are ordered in the ascending order of size: $i = 1$ and $i = I$ correspond to the smallest and largest size groups, respectively. The production inputs included are: the number of workers (x_1) as labor, the fixed assets at the beginning of each year (x_2) as capital, and the intermediate goods (x_3) as raw material, all measured per establishment.[14,15] Capital (x_2) is adjusted for by the industry-specific capital utilization rate reported by METI.

The corresponding input prices used are: the average annual cash earnings per worker (w_1) for x_1, the depreciation rate for fixed assets plus the average interest rate for one-year term-deposit (w_2) for x_2. Intermediate goods price w_3 is assumed to be one since it is common for all observations for each industry and for each year. Output (y) is measured as net sales plus net increases in the inventories of final products.

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[13] Formerly the Ministry of International Trade and Industry (MITI).

[14] Establishment data of this sort exist, for example, for Japan and Norway. Recall the input price vector is denoted by $w = (w_1, w_2, ..., w_N)$, where w_k is the price for the k-th input w_k, $k = 1,2,...,N$.

[15] It is possible that the costs of capital, for example, facing establishments of systematically differ depending on firm size. Since our data base does not allow identification of the sizes of firms which own establishments in our sample, we did not attempt to use size-based costs of capital in this paper.

In order to estimate equation (3-9) using our data pooled over time periods and establishments, it is necessary to deflate (1964=100) some of the quantities defined above. The Bank of Japan output price index by industry is used to deflate our output variable y (sales). In computing the capital stock x_2, new investment in fixed assets is deflated using the investment goods deflator by industry published by the Economic Planning Agency. The input price of capital (w_2) is also adjusted by the investment goods deflator. The input of intermediate goods (w_3) is now deflated by the Bank of Japan input price deflator which is also used as the price of intermediate goods (w_3).[16]

Firm data

The primary source of our firm data is the company financial statements filed with the Ministry of Finance and compiled by the Japan Development Bank. We use the following four production inputs: the number of workers (x_1) as labor, the fixed assets at the beginning of each year (x_2) as capital, raw material (x_3) and other input goods (x_4),[17] all measured per firm. Capital (x_2) is adjusted for by the industry-specific capital utilization rate reported by METI.

The corresponding input prices used are: the average annual cash earnings per worker (w_1) for x_1, the depreciation rate for fixed assets plus the average interest rate for one-year term-deposit (w_2) for x_2, the Bank of Japan input price index is used as the price of raw materials (w_3), and the GDP deflator is used as the price of other inputs (w_4). Firms' net sales is used as output (y) and Bank of Japan's industry output price index is used as the deflator of output (1988=100).

In computing the capital stock x_2, new investment in fixed assets is deflated using the investment goods deflator by industry published by the Economic Planning Agency. The input price of capital (w_2) is also adjusted by the investment goods deflator.

Estimated aggregate TFPG at the industry level is calculated as the sum between estimated industry level technical change and scale elasticity, where the industry level estimates for technical change and parameters were obtained by aggregating PU level estimates.[18]

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[16] Because of the lack of correct industry-specific deflators not all manufacturing industries will be included in our empirical analysis for all time periods.

[17] This is measured on a cost basis and includes all expenses other than the expenses for labor, raw material and depreciation.

[18] The specific method we used is Nakajima, Nakamura and Yoshioka (1998, Eq. (A18)). Alternatively a standard method to measure TFPG is

(*) $\ln[TFP(t+1)/TFP(t)]=\ln[Y(t+1)/Y(t)]-\Sigma_{k=1}^{N}\ (1/2)\{s_k(t)+s_k(t+1)\}\ln[x_k(t+1)/x_k(t)]$,

where aggregate output Y and aggregate production input indices x_k are defined by $Y(t) = I(t)\int y dF_t(y)$ and $x_k(t) = I(t)\int x_k dG_t(x_k)$, respectively. In the definitions above $s_k(t)$ denotes the scalar cost share for the k-th aggregate production input; I(t) denotes the total number of establishments in period t; y and x_k denote the random variables representing, respectively, the output and the k-th production input for a representative establishment; and $F_t(y)$ and $G_t(x_k)$ denote, respectively, the distribution functions for random variables y and x_k in period t. Strictly speaking, the above definition (*) of TFPG is a valid measure of TFP growth under the assumption of constant returns to scale. This assumption seems satisfied at the industry level in this study. (See Chan and Mountain (1983) for a modification of the above when constant returns to scale cannot be assumed.) We have also estimated the industry level TFPG using the above standard method (*). The estimated results were similar for both methods (Table A1).

3. Estimation Results: the Rate of Technical Change, the Elasticity of Scale and TFP Growth

Establishments

Our estimation results for TC, the elasticity of scale and TFPG for establishments for the period 1964-1998 are presented in Tables 1,2 and 3, respectively. Technical change and elasticity of scale estimates are summarized in Figures 1-5 for various sub-sample periods. Since estimation results for establishments for 1964-88 are discussed in detail elsewhere,[19] we discuss our results for 1988-98 here. All of the Japanese manufacturing industries recorded significant reductions in TFP between the 1964-88 period and the 1988-98 period, showing the drastic negative impact of the burst of the financial bubble in the 1990-91 period and the subsequent economic problems on the Japanese manufacturing industries.[20] 8 manufacturing industries (apparels, furniture/wood products, petroleum/coal products, rubber products, steel/iron, electrical machinery, transportation machinery and precision) registered average TFP growth rates above 4% during the 1964-88 period, with the highest growth rate registered by the electrical machinery industry. Only the electrical machinery industry achieved TFP growth of above 1% (i.e. 2.37%) for the period 1988-98. The second highest TFP growth was recorded by the precision industry (0.59%). This is consistent with estimates for TFP growth reported elsewhere for Japan.[21]

Since a relatively large portion of the long-run variation over time in Japanese TFPG is typically explained by technical change,[22] what is said about the behavior of TFPG above carries over to TC to some extent.[23] The rate of TC declined for all Japanese manufacturing industries from the 1964-88 period to the 1988-1998 period. 10 manufacturing industries registered the average rates of technical progress above 1% over the period 1964-88. Chemicals, electrical machinery, transportation machinery and precision registered technical progress rates above 2%. For the 1988-98 period only the electrical machinery industry achieved the average rate of technical progress above 2%. Unlike TFP growth, however, we see some other industries which recorded technical progress rates close to 1%: Chemicals (0.903%) and textiles (0.845%), to be followed by plastic products (0.604%), rubber products (0.577%), precision (0.550%), steel/iron (0.423%) and transportation machinery (0.266%). This performance of technical progress of the Japanese manufacturing industries at the establishment level was not outstanding but was quite robust. This behavior in technical progress of Japanese manufacturing may provide partial

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[19] Nakajima, Nakamura and Yoshioka (1998) and Yoshioka, Nakajima and Nakamura (1994).

[20] Our sample period 1988-98 includes the years (1990-91) when the financial bubble is thought to have burst.

[21] For example, OECD reports the following business sector TFP growth rates for the periods 1960-73, 1973-79 and 1979-1997: 4.9%, 0.7% and 0.9% for Japan; 1.9%, 0.1% and 0.7% for the U.S.; and 3.7%, 1.6% and 1.3% for France.

[22] See Table 7 for decompositions of TFP growth into technical change and scale economies for 1964-88. See Tables 8A and 8B for decompositions of TFP for 1988-98.

[23] A number of papers have pointed out that a rapid growth of output is possible over a period of years even though TFP growth during those years is negative. For example, Park and Kwon (1995) attribute the rapid growth of the South Korean economy for the period 1966-89 to the effects of scale economies in particular while the TFP growth during the same period is often non-existent or negative. Their findings seem to be consistent with Kim and Lau's (1995) findings that the rapid economic growth of newly industrialized countries in East Asia was accompanied by little indigenously generated technical progress.

explanations for Japan's continuing strengths in exports of manufacturing goods. This may deserve further investigation.

Our estimates for the elasticity of scale for establishments are reported in Table 3. For both the 1964-88 and 1988-98 periods the null hypothesis of constant returns to scale (k=1) is decisively rejected for many industries and many years in favor of the alternative hypothesis of increasing returns to scale (k>1).[24] Our establishment data for the 1964-88 period is not adjusted for the idle capacity of physical capital stock. This may affect our scale elasticity estimates for this earlier period but the direction of a potential bias from this is unclear.[25] The establishment data is adjusted for idle capital stock for the 1988-98 period. While our year-by-year estimates for the elasticity of scale suggests the presence of increasing returns to scale for many industries, the estimated effects of scale economies on TFPG are generally very small, compared to the large contribution of technical change. More than 90% of the gains in TFP at establishments during our sample period 1964-98 is typically due to technical progress (Tables 7 and 8A).[26]

These results also support the standard practice in macro econometric modeling (e.g. Solow (1957) and Jorgenson, Gollop and Fraumeni (1987)) that attributes gains in TFP at the aggregate level to technical change by specifying an aggregate production function to be homogeneous of degree one.[27]

Our findings that the effects of scale economies exist at the establishment level but disappear at the aggregate level imply, among other things, that establishment size does not adjust rapidly within the time period we consider. That is, large establishments do not grow at the expense of small establishments. It is the slowly increasing technical level that explains most of the gains in aggregate TFP in the Japanese manufacturing sector. Our empirical results suggest the presence of slow but steady technical progress for the Japanese manufacturing sector.[28]

Firms

Our estimation results for TFPG, TC and elasticity of scale (ES) for manufacturing firms for the period 1988-1998 are presented in Tables 4,5 and 6, respectively. Estimates for TP and ES are summarized in Figures 6-9 for various sub-sample periods.

By comparing TFPG estimates for firms and establishments for 1988-98 (Tables 1 and 4) we see that TFPG for firms was higher than TFPG for establishments for 8 out of 20

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[24] The exceptions are textile, pulp, non-ferrous metals and steel/iron industries for 1964-88.

[25] During business downturns in Japan it is typical that small establishments suffer from excess capacity much more than large establishments, resulting in an overestimation of scale elasticity. During the 1970s and the 1980s when depressed industries were restructured, however, many of the small establishments in these depressed industries dropped out of our data sample. When a data sample has a relatively large number of large establishments with idle capacity, scale elasticity is usually underestimated.

[26] However, the Table 8A shows that the massive downsizing that has been taking place at Japanese manufacturing establishments in the 1990s has driven some of our scale elasticity estimates to be negative.

[27] Other researchers have also found little empirical evidence suggesting that the long-run behavior of Japanese manufacturing industries deviates from that of the standard perfect competition model with constant returns to scale (e.g. Nishimura and Shirai (2000)).

[28] Using aggregate time series data for the period 1961-1980 Tsurumi, Wago and Ilmakunnas (1986) also find that Japanese manufacturers spend relatively long periods of time (up to ten years) to adjust their production methods to iwncorporate new technological requirements. Their findings are consistent with ours.

manufacturing industries.[29] A similar comparison of the rate of TC between firms and establishments (Tables 2 and 5) reveals that the rate of technical progress was higher for firms than for establishments for 12 industries. This may suggest that firm-level technical progress involving the efficiency gains due to not only the standard reductions in inputs such as labor and capital equipment caused by restructuring but also the more effective use of information technologies and R&D efforts may be taking place, often more than that reflected in the rates of technical progress at establishments (Nakajima, Nakamura and Yoshioka (2001)). Ascertaining the reasons for these systematic differences in the rates of technical progress between establishments and firms deserves further investigation.

Comparing the elasticity of scale between establishments and firms (Tables 3 and 6) we see clearly that the scale elasticity estimates for firms are consistently smaller (and slightly less than one) than the estimates for establishments. This reflects the fact that production units are becoming increasingly less important in the operations of typical Japanese manufacturing firms primarily due to the hollow out. Production operations now constitute less than 70% of the total cost of many Japanese manufacturing firms.[30]

The bubble

Table 9 shows our estimates for the rate of technical progress for establishments right before and after the burst of a Japanese financial bubble in 1990. Figure 10 also shows these estimates for some industries. We see that Japan's most valued manufacturing industries in the pre-bubble period such as electrical, general and transportation machinery and precision industries are the industries which have experienced the largest drop in the rate of technical progress in the few years prior to the bubble (1986-89). Yet at that time the Japanese economy was thought to be enjoying the best prosperity ever in its history, with virtually no inflation observed in the consumer price index. However, during this period the prices of assets of all kinds (e.g. stock and land prices, golf club membership) were appreciating at a rapid rate.

In the pre-bubble period Japanese households as well as businesses and government agencies all revised upward their expected rates of return in every type of investment. Consequently Japanese manufacturers increased their output by investing massively in production inputs in these pre-bubble-burst years. Since such an expansion of their production facilities was not accompanied by technical progress, as Table 9 and Figure 10 show, it was inevitable that they were going to suffer from a significant amount of excess production capacity. This over-investment situation was much worse in certain non-manufacturing sectors such as real estate development and construction sectors than manufacturing sectors. In fact the excess capacity which was caused by the excessive and misguided investment in the late 1980s is still plaguing the Japanese economy in terms of the non-performing loans.

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[29] General machinery (a) and (b) include, respectively, (a) firms engaged in production of boilers and generators, metal processing machinery and general machine parts, and (b) all other machinery including machines used for industrial, commercial and household use. Electrical machinery (a) and (b) include, respectively, (a) industrial electrical and electronic machinery, and other industrial machinery, and (b) industrial and civilian communication equipment including televisions and radios.

[30] This means that the cost of operation associated with a firm's establishments including wage bills and the cost of materials and equipment is about 70% of the total budget of the firm. It used to be close to 90% in the 1980s.

It is also of interest to see the effects of the bubble on the rate of technical change at the firm level. We see from Table 5 that the rates of technical progress fell between 1988-89 and 1989-90 for 10 out of 23 manufacturing industries, compared to 17 out of 22 industries at the establishment level (Table 2). This suggests that the non-production parts of Japanese manufacturers (or more precisely, those operations which are not included in the METI's survey of manufacturing establishments) did not suffer as much damage as their establishment units from excessive investments in inputs. It may also mean that the management efficiency gains continued to occur over these years.

4. Technical Change: Dynamics and R&D

An important topic of interest for public policy makers and business firm managers is to ascertain if and how firms' investments in R&D contributes to firms' TC. In this section we explore empirical relationships that may exist between TC and R&D investments for our sample period for Japan.

As was discussed in Section 1, empirical findings derived in previous studies using Japanese data from earlier time periods on the relationships between output productivity (e.g. TFPG) and R&D are mixed. These previous studies, however, did not test the direct relationship between TC and R&D, as was originally by Griliches (1979). The use of TFPG as a proxy for TC may confound the estimating procedure for such relationships since Japanese firms' TFPG contains significant short-run scale economy effects which vary systematically among production units. For these reasons it is of interest to use TC as the dependent variable in testing the Griliches hypothesis for the Japanese manufacturing industries in the 1990s.

Using our estimates for technical progress (TP) for Japanese manufacturing industries for 1988-98 for establishments and firms given in Tables 2 and 5, respectively, we estimated the following equation:

$$(4.1) \qquad TC = a_1 + a_2 \, R\&D + \text{error term}$$

where R&D is the ratio (in per cent) of R&D expenditures to total sales revenue at the industry level. Equation (4.1) was estimated for both establishments and firms. Since we have both industry and time dimensions in our data, we estimated equation (4.1) using OLS as well as fixed and random effects models. Our estimation results are summarized in Tables 10A and 10B.

R&D is not statistically significant at the establishment level (Table 10A). This implies that TC that occurs at the establishment level is not affected by the firms' current R&D expenditures. On the other hand R&D has statistically significant positive impacts on TC at the firm level (Table 10B). Both OLS and random effects model estimates suggest that an increase in firms' R&D-sales ratio by one per cent results in an increase of a 0.48% in firms' TC at the margin.[31] It is of interest that Japanese manufacturers' R&D efforts appear to have had positive effects on their firm-level TC for the manufacturing industries during the sample period (1988-98), which includes the long-lasting recession following the burst of the bubble. The Japanese

[31] Our estimates seem to be within the range of previously obtained estimates for the impact of an increase in R&D expenditures on an increase in TFP growth for the U.S. industries. For example, 0.09-0.50 (for 1959-76) by Griliches and Lichtenberg (1984), 0.20 (for 1972-86) by Clark and Griliches (1984) and 0.64 (for 1972-81) by Nguyen and Kokkelenberg (1992). Caution, however, is warranted for a simple comparison of these estimates, since these estimates were obtained using different data sets and estimation methods for various time periods.

government has been implementing various new policy measures in its science and technology policy in the 1990s, which aim, for example, to promote more effective university-industry collaborations in R&D in the areas where Japanese industries are lagging their global competitors. These new efforts in R&D may have additional impacts on the rates of TC for Japanese manufacturing industries.

Our empirical results at the firm level are consistent with the notion originally suggested by Griliches (1979) that R&D investments encourage TFP growth via TC. In this sense TC (and hence TFP growth) may be at least in part endogenously determined at the firm level. This in turn implies that TC at the firm level is not a random walk and evolves over time with some positive autocorrelation. We ran an auto regression of TC on its immediate past to test this hypothesis. Table 11 shows that the coefficient of lagged TC at the firm level is positive and statistically significant at a 10% level. This provides limited evidence that TC evolves with positive autocorrelation.

5. Concluding Remarks

In this paper we have presented an econometric method based on index number theory for estimating firms' technical change and returns to scale using panel data. Then we have used the method to estimate technical change, returns to scale and total factor productivity growth for Japanese manufacturing industries at both establishment and firm levels for the period 1988-98. We have discussed the movement of these estimated quantities over time, particularly around the burst of the financial bubble. We have argued that a significant decline in technical change, and, to a lesser extent, a decline in total factor productivity growth for many of the manufacturing industries was observed during the period when the bubble was being formed but prior to the burst of the bubble. This is consistent with the interpretation that massive investments in inputs were made by Japanese manufacturers in the late 1980s to increase their output, while such an expansion of the output was not accompanied by technical change. This has resulted in the excess capacity for Japanese manufacturing firms. Many Japanese manufacturers are still suffering from the excess capacity. The excess capacity is also a significant cause of Japanese banks' non-performing loans.[32]

Despite the negative post-bubble circumstances and the lack of effective government and Bank of Japan policies to move Japan's economy out of the long-lasting recession, many parts of the Japanese manufacturing sector did not collapse in the 1990s and some parts have continued to maintain a certain level of global competitiveness.[33] One of the reasons for this may be the technical change that might have been taking place at firm level in the Japanese manufacturing industries. We have also provided limited empirical evidence that Japanese manufacturing firms' technical change is positively impacted by their R&D efforts and is postitively auto-correlated. We have interpreted these findings to mean that Japanese manufacturers' technical change might be in part endogenously generated. How much of the realized technical change

[32] Excessive investment in other sectors such as real estate and property development during the bubble period is another factor which has damaged the Japanese economy.

[33] For example, Japanese manufacturing industries ranging from what many regard as declining industries (e.g. shipbuilding, steel) to traditionally competitive industries (e.g. auto, electronics) have shown persistent resilience in their global competitiveness.

during our sample period is attributable to the manufacturers' and Japanese government's efforts to promote R&D, respectively, remains to be studied.[34]

[34] Another factor that may prove important in explaining Japanese manufacturing firms' technical change is R&D spillovers from their domestic and foreign competitors and suppliers. Mohnen (1996) provides a survey of the issue. Goto and Suzuki (1989) and Odagiri and Kinukawa (1997) provide estimates for domestic spillover effects, while Bernstein and Mohnen (1998) provide estimates for U.S.-Japan cross-border spillover effects.

Appendix A. Alternative Proof of (2-6) – (2-8) for the Translog Case

We apply the Quadratic Approximation lemma (Diewert (1976)) to (2-9) and evaluate it at two PUs, I and j.[35] We get

(A1) $k^{-1}\ \{\ln y^j - \ln y^i\}$

$$= 1/2\ \{k^{-1}\nabla \ln y^j + k^{-1}\nabla \ln y^i\}'\ (\ln x^j - x^i)$$

$$= 1/2\ \{(k\ y^j)^{-1}\mathbf{X}^j\ \nabla y^j + (ky^i)^{-1}\mathbf{X}^i\ \nabla y^i\}'\ (\ln x^j - \ln x^i),$$

where $\nabla \ln y^i$ ($\nabla \ln y^j$) and ∇y^i and ∇y^j are the gradients of $\ln y^i$ ($\ln y^j$) with respect to $\ln x^i$ ($\ln x^j$) and x^i (x^j), respectively, and where $\mathbf{X}^i$ ($\mathbf{X}^j$) denotes the diagonal matrix with its (l,k)th element equal to the k-th element of x^i (x^j).

By Euler's theorem we have $ky = \nabla f(x)'x$. Cost minimization implies the input price vector p is proportional to $\nabla f(x)$, i.e. $p \propto f(x)$. Thus we have

(A3) $\nabla f(x)'/ky = \nabla f(x)'/(\nabla f(x)'x) = w'/w'x.$

By applying (A2) to (A1), we get

(A3) $k^{-1}\{\ln y^j - \ln y^i\} = (1/2)\ [(x^{j\prime}w^{j\prime\prime})/(\ w^{j\prime}x^{j\prime\prime}) + (x^{i\prime}w^{i\prime\prime})/(w^{i\prime}x^{i\prime\prime})]\ (\ln x^j - \ln x^i)$

or

$$k = (\ln\ Q_T^{*i,j})^{-1}\ \{\ln y^j\ - \ln y^i\}$$

or

$$k = (\ln Q_T^{*i,j})^{-1}\ \{\ln f(x^j) - \ln f(x^i)\}.$$

where $Q_T^{*i,j}$ is given by (2-7).

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[35] It is assumed without loss of generality that output for PU j is greater than output for PU i.

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Table 1. TFP growth: establishments, 1964-98

	1964-88	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	0.02167	-0.00991	-0.00354	-0.00619	-0.00624	-0.01135	-0.02295	0.00458	0.01826	-0.00252	-0.01087	-0.01903	-0.01707	-0.01039	0.00890
Beverage	---	0.01757	-0.00215	0.00039	0.00453	0.04832	0.03226	-0.02786	0.00739	-0.02135	0.00884	-0.00347	0.02159	0.00204	-0.02245
Textile	0.02281	-0.00739	0.02438	0.00462	0.00892	-0.01608	0.01588	-0.02196	-0.00596	-0.00858	0.08796	0.02411	0.02540	0.03053	-0.04206
Apparels	0.05027	-0.00536	-0.01139	-0.01509	-0.01069	0.03321	-0.02350	-0.02579	0.00054	-0.04235	-0.01816	0.01442	-0.00221	0.00116	-0.04423
Lumber/wood products	0.02313	-0.00028	0.00938	-0.00458	0.00229	0.00788	0.00271	-0.01143	0.00914	-0.00733	0.03333	0.00236	0.00669	-0.02297	0.00255
Furniture/fixture	0.04135	-0.01104	-0.01746	-0.01443	-0.01463	0.00999	-0.03337	-0.00975	-0.02971	-0.02872	-0.01364	0.00222	0.00506	0.01085	-0.05919
Pulp	0.02961	-0.01077	0.01551	0.00659	0.00495	0.01919	-0.01661	-0.03489	-0.00134	0.00188	0.01628	0.04522	-0.00070	0.01893	0.00153
Printing	---	-0.00628	-0.00009	-0.00314	-0.00286	-0.01182	0.00298	-0.01001	-0.02509	0.00487	0.00580	0.01406	0.01168	-0.00449	-0.01662
Chemicals	0.02956	0.01390	0.00907	0.00324	0.00877	0.02635	0.00328	0.01208	0.00450	0.00186	0.00543	0.02449	0.01025	0.01092	-0.01144
Petroleum/coal products	0.05489	-0.02190	-0.01698	0.00139	-0.01295	0.00497	-0.00810	-0.06258	0.03548	-0.10958	-0.00487	0.01104	0.11808	0.00236	-0.11627
Plastic prod	---	0.00028	0.00681	0.01000	0.00581	0.00709	0.00544	-0.01169	0.01003	0.00645	0.00789	0.00286	0.01278	0.01639	0.00083
Rubber products	0.04627	0.01232	0.00684	-0.00280	0.00559	-0.00923	0.02632	0.01986	0.00333	-0.00525	0.01636	0.01291	0.00323	0.02072	-0.03234
Leather prod	0.03996	-0.00920	-0.00328	-0.00078	-0.00431	0.01969	-0.01912	-0.02818	-0.02042	-0.02743	-0.00157	0.03631	-0.00219	0.00694	-0.00709
Pottery	0.03192	-0.00934	0.00596	-0.00204	-0.00103	0.00052	-0.01389	-0.01466	-0.00999	0.00467	0.03307	-0.00392	0.01068	0.00934	-0.02615
Steel	0.0448	0.00497	-0.00438	0.01133	0.00314	0.02160	-0.00273	-0.00397	-0.01296	-0.02434	-0.00292	0.02269	0.01622	0.01426	0.00352
Non-ferrous metals	0.03759	-0.02203	0.00436	-0.00641	-0.00679	0.00238	-0.01566	-0.05281	-0.02788	-0.05894	0.05585	0.04842	-0.00557	0.03803	-0.05170
Metal products	0.03218	-0.02012	0.01828	-0.00263	0.00049	-0.01900	-0.01692	-0.02445	-0.01748	0.04586	0.01765	0.02710	0.01383	-0.01557	-0.00616
Gen mach	0.02707	0.00532	-0.00192	-0.00105	0.00052	0.00215	0.00435	0.00946	-0.01592	-0.01228	-0.00285	0.02339	-0.00013	0.00784	-0.01086
Elec mach	0.05186	0.03269	0.02979	0.00648	0.02367	0.03407	0.01961	0.04439	0.00677	0.03267	0.02845	0.05128	0.01043	0.00473	0.00428
Transp mach	0.04332	0.00817	0.01072	-0.01276	0.00291	-0.00021	0.01277	0.01196	-0.00048	0.01675	0.00123	0.02538	-0.02099	0.00216	-0.01946
Precision	0.04324	0.00513	0.00818	0.00350	0.00586	0.03672	-0.02479	0.00347	-0.01749	0.01495	0.00355	0.03171	0.02050	-0.00789	-0.00212
Other	---	0.01759	-0.01233	0.00086	0.00061	0.03418	0.00326	0.01532	-0.00631	-0.00554	0.00047	-0.03792	0.01133	0.00987	-0.01861

Table 2. Technical change: establishments, 1964-98

	1964-88	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	-0.0001	-0.01102	-0.00386	-0.00603	-0.00666	-0.01261	-0.02455	0.00409	0.01854	-0.00201	-0.01004	-0.02194	-0.01696	-0.01106	0.00994
Beverage	---	0.00712	-0.00443	0.00740	0.00258	0.05356	0.01650	-0.04870	0.01893	-0.02938	-0.01071	0.00344	0.03875	0.01394	-0.03049
Textile	0.0164	-0.00834	0.02390	0.00464	0.00845	-0.01715	0.01504	-0.02292	-0.00551	-0.00863	0.08571	0.02401	0.02531	0.03051	-0.04190
Apparels	0.004	-0.00494	-0.01397	-0.01486	-0.01153	0.03412	-0.02512	-0.02383	0.00032	-0.04348	-0.02609	0.01336	-0.00229	0.00154	-0.04382
Lumber/wood products	0.0056	-0.00025	0.00861	-0.00370	0.00226	0.00922	0.00168	-0.01165	0.00870	-0.00685	0.03211	0.00048	0.00523	-0.02461	0.00828
Furniture/fixture	0.009	-0.01466	-0.01723	-0.01306	-0.01521	0.00505	-0.03942	-0.00962	-0.02582	-0.02833	-0.01346	-0.00130	0.00423	0.01340	-0.05682
Pulp	0.0118	-0.01212	0.01577	0.00662	0.00466	0.01687	-0.01835	-0.03489	-0.00124	0.00171	0.01653	0.04608	-0.00311	0.01932	0.00364
Printing	---	-0.00885	-0.00012	-0.00314	-0.00364	-0.01572	-0.00005	-0.01078	-0.02001	0.00013	0.00745	0.01197	0.00837	-0.00434	-0.01346
Chemicals	0.0206	0.01223	0.00983	0.00476	0.00903	0.02367	-0.00022	0.01324	0.00391	0.00422	0.00658	0.02460	0.01140	0.00787	-0.00499
Petroleum/coal products	0.0088	-0.02392	-0.01677	-0.00099	-0.01418	0.00424	-0.01268	-0.06331	0.03658	-0.11127	-0.00443	0.01206	0.12001	-0.00677	-0.11621
Plastic prod	---	-0.00040	0.00719	0.01096	0.00604	0.00667	0.00514	-0.01301	0.01080	0.00712	0.00816	0.00266	0.01461	0.01569	0.00259
Rubber products	0.0124	0.01129	0.00809	-0.00284	0.00577	-0.00960	0.02450	0.01896	0.00518	-0.00187	0.01870	0.01036	0.00087	0.02113	-0.03051
Leather prod	0.0065	-0.01016	-0.00333	0.00005	-0.00437	0.02148	-0.02158	-0.03037	-0.02117	-0.02944	-0.00009	0.03738	-0.00419	0.01026	-0.00593
Pottery	0.0135	-0.01118	0.00584	-0.00228	-0.00170	-0.00111	-0.01755	-0.01489	-0.00876	0.00837	0.02868	-0.00492	0.00990	0.00697	-0.02370
Steel	0.0036	0.00390	-0.00244	0.01345	0.00423	0.02088	-0.00478	-0.00441	-0.00810	-0.02386	-0.00030	0.02251	0.01901	0.01388	0.00747
Non-ferrous metals	-0.0014	-0.02160	0.00437	-0.00619	-0.00659	0.00160	-0.01451	-0.05190	-0.02767	-0.05813	0.05500	0.04826	-0.00550	0.03797	-0.05104
Metal products	0.0147	-0.02164	0.01848	-0.00152	0.00044	-0.02076	-0.01738	-0.02678	-0.01605	0.04600	0.01704	0.02693	0.01318	-0.01471	-0.00304
Gen mach	0.0187	0.00460	-0.00216	-0.00111	0.00018	0.00028	0.00427	0.00924	-0.01512	-0.01136	-0.00337	0.02121	-0.00087	0.00772	-0.01017
Elec mach	0.026	0.03011	0.02885	0.00528	0.02216	0.03162	0.01616	0.04255	0.00849	0.03177	0.02724	0.04791	0.00624	0.00271	0.00690
Transp mach	0.0245	0.00733	0.01090	-0.01300	0.00266	-0.00200	0.01208	0.01192	-0.00058	0.01695	0.00168	0.02554	-0.02123	0.00084	-0.01861
Precision	0.0316	0.00429	0.00837	0.00287	0.00550	0.03585	-0.02602	0.00303	-0.01730	0.01518	0.00390	0.03171	0.02036	-0.00928	-0.00248
Other	---	0.01693	-0.01354	-0.00119	-0.00069	0.03172	0.00175	0.01732	-0.01063	-0.00513	0.00103	-0.03942	0.01092	0.01086	-0.02536

Table 3. Elasticity of scale: establishments, 1964-98

	1964-88	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	1.08	1.06746	1.06464	1.06442	1.06542	1.06982	1.06262	1.06995	1.05887	1.06283	1.06853	1.06831	1.07060	1.05602	1.06663
Beverage	---	1.33079	1.34103	1.38904	1.35236	1.33516	1.33793	1.31929	1.30722	1.35810	1.35841	1.34039	1.35212	1.38608	1.42893
Textile	1.004	1.03951	1.00619	1.00538	1.01594	1.04798	1.03750	1.03306	0.97204	1.03148	1.01670	1.00453	1.01079	0.99893	1.00642
Apparels	1.019	1.01306	1.04238	1.03434	1.03117	1.02652	1.03132	0.98135	0.98347	1.06419	1.06003	1.06182	1.03019	1.04103	1.03179
Lumber/wood products	1.018	1.03383	1.03966	1.04883	1.04066	1.05196	1.04312	1.00642	1.02381	1.04622	1.03194	1.05668	1.04945	1.04829	1.04874
Furniture/fixture	1.047	1.05880	1.05167	1.04405	1.05153	1.08568	1.06086	1.02987	1.04889	1.04385	1.05714	1.05681	1.04690	1.05178	1.03347
Pulp	1.008	1.01556	1.01009	1.05152	1.02416	1.02540	1.02310	0.99819	1.00325	0.99710	1.00819	1.03183	1.04738	1.04558	1.06160
Printing	---	1.06745	1.06872	1.06475	1.06715	1.07470	1.06203	1.06563	1.06850	1.06998	1.06611	1.07028	1.07208	1.05941	1.06276
Chemicals	1.046	1.07592	1.07844	1.09099	1.08145	1.07939	1.08801	1.06036	1.06715	1.07600	1.08629	1.08431	1.09208	1.09162	1.08926
Petroleum/coal products	1.012	1.02952	1.04697	1.04316	1.04059	1.04735	1.03125	1.00996	1.01594	1.03009	1.05432	1.08752	1.02425	1.04857	1.05665
Plastic prod	---	1.03015	1.03163	1.03633	1.03260	1.02994	1.03658	1.02392	1.02835	1.03197	1.03295	1.03325	1.05593	1.02771	1.02535
Rubber products	1.047	1.06241	1.07378	1.08590	1.07400	1.06486	1.06148	1.06088	1.07659	1.07276	1.06829	1.07746	1.07546	1.08294	1.09931
Leather prod	1.016	1.01769	1.06118	1.02391	1.03695	0.93356	1.07730	1.04220	1.04082	1.11505	1.06056	1.02828	1.05862	1.06841	0.94471
Pottery	1.073	1.05665	1.05195	1.05556	1.05444	1.06187	1.05923	1.04884	1.04550	1.04959	1.06309	1.04960	1.04640	1.05544	1.06484
Steel	1.012	1.04477	1.04308	1.05991	1.04864	1.04877	1.05320	1.03234	1.04298	1.04339	1.04495	1.04098	1.06018	1.05730	1.06226
Non-ferrous metals	1.008	0.99904	0.99043	1.00118	0.99624	1.01203	0.99192	0.99318	0.99205	0.98874	0.99187	0.98905	0.99893	0.99780	1.00681
Metal products	1.03	1.03109	1.03834	1.05855	1.04223	1.03160	1.02409	1.03757	1.02734	1.05635	1.04029	1.02939	1.06318	1.07176	1.04072
Gen mach	1.019	1.01604	1.01517	1.01997	1.01687	1.01699	1.01435	1.01677	1.01122	1.01301	1.01375	1.02269	1.02309	1.02151	1.01532
Elec mach	1.044	1.05175	1.03807	1.03510	1.04128	1.05228	1.05913	1.04383	1.03989	1.03771	1.03547	1.03921	1.04148	1.03089	1.03292
Transp mach	1.016	1.01126	1.00559	1.01445	1.00995	1.01545	1.01403	1.00431	1.00414	1.00428	1.00673	1.00720	1.01217	1.01461	1.01657
Precision	1.021	1.00947	1.00240	1.00459	1.00517	1.01596	1.00685	1.00559	1.00207	1.00328	1.00568	0.99855	0.99801	1.00893	1.00682
Other	---	1.03313	1.03271	1.00594	1.02481	1.02603	1.04588	1.02749	1.03113	1.02760	1.03397	1.03814	1.00425	0.98341	1.03016

Table4. TFP growth: firms, 1988-98

	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	-0.00464	0.00876	0.00394	0.00329	-0.00627	-0.00162	-0.00602	0.03246	0.00918	0.00092	-0.00753	0.01181	-0.01458	0.01458
Beverage	0.00801	0.00166	-0.02141	-0.00336	0.01542	0.01437	-0.00576	-0.03136	0.03821	-0.01591	0.01568	-0.02741	0.00649	-0.04331
Textile	0.01259	0.03168	0.00753	0.01871	0.00169	0.03903	-0.00295	0.00912	0.07581	0.01873	0.02306	0.00462	0.00982	0.00815
Apparels	0.00114	-0.01834	-0.01332	-0.01099	-0.00029	-0.02525	0.02895	-0.06687	-0.02858	0.00898	0.01313	0.02926	-0.01659	-0.05262
Lumber/wood products	-0.01949	0.02549	-0.01315	0.00041	-0.01882	0.00464	-0.04429	0.08293	-0.00864	0.05449	-0.02681	-0.01266	-0.09567	0.06889
Furniture/fixture	-0.01945	-0.01024	-0.01059	-0.01311	0.02702	-0.04001	-0.04537	-0.01567	-0.00039	-0.03310	0.00822	0.00501	0.00861	-0.04539
Pulp	-0.01245	0.01307	-0.00914	-0.00125	-0.04419	0.01357	-0.00674	0.01533	0.00627	0.01115	0.01952	0.00073	-0.02153	-0.00662
Printing	-0.01051	-0.00802	-0.00340	-0.00738	-0.03758	-0.00250	0.00855	-0.02779	0.00937	0.00533	-0.01898	0.00123	-0.00995	-0.00147
Chemicals	-0.00313	0.00786	0.01186	0.00576	-0.02458	-0.00084	0.01603	0.00033	0.02238	0.01339	-0.00467	0.02616	-0.00810	0.01753
Petroleum/coal products	-0.02890	-0.02270	-0.01255	-0.02151	0.01822	-0.03473	-0.07018	-0.01476	-0.04065	-0.04813	0.01274	0.00713	-0.01927	-0.02551
Plastic products	0.00418	0.03010	0.00200	0.01389	0.00735	0.00444	0.00076	0.07637	0.01807	0.01668	0.00927	0.01627	-0.02280	0.01252
Rubber products	0.02911	0.01085	-0.01718	0.00792	0.01247	0.01928	0.05557	-0.01029	0.00260	0.01564	0.03543	-0.00594	-0.02180	-0.02381
Leather prod	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pottery	-0.01140	0.00850	0.00345	0.00102	-0.00121	0.00531	-0.03831	0.00186	0.00160	0.01561	0.01494	0.01149	-0.01470	0.01356
Steel	-0.01210	0.00780	0.00091	-0.00024	-0.01065	0.00369	-0.02935	0.00380	-0.01825	0.03359	0.01207	0.02742	-0.01848	-0.00620
Non-ferrous metals	-0.00416	-0.00191	-0.00443	-0.00334	-0.00414	0.01441	-0.02274	-0.03945	0.00155	0.01209	0.01818	0.00564	0.00652	-0.02544
Metal products	-0.04026	0.01868	-0.01084	-0.00786	-0.07325	-0.02345	-0.02408	-0.00033	0.03590	0.03276	0.00637	-0.00778	-0.01003	-0.01472
Gen mach (a)[a]	-0.01506	0.00215	0.01075	-0.00044	-0.00361	-0.00493	-0.03665	-0.04635	-0.01590	0.02079	0.05004	0.04393	-0.00091	-0.01076
Gen mach (b)[b]	-0.00097	-0.00097	-0.00097	-0.00097	0.00665	-0.00983	-0.01018	-0.00178	0.01007	0.00334	0.00608	-0.00827	-0.01594	0.01016
Elec mach (a)[c]	0.02690	0.04323	0.01348	0.02941	0.03372	0.01804	0.02894	0.03259	0.04449	0.05105	0.04478	0.01407	0.03426	-0.00789
Elec mach (b)[d]	0.02767	0.02767	0.02767	0.02767	0.04162	0.00630	0.01614	0.08191	0.06522	0.03060	0.05368	0.01376	-0.00772	-0.02478
Transp mach	0.00645	0.01010	-0.01884	0.00032	0.00686	0.00536	0.00712	0.00488	0.01057	0.01515	0.00979	-0.01110	-0.01792	-0.02751
Precision	-0.00583	0.01187	-0.01053	-0.00016	0.01458	-0.01308	-0.01898	-0.01182	0.01937	0.01098	0.02895	0.02665	-0.03424	-0.02401
Other	-0.00396	0.00470	-0.00530	-0.00090	-0.00647	0.00467	-0.01007	-0.01339	0.01013	0.02437	-0.00232	0.00238	0.01416	-0.03244

[a] This category includes boilers, engines, metal processing machinery and general machinery parts.
[b] This category include general machinery which is not included in General Machinery (a).
[b] This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery.
[b] This category includes industrial communication equipment and civilian communication equipment.

Table 5. Technical change: firms, 1988-98

	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	-0.00376	0.00535	0.00376	0.00214	-0.00548	-0.00074	-0.00507	0.02468	0.00749	-0.00199	-0.00878	0.01164	-0.01441	0.01404
Beverage	0.00986	0.00050	-0.01644	-0.00177	0.00719	0.02275	-0.00035	-0.03325	0.03879	-0.01541	0.01187	0.02279	-0.00002	-0.07208
Textile	0.01332	0.02542	0.00564	0.01585	0.00198	0.04033	-0.00236	0.00323	0.06817	0.01330	0.01698	0.00431	0.00933	0.00327
Apparels	0.01365	-0.02802	-0.01546	-0.01175	0.01124	-0.00385	0.03357	-0.06958	-0.03935	-0.00380	0.00067	0.02852	-0.02245	-0.05246
Lumber/wood products	0.00207	0.03485	-0.02361	0.00748	0.01186	0.02320	-0.02885	0.08116	-0.01132	0.06646	0.00311	0.04673	-0.12748	0.00991
Furniture/fixture	0.00571	-0.01111	-0.00261	-0.00351	0.07382	-0.01128	-0.04540	-0.02760	-0.00784	-0.01951	0.01050	0.00090	0.01136	-0.02009
Pulp	-0.01050	0.01442	-0.00330	0.00163	-0.03957	0.01519	-0.00713	0.01161	0.01222	0.01413	0.01972	0.01684	-0.01470	-0.01203
Printing	-0.00902	-0.00826	-0.00255	-0.00677	-0.03671	0.00008	0.00958	-0.03096	0.00850	0.00592	-0.01649	0.00453	-0.00890	-0.00327
Chemicals	0.00447	0.00791	0.01038	0.00762	-0.00690	0.01087	0.00945	-0.00121	0.01011	0.02520	-0.00247	0.03531	-0.00905	0.00487
Petroleum/coal products	-0.03092	-0.02805	-0.01919	-0.02625	0.01143	-0.03513	-0.06905	-0.01689	-0.04005	-0.05864	0.00337	0.01176	-0.03019	-0.03915
Plastic products	0.01146	0.02048	-0.00074	0.01141	0.02040	0.01532	-0.00134	0.01892	0.00655	0.04144	0.01502	0.02932	-0.02634	-0.00519
Rubber products	0.02949	0.01362	-0.01618	0.00944	0.01245	0.01890	0.05711	-0.00744	0.00600	0.01961	0.03629	-0.00128	-0.02006	-0.02720
Leather prod	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pottery	-0.00801	0.00917	0.00160	0.00174	0.00245	0.01192	-0.03840	-0.00031	0.00085	0.01970	0.01642	0.01204	-0.01791	0.01067
Steel	-0.01109	0.00603	-0.00012	-0.00095	-0.01031	0.00573	-0.02869	0.00154	-0.02047	0.03224	0.01080	0.02750	-0.01934	-0.00851
Non-ferrous metals	-0.00984	-0.00220	-0.00389	-0.00500	-0.00891	0.00795	-0.02856	-0.03895	0.00030	0.01137	0.01848	0.00322	0.00850	-0.02338
Metal products	-0.02635	0.01979	-0.01699	-0.00509	-0.04059	-0.01727	-0.02119	0.00022	0.03644	0.03338	0.00913	0.00515	-0.02158	-0.03454
Gen mach (a) [a]	-0.00734	0.00242	0.01128	0.00215	0.01044	0.00112	-0.03357	-0.04553	-0.01536	0.02050	0.05006	0.04608	-0.00135	-0.01090
Gen mach (b) [b]	0.00108	0.00108	0.00108	0.00108	0.01183	-0.00063	-0.00843	-0.00287	0.00602	0.00700	0.01073	-0.00453	-0.01481	0.00646
Elec mach (a) [c]	0.03391	0.04799	0.01842	0.03489	0.04069	0.02826	0.03277	0.02983	0.04232	0.05433	0.06548	0.03313	0.03408	-0.01196
Elec mach (b) [d]	0.03480	0.03480	0.03480	0.03480	0.04702	0.02147	0.02788	0.07056	0.05842	0.02907	0.05883	0.02262	0.02688	-0.01474
Transp mach	0.00907	0.00842	-0.01876	0.00046	0.01045	0.00778	0.00897	0.00445	0.00665	0.01416	0.00842	-0.00923	-0.01935	-0.02770
Precision	0.00159	0.01664	0.00034	0.00724	0.02524	0.00324	-0.02372	-0.01379	0.02419	0.01997	0.03620	0.03937	-0.00989	-0.02846
Other	-0.00435	0.00318	-0.00316	-0.00098	-0.00628	0.00515	-0.01192	-0.01233	0.00959	0.01078	0.00466	0.01520	0.00814	-0.03282

[a] This category includes boilers, engines, metal processing machinery and general machinery parts.
[b] This category include general machinery which is not included in General Machinery (a).
[b] This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery.
[b] This category includes industrial communication equipment and civilian communication equipment.

Table 6. Elasticity of scale: firms, 1988-98

	1988-91	1991-95	1995-98	1988-98	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98
Food	0.94644	0.95800	0.95562	0.95382	0.98125	0.90878	0.94929	0.93355	0.92121	0.95072	1.02652	1.01574	0.94451	0.90662
Beverage	0.93068	0.95111	0.61474	0.84407	1.06408	0.87361	0.85435	0.85621	0.98449	1.03380	0.92995	0.57194	0.59274	0.67954
Textile	0.85601	0.86565	0.96461	0.89245	0.98379	0.79502	0.78922	0.85541	0.88940	0.82229	0.89550	0.99571	0.99631	0.90181
Apparels	0.77128	0.67275	0.82842	0.74901	0.84947	0.70535	0.75901	0.96069	0.69177	0.54847	0.49008	0.88152	0.64321	0.96054
Lumber/wood products	0.24358	0.59689	0.57404	0.48404	0.11151	0.46006	0.15918	0.55542	0.65496	0.70836	0.46883	0.59559	0.59105	0.53547
Furniture/fixture	0.59822	0.74225	1.13618	0.81722	0.47492	0.48821	0.83154	0.78528	0.72741	0.76937	0.68692	1.04469	1.04225	1.32161
Pulp	0.94909	0.93558	0.92639	0.93688	0.95787	0.96427	0.92514	0.94416	0.95656	0.91160	0.93000	0.91600	0.92726	0.93590
Printing	0.96767	0.95972	0.92865	0.95279	0.98171	0.95966	0.96164	0.94994	0.96777	0.97534	0.94583	0.93676	0.91657	0.93263
Chemicals	0.81330	0.82140	0.84037	0.82466	0.80751	0.83098	0.80140	0.86277	0.77768	0.79898	0.84615	0.75241	0.90669	0.86201
Petroleum/coal products	1.08564	1.08251	0.91830	1.03419	1.02815	1.11544	1.11334	1.08620	1.02647	1.11768	1.09969	0.94645	0.89457	0.91387
Plastic products	0.80694	0.59806	0.86831	0.74180	0.76476	0.87751	0.77854	0.70200	0.74685	0.07097	0.87242	0.82986	0.91051	0.86455
Rubber products	1.03629	0.99808	0.93392	0.99030	1.00258	1.05441	1.05189	1.03171	1.03937	0.94942	0.97180	0.91887	0.93748	0.94542
Leather prod	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pottery	0.91655	0.94152	0.94894	0.93626	0.94785	0.89304	0.90877	0.92552	0.96471	0.92597	0.94987	0.95527	0.93887	0.95269
Steel	0.95657	0.94493	0.96397	0.95413	0.95948	0.95728	0.95295	0.94435	0.94555	0.95010	0.93972	0.96294	0.96127	0.96769
Non-ferrous metals	1.05655	1.04309	1.03986	1.04616	1.05416	1.05561	1.05988	1.05144	1.04301	1.04416	1.03373	1.04255	1.04482	1.03222
Metal products	0.87618	0.93772	0.80643	0.87987	0.78661	0.91540	0.92652	0.96763	0.94975	0.96277	0.87071	0.85709	0.79750	0.76471
Gen mach (a) [a]	0.90680	0.98354	0.92392	0.94263	0.85218	0.90954	0.95869	0.98662	0.98625	0.96185	0.99944	0.93416	0.91336	0.92423
Gen mach (b) [b]	0.92280	0.92280	0.92280	0.92280	0.90037	0.87241	0.92045	0.96023	0.94054	0.89714	0.90427	0.95301	0.94156	0.93797
Elec mach (a) [c]	0.90188	0.88623	0.85437	0.88136	0.89664	0.88580	0.92319	0.89870	0.89521	0.90101	0.84999	0.84630	0.83333	0.88347
Elec mach (b) [d]	0.81585	0.81585	0.81585	0.81585	0.93265	0.90476	0.85248	0.90157	0.88510	0.67964	0.71220	0.83768	0.59239	0.85999
Transp mach	0.96718	0.96255	0.98696	0.97126	0.97057	0.96844	0.96252	0.96720	0.96108	0.95413	0.96780	0.97734	0.98879	0.99475
Precision	0.89488	0.91206	0.83426	0.88356	0.90331	0.88836	0.89296	0.91209	0.91268	0.90401	0.91946	0.84538	0.80588	0.85151
Other	0.99868	0.93295	0.89249	0.94053	0.97507	0.97904	1.04192	0.99194	0.96013	0.89626	0.88345	0.82862	0.91359	0.93525

[a] This category includes boilers, engines, metal processing machinery and general machinery parts.
[b] This category include general machinery which is not included in General Machinery (a).
[b] This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery.
[b] This category includes industrial communication equipment and civilian communication equipment.

TABLE 7. DECOMPOSITION OF AVERAGE TFP ANNUAL GROWTH AT ESTABLISHMENTS, 1964-1988

Industry	TFP Growth[a]	Technical Change[b]	Scale Economies[b]
FOOD/KINDRED PRODUCTS	0.02167	0.02072 (96%)	0.00095 (4)
TEXTILES	0.02281	0.02279 (100)	0.00002 (0)
APPARELS	0.05027	0.05058 (101)	-0.00031 (-1)
LUMBER/WOOD PRODUCTS	0.02313	0.02213 (96)	0.00100 (4)
FURNITURE/FIXTURE	0.04135	0.04016 (97)	0.00119 (3)
PULP/PAPER PRODUCTS	0.02961	0.02925 (99)	0.00036 (1)
CHEMICALS	0.02956	0.02874 (97)	0.00082 (3)
PETROLEUM/COAL PRODUCTS	0.05489	0.05478 (100)	0.00011 (0)
RUBBER/PLASTIC PRODUCTS	0.04627	0.04207 (91)	0.00420 (9)
LEATHER/LEATHER PRODUCTS	0.03996	0.03836 (96)	0.00160 (4)
POTTERY/GLASS PRODUCTS	0.03192	0.03292 (103)	-0.00100 (-3)
IRON/STEEL	0.04480	0.03434 (77)	0.01046 (23)
NON-FERROUS METALS	0.03759	0.03691 (98)	0.00068 (2)
METAL PRODUCTS	0.03218	0.03224 (100)	-0.00006 (0)
GENERAL MACHINERY	0.02707	0.02479 (92)	0.00228 (8)
ELECTRICAL MACHINERY	0.05186	0.04667 (90)	0.00519 (10)
TRANSPORTATION MACHINERY	0.04332	0.03983 (92)	0.00349 (8)
PRECISION	0.04324	0.04163 (96)	0.01161 (4)

[a,b]These were calculated using Nakajima, Nakamura and Yoshioka (1998, Eq. (A18)).
Numbers in parentheses are percentage contributions.

TABLE 8A. DECOMPOSITION OF AVERAGE ANNUAL TFP GROWTH AT ESTABLISHMENTS, 1988-98

Industry	TFP growth[a]	Technical change[b]		Scale economies[b]	
Food	-0.00624	-0.00666	107%	0.00042	-7%
Beverage	0.00453	0.00258	57	0.00195	43
Textile	0.00892	0.00845	95	0.00048	5
Apparels	-0.01069	-0.01153	108	0.00084	-8
Lumber/wood products	0.00229	0.00226	98	0.00003	1
Furniture/fixture	-0.01463	-0.01521	104	0.00058	-4
Pulp	0.00495	0.00466	94	0.00029	6
Printing	-0.00286	-0.00364	127	0.00078	-27
Chemicals	0.00877	0.00903	103	-0.00026	-3
Petroleum/coal products	-0.01295	-0.01418	109	0.00123	-9
Plastic products	0.00581	0.00604	104	-0.00024	-4
Rubber products	0.00559	0.00577	103	-0.00018	-3
Leather/leather products	-0.00431	-0.00437	101	0.00006	-1
Pottery	-0.00103	-0.00170	164	0.00067	-64
Steel	0.00314	0.00423	135	-0.00109	-35
Non-ferrous metals	-0.00679	-0.00659	97	-0.00019	3
Metal products	0.00049	0.00044	91	0.00004	9
General machinery	0.00052	0.00018	35	0.00033	65
Electrical machinery	0.02367	0.02216	94	0.00151	6
Transportation machinery	0.00291	0.00266	91	0.00025	9
Precision	0.00586	0.00550	94	0.00037	6
Other	0.00061	-0.00069	-115	0.00130	215

[a,b]These were calculated using Nakajima, Nakamura and Yoshioka (1998, Eq. (A18)).
Numbers in parentheses are percentage contributions.

TABLE 8B. DECOMPOSITION OF AVERAGE ANNUAL TFP GROWTH AT FIRMS, 1988-98

Industry	TFP growth[a]	Technical change[b]		Scale economies[b]	
Food	0.00329	0.00214	65	0.00115	35
Beverage	-0.00336	-0.00177	53	-0.00159	47
Textile	0.01871	0.01585	85	0.00286	15
Apparels	-0.01099	-0.01175	107	0.00076	-7
Lumber/wood products	0.00041	0.00748	1842	-0.00707	-1742
Furniture/fixture	-0.01311	-0.00351	27	-0.00959	73
Pulp	-0.00125	0.00163	-130	-0.00288	230
Printing	-0.00738	-0.00677	92	-0.00061	8
Chemicals	0.00576	0.00762	132	-0.00186	-32
Petroleum/coal products	-0.02151	-0.02625	122	0.00474	-22
Plastic products	0.01389	0.01141	82	0.00248	18
Rubber products	0.00792	0.00944	119	-0.00153	-19
Leather/leather products	na	na	na	na	na
Pottery	0.00102	0.00174	172	-0.00073	-71
Steel	-0.00024	-0.00095	403	0.00072	-304
Non-ferrous metals	-0.00334	-0.00500	150	0.00166	-50
Metal products	-0.00786	-0.00509	65	-0.00278	35
General machinery (a) [c]	-0.00044	0.00215	-494	-0.00259	594
General machinery (b) [d]	-0.00097	0.00108	-111	-0.00205	211
Electrical machinery (a) [e]	0.02941	0.03489	119	-0.00549	-19
Electrical machinery (b) [f]	0.02767	0.03480	126	-0.00713	-26
Transportation machinery	0.00032	0.00046	144	-0.00014	-43
Precision	-0.00016	0.00724	-4522	-0.00740	4622
Other	-0.00090	-0.00098	110	0.00009	-10

[a,b] These were calculated using Nakajima, Nakamura and Yoshioka (1998, Eq. (A18)).
Numbers in parentheses are percentage contributions.
[c] This category includes boilers, engines, metal processing machinery and general machinery parts.
[d] This category include general machinery which is not included in General Machinery (a).
[e] This category includes industrial electrical equipment, industrial electronic applications equipment and other electrical machinery.
[f] This category includes industrial communication equipment and civilian communication equipment.

Table 9. Technical change: establishments, 1964-98

	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95
Food	-0.0076	0.0153	-0.0126	-0.0246	0.0041	0.0185	-0.0020	-0.0100	-0.0219
Beverage	---	---	0.0536	0.0165	-0.0487	0.0189	-0.0294	-0.0107	0.0034
Textile	0.0346	-0.0176	-0.0172	0.0150	-0.0229	-0.0055	-0.0086	0.0857	0.0240
Apparels	0.0250	-0.0017	0.0341	-0.0251	-0.0238	0.0003	-0.0435	-0.0261	0.0134
Lumber/wood products	0.0131	-0.0238	0.0092	0.0017	-0.0117	0.0087	-0.0069	0.0321	0.0005
Furniture/fixture	0.0250	-0.0090	0.0051	-0.0394	-0.0096	-0.0258	-0.0283	-0.0135	-0.0013
Pulp	0.0057	0.0434	0.0169	-0.0184	-0.0349	-0.0012	0.0017	0.0165	0.0461
Printing	---	---	-0.0157	-0.0001	-0.0108	-0.0200	0.0001	0.0075	0.0120
Chemicals	0.0080	0.0383	0.0237	-0.0002	0.0132	0.0039	0.0042	0.0066	0.0246
Petroleum/coal products	0.2234	-0.1780	0.0042	-0.0127	-0.0633	0.0366	-0.1113	-0.0044	0.0121
Plastic prod			0.0067	0.0051	-0.0130	0.0108	0.0071	0.0082	0.0027
Rubber products	0.0283	0.0486	-0.0096	0.0245	0.0190	0.0052	-0.0019	0.0187	0.0104
Leather prod	0.0422	0.0305	0.0215	-0.0216	-0.0304	-0.0212	-0.0294	-0.0001	0.0374
Pottery	0.0149	0.0305	-0.0011	-0.0176	-0.0149	-0.0088	0.0084	0.0287	-0.0049
Steel	-0.0201	0.0436	0.0209	-0.0048	-0.0044	-0.0081	-0.0239	-0.0003	0.0225
Non-ferrous metals	0.0419	0.1064	0.0016	-0.0145	-0.0519	-0.0277	-0.0581	0.0550	0.0483
Metal products	0.0161	-0.0143	-0.0208	-0.0174	-0.0268	-0.0161	0.0460	0.0170	0.0269
Gen mach	-0.0080	0.0288	0.0003	0.0043	0.0092	-0.0151	-0.0114	-0.0034	0.0212
Elec mach	0.0110	0.0615	0.0316	0.0162	0.0426	0.0085	0.0318	0.0272	0.0479
Transp mach	0.0190	0.0198	-0.0020	0.0121	0.0119	-0.0006	0.0170	0.0017	0.0255
Precision	-0.0163	0.0571	0.0359	-0.0260	0.0030	-0.0173	0.0152	0.0039	0.0317
Other	---	---	0.0317	0.0018	0.0173	-0.0106	-0.0051	0.0010	-0.0394

Table 10A. The Effects of R&D on Technical Change: Regression Results for Establishments, 1988-98

	Constant	R&D	R-squared	No. of obs.
OLS without ind. and year dummy variables[a]	-.0053 (.1.34)[b]	.0012 (.955)	.006	144
Fixed effects model	-.0422 (1.49)	.0149 (1.42)	..230	144
Random effects model	-.0054 (1.20)	.0012 (.991)	.006	144
Hausman test (FEM vs. REM)[c]	1.71 (probability value for 1 d.f. = .191)			

[a] Industry and yearl dummy variables represent the included manufacturing industries and years (1988-98).
[b] Numbers in parentheses are absolute t-statistics.
[c] High value favors FEM.

Table 10B. The Effects of R&D on Technical Change: Regression Results for Firms, 1988-98

	Constant	R&D	R-squared	No. of obs.
OLS without ind. and yearly dummy variables[a]	-.0091 (2.61)[b]	.0047 (4.33)	.105	162
Fixed effects model	-.0204 (.824)	.0090 (.976)	.266	162
Random effects model	-.0091 (2.31)	.0048 (4.04)	.105	162
Hausman test (FEM vs. REM)[c]	.21 (probability value for 1 d.f. = .645)			

[a] Industry and yearl dummy variables represent the included manufacturing industries and years (1988-98).
[b] Numbers in parentheses are absolute t-statistics.
[c] High value favors FEM.

Table 11. The Effects of Lagged Technical Change on Technical Change: Regression Results for Establishments and Firms, 1988-98

	Constant	TC_{t-1}	R-squared	No. of obs.
Establishments				
OLS	-.0021 (1.27)[a]	-.1250 (1.54)	.013	189
Firms				
OLS	.0018 (.881)[a]	.1205 (1.70)	.014	198

[a] Numbers in parentheses are absolute t-statistics based on heteroskedasticity-corrected standard errors.

Table A1. Comparison of Alternative TFP Growth Estimates, 1988-98

TFPG at Establishments

	TFPG[a]	TFPG1e[b]
Food	-0.00624	-0.00584
Beverage	0.00453	0.00745
Textile	0.00892	0.00784
Apparels	-0.01069	-0.00816
Lumber/wood products	0.00229	-0.00026
Furniture/fixture	-0.01463	-0.01371
Pulp	0.00494	0.00117
Printing	-0.00286	-0.00384
Chemicals	0.00877	0.00798
Petroleum/coal products	-0.01295	-0.00608
Plastic prod	0.00580	0.00447
Rubber products	0.00559	0.00613
Leather prod	-0.00431	-0.00684
Pottery	-0.00103	-0.00294
Steel	0.00313	0.00211
Non-ferrous metals	-0.00679	-0.00724
Metal products	0.00048	-0.00141
Gen mach	0.00051	-0.00191
Elec mach	0.02366	0.01389
Transp mach	0.00291	-0.00194
Precision	0.00586	0.00343
Other	0.00060	-0.00329

TFPG at Firms

	TFPG[a]	TFPG1f[c]
Food	0.00329	0.01346
Beverage	-0.00336	-0.00391
Textile	0.01870	0.01761
Apparels	-0.01099	-0.01217
Lumber/wood products	0.00040	-0.00169
Furniture/fixture	-0.01311	-0.00783
Pulp	-0.00125	-0.00044
Printing	-0.00738	-0.00731
Chemicals	0.00576	0.00773
Petroleum/coal products	-0.02151	-0.03193
Plastic products	0.01389	0.01667
Rubber products	0.00791	0.00250
Pottery	0.00101	-0.00514
Steel	-0.00024	-0.00083
Non-ferrous metals	-0.00334	-0.01124
Metal products	-0.00786	-0.01782
Gen mach (a) a	-0.00044	-0.00190
Gen mach (b) b	-0.00097	-0.00191
Elec mach (a) c	0.02940	0.02143
Elec mach (b) d	0.02767	0.02341
Transp mach	0.00032	-0.00034
Precision	-0.00016	0.00344
Other	-0.0009	-0.00703

Notes: This Table presents estimates averaged over the period 1988-98 for TFPG calculated by the methods used in this paper and two alternative methods in the literature. TFPGe is calculated by the method given in Footnote 14 (equation (8)), which is a conventional method for calculating TFPG. TFPGf is calculated using the method proposed by Caves, Christenssen and Diewert (1982a).

[a] Based on the method used in this paper. (Nakajima, Nakamura and Yoshioka (1998, Eq. (A18)).
[b] Based on the conventional method given in Footnote 14 (Eq. (*)) in the text.
[c] Based on the multilateral method in Caves, Christenssen and Diewert (1982a).

Figure 1. Establishments, 1964-88

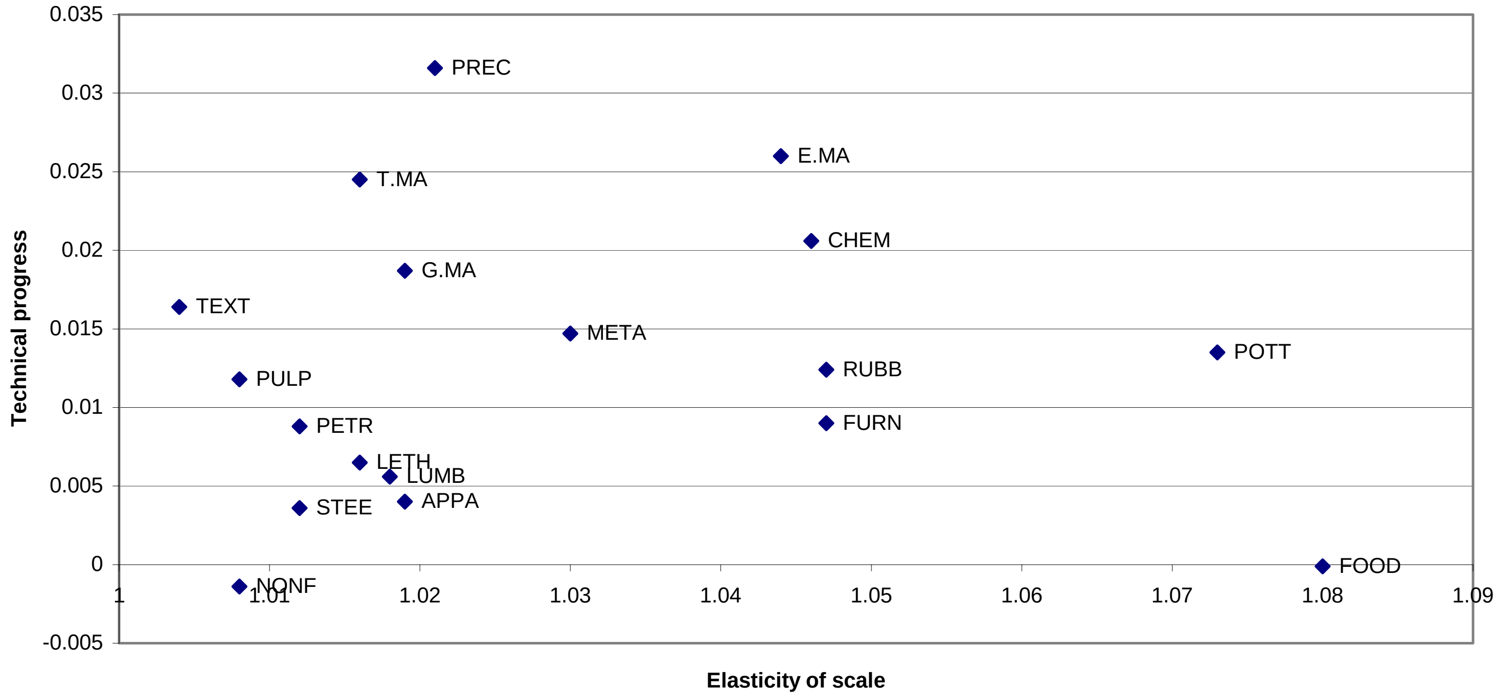

Figure 2. Establishments, 1988-91

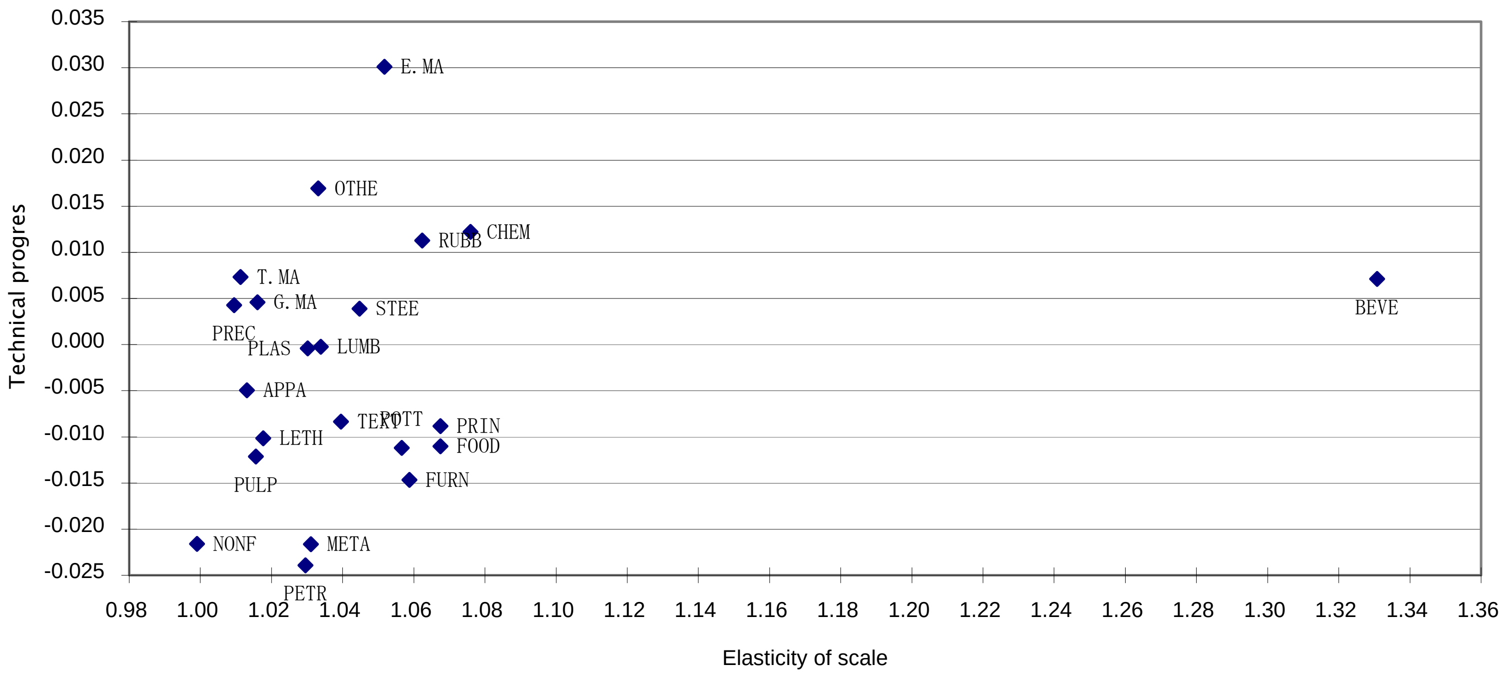

Figure 3. Establishments, 1991-95

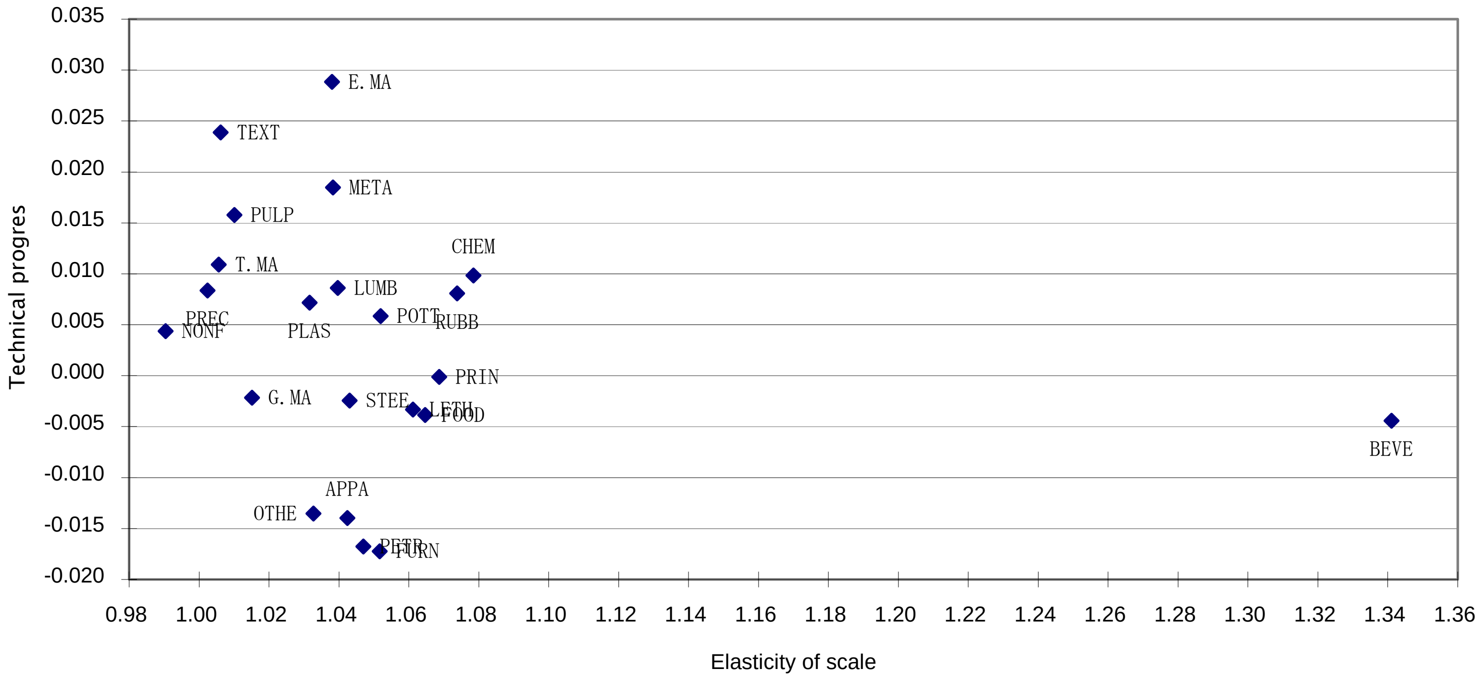

Figure 4. Establishments, 1995-98

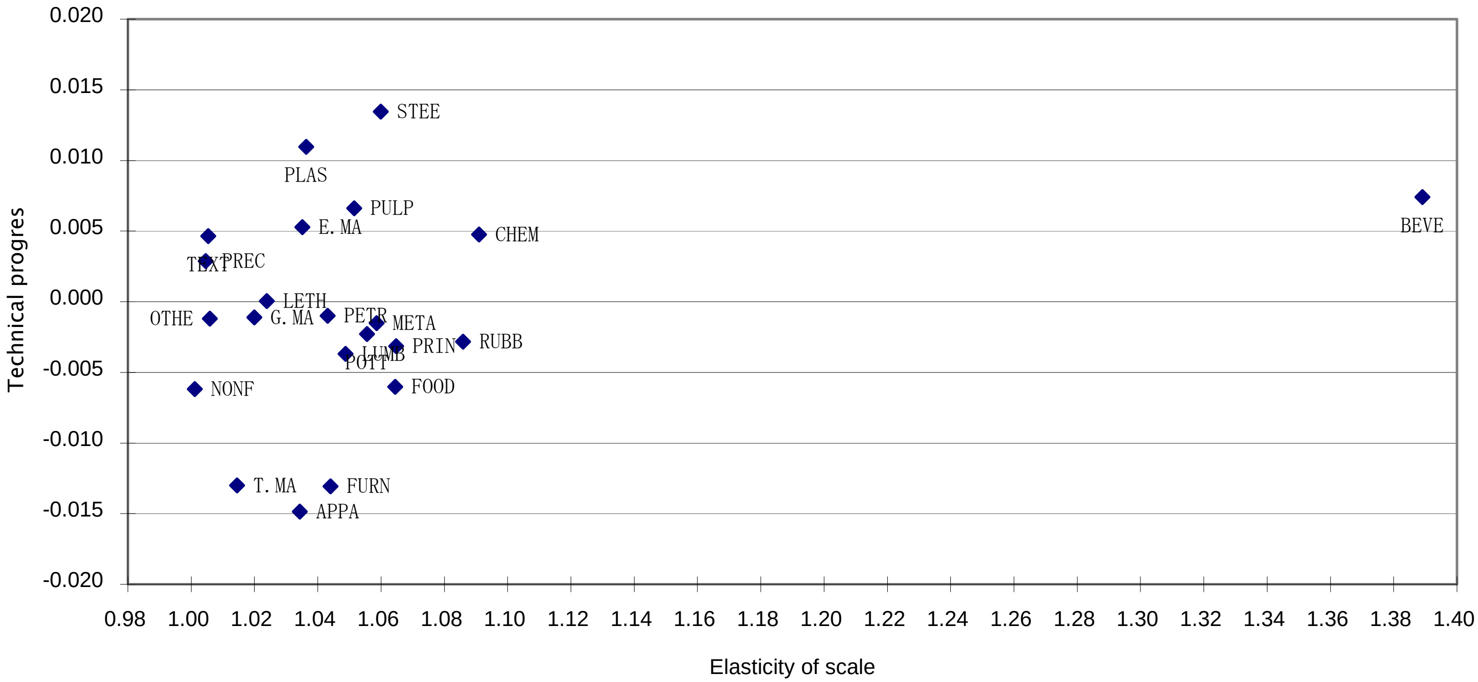

Figure 5. Establishments, 1988-98

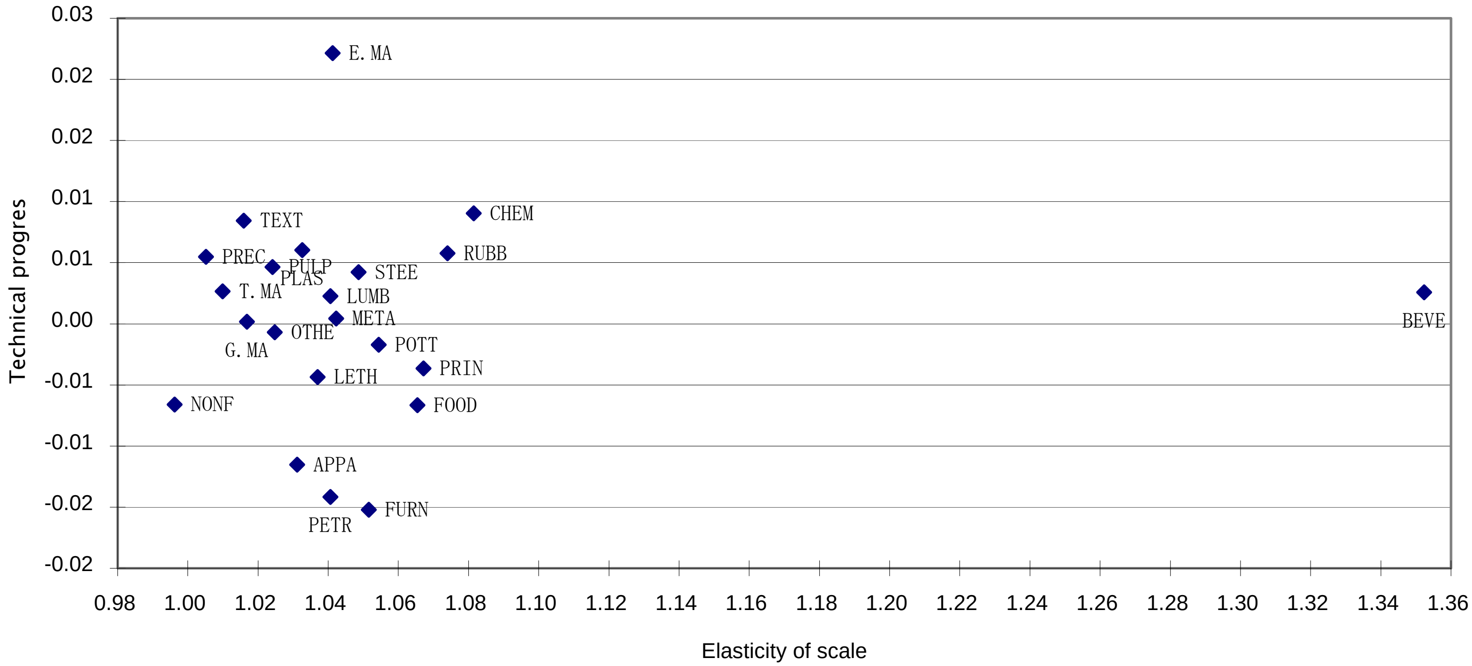

Figure 6. Firms, 1988-91

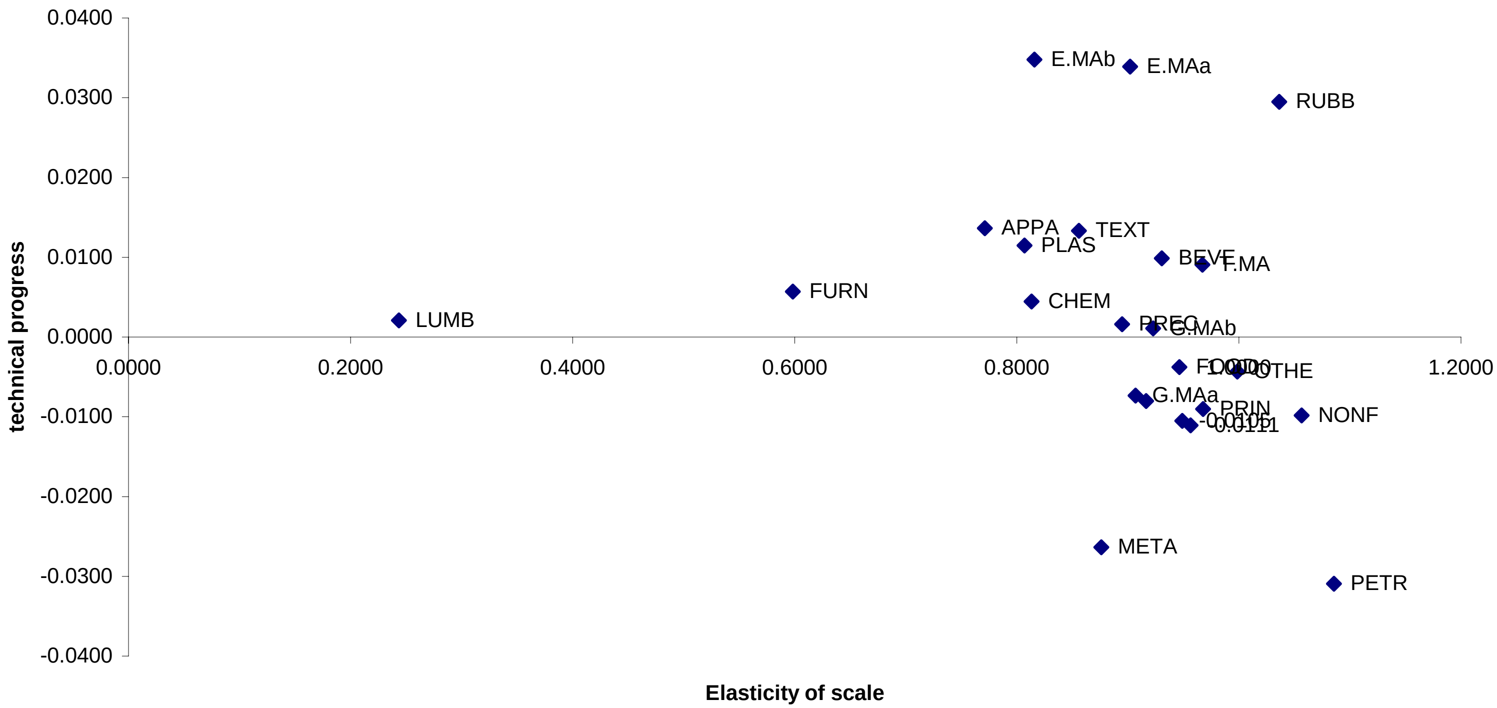

Figure 7. Firms, 1991-95

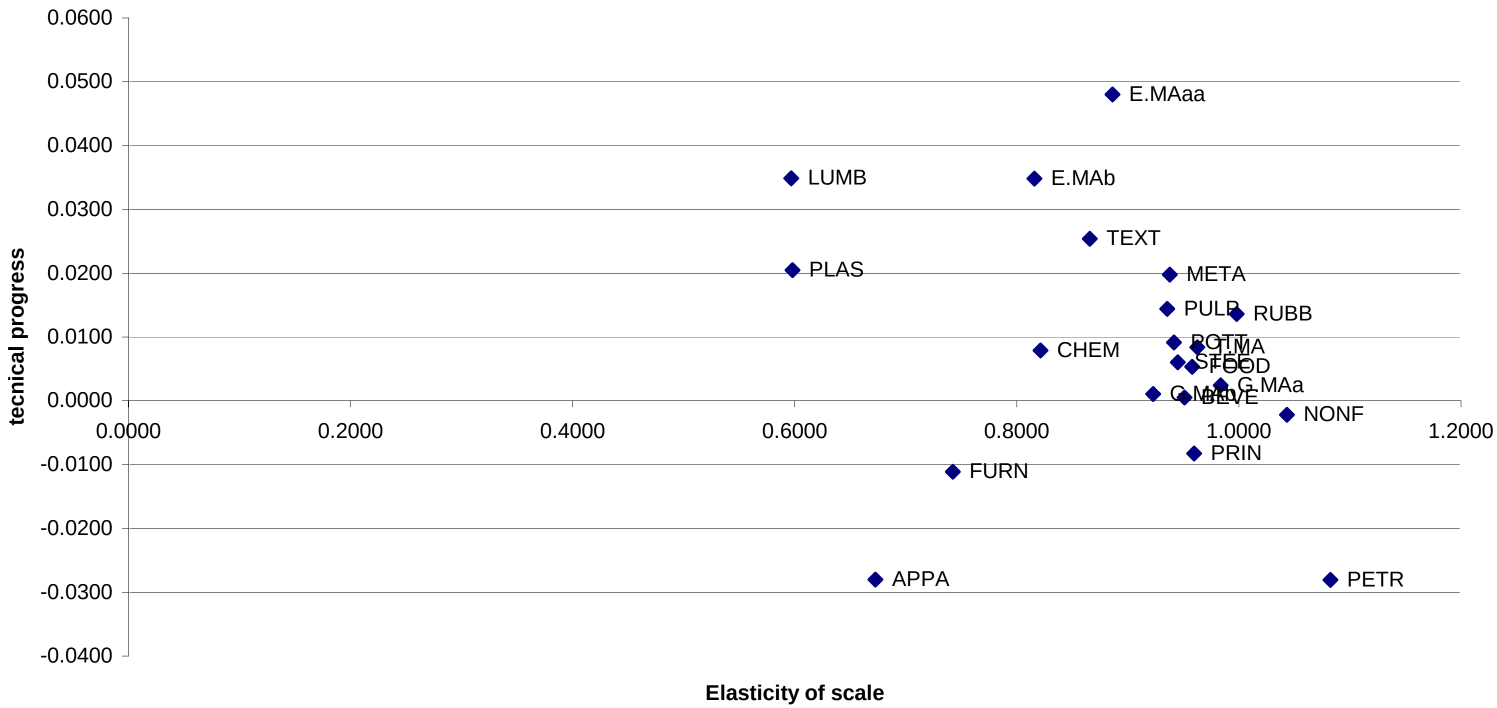

Figure 8. Firms, 1995-98

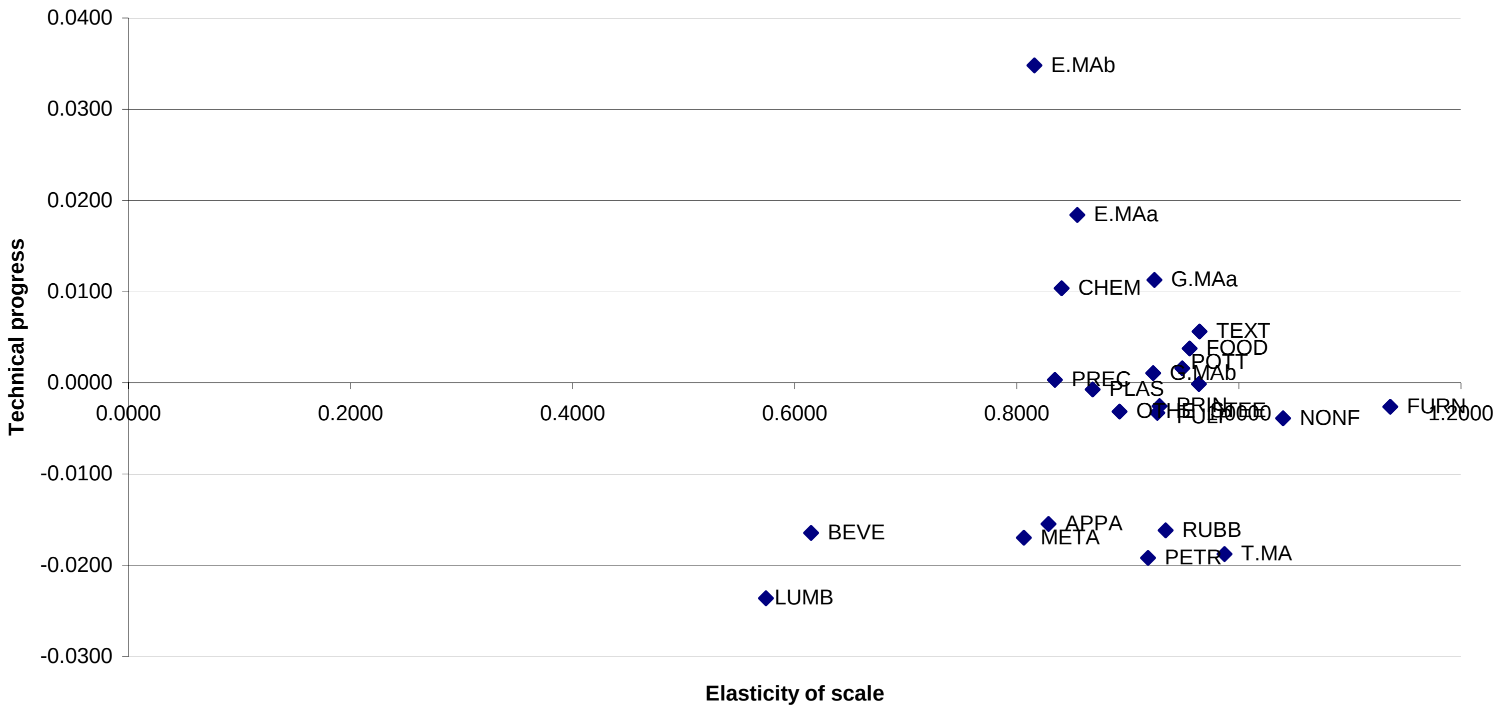

Figure 9. Firms, 1988-98

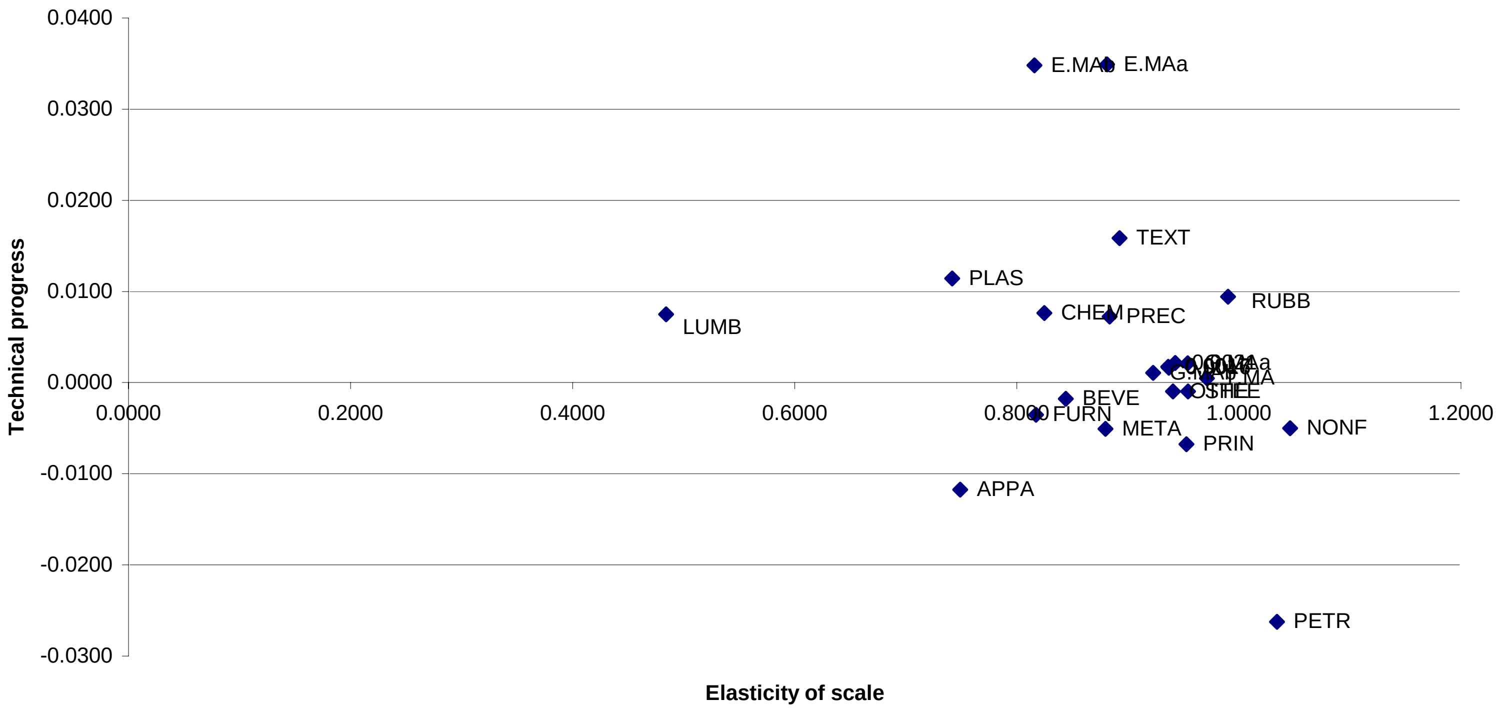

Figure 10. Technical Progress for Establishments, 1986-1995