adoption: A Stata routine for consistent estimation of population technology adoption parameters

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Stata Conference, July 26-27, 2012
San Diego, California

Outline of presentation

- Background
- Population adoption parameters and functions: A structural view
- ATE estimation of structural population adoption parameters
- Implementation of the Command
- Example
- Conclusion

The problem addressed

- **Estimation of population *adoption* parameters for a new technology not universally *<u>known</u>* in the population:**
  - **Mean population adoption rates**
  - **Population adoption gap**
  - **Determinants of adoption**
- **Separation of adoption and diffusion concepts/factors**
  - **Adoption= incidence or extent of use of a technology**
  - **Diffusion= extent of awareness or knowledge of the existence of a technology in the population**

The Literature

- ❑ **Empirical models of adoption include source of information, contact with extension, or education as explanatory variables to account for the role of information (Feder, Just and Zilberman (1985))**
- ❑ **But separation of adoption and diffusion parameters remains an issue**
  - **Besley and Case (1993): difficulty in interpreting the coefficients of adoption models under incomplete diffusion of the technology**
  - **Saha et al (1994) and Dimara. and Skuras (2003): Daberkow and McBride (2003) separate models for information acquisition and adoption but discussion and estimation in terms of a classic sample selection problem**

Contribution

- **Stata routine that implement the estimation procedure described in Diagne and Demont. 2007. "Taking a New look at Empirical Models of Adoption: Average Treatment Effect estimation of Adoption rate and its Determinants". Agricultural Economics, Vol 37:3. pp. 201-210.**
- **Show that sample adoption rates and classical adoption models do not inform about population potential adoption when the awareness of the technology in the population is not universal**
- **Estimate parameters that allow to assess the intrinsic merit of a new technology in terms of its potential demand independently of diffusion issues**

Population adoption parameters and functions: A structural view

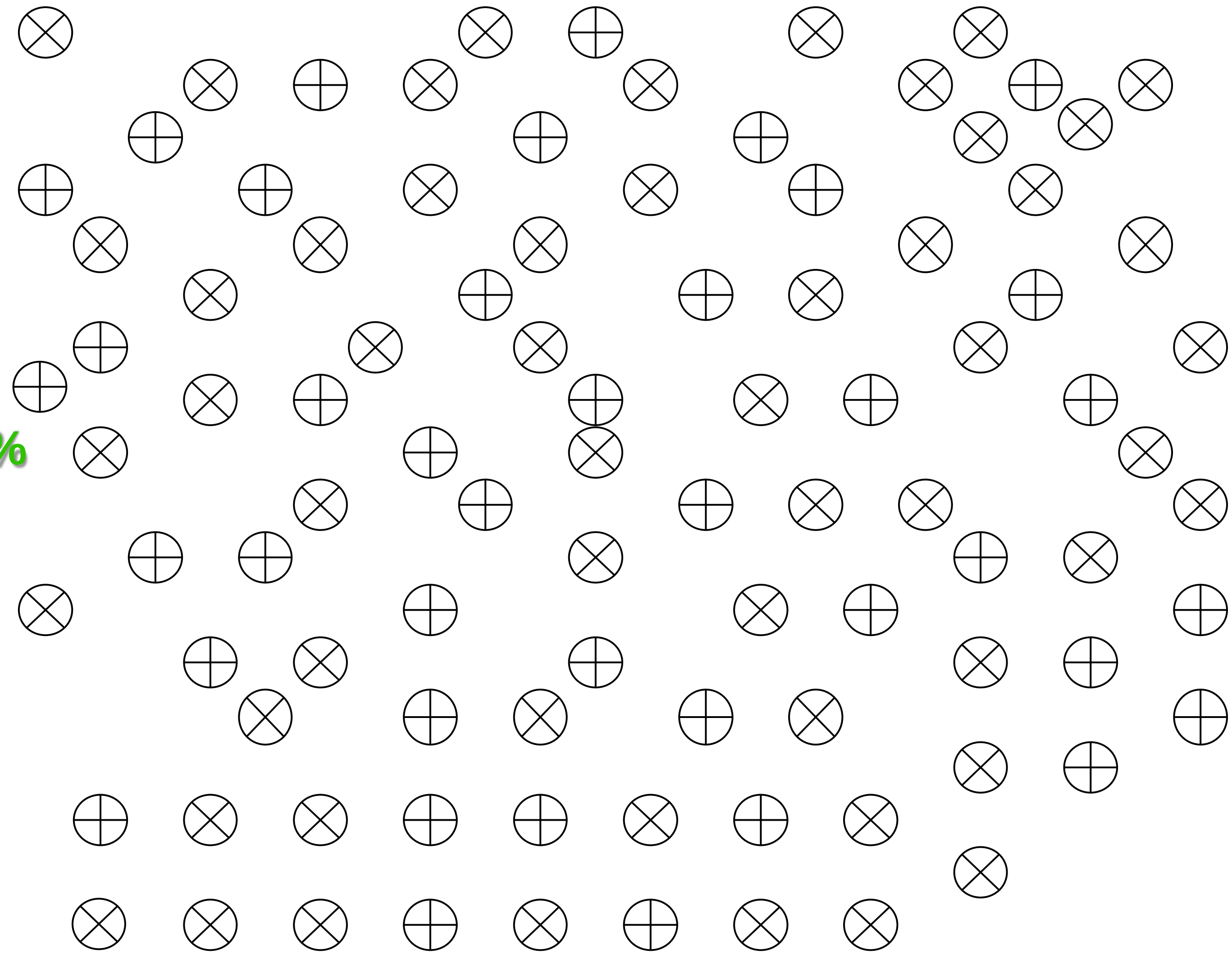
Partitioning of a population by a technology: Structural population adoption parameters

Total population size =100

⊕ **adopter type (40)**

⊗ **non-adopter type (60)**

Potential adoption rate = 40%



The structural population adoption function

$$R^K \times R^L \mapsto \{\oplus \otimes\}$$

$$(x,u) \quad \to f(x,u)$$

⊕ **adopter type**
⊗ **non-adopter type**

x = observed covariates
***u* = unobserved covariates**

Population after partial exposure to the technology

Total population size =100

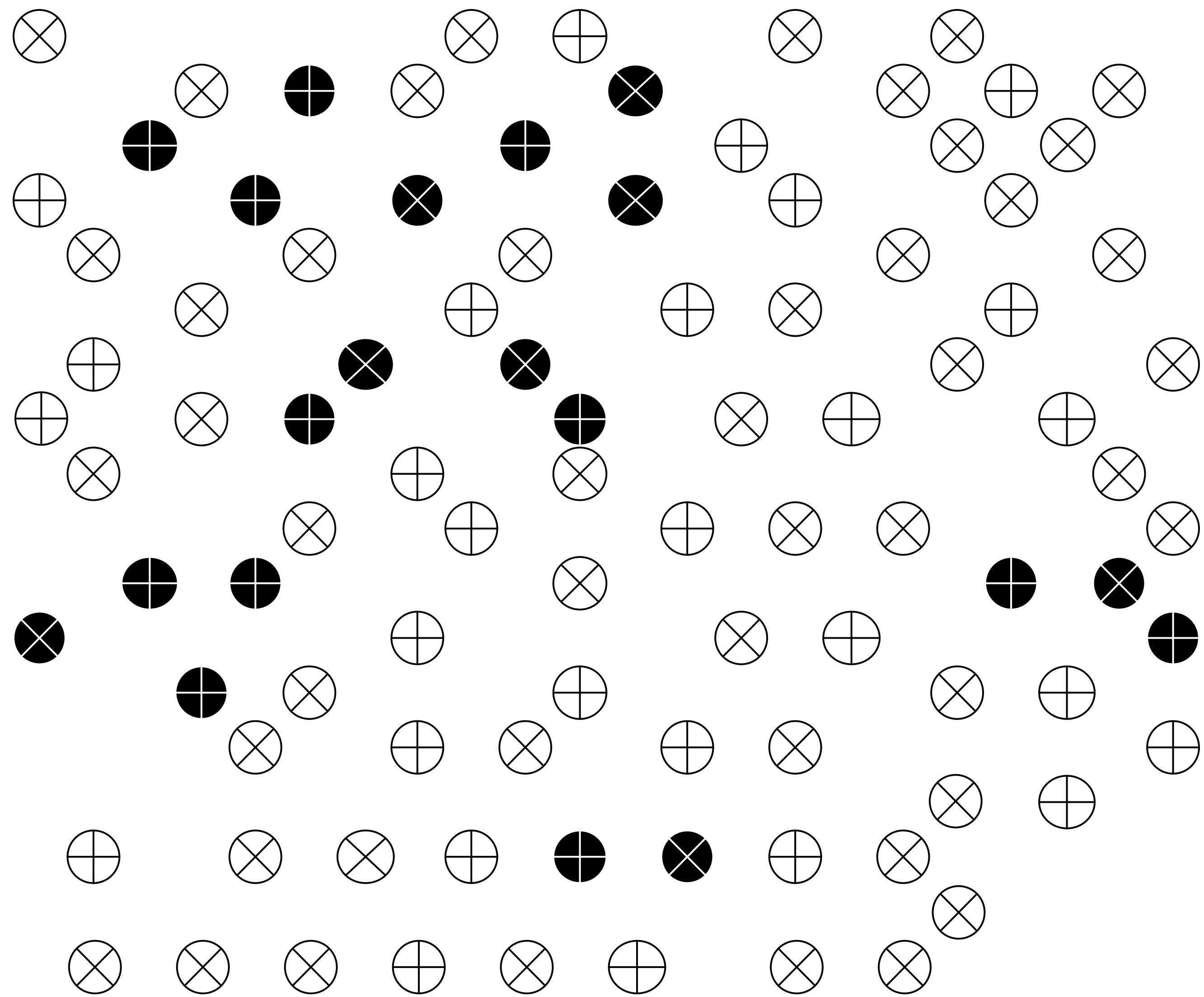
- adopter type (40)
- non-adopter type (60)
- exposed (20)

Population exposure rate = 20%

Population adoption rate = 40%

Population exposure and adoption rate =12%

Adoption rate among the exposed: = 60%



Structural adoption and exposure functions

Adoption function

$$f : R^K \times R^L \mapsto \{\oplus \ \otimes\}$$ *not observed*

$$(x, u) \to f(x,u)$$

Exposure function

$$e : R^M \times R^N \mapsto \{\bigcirc \ \bullet\}$$ *observed*

$$(z, v) \to e(z,v)$$

Joint exposure and adoption function

$$\{\oplus \ \otimes\}$$ *not observed*

$$h : R^M \times R^K \times R^L \times R^N \mapsto \{\oplus \ \otimes \ \bigcirc\}$$ *observed* (filled $\oplus$, filled $\otimes$)

$$(z, x, u, v) \to h(z, x, u, v) = e(z,v) \times f(x,u)$$

$\oplus$ adopter type
$\otimes$ non-adopter type

$\bullet$ exposed
$\bigcirc$ non-exposed

x,z = observed covariates
u,v = unobserved covariates

Structural and classical adoption functions

The structural joint exposure and adoption function: exposure observed

$\{\oplus \; \otimes\}$ *not observed*

$$h : R^M \times R^K \times R^L \times R^N \;\mapsto\; \{\text{●}\!\!\!\!\oplus \; \text{●}\!\!\!\!\otimes \; \bigcirc\} \quad \textit{observed}$$

$$(z, x, u, v) \;\rightarrow\; h(z, x, u, v) = e(z,v) \times f(x,u)$$

The classical "adoption" function: exposure *not* observed

$\{\text{●}\!\!\!\!\otimes \; \oplus \; \otimes\}$ *not observed*

$$g : R^M \times R^K \times R^{L+N} \;\mapsto\; \{\text{●}\!\!\!\!\oplus \; \bigcirc\} \quad \textit{observed}$$

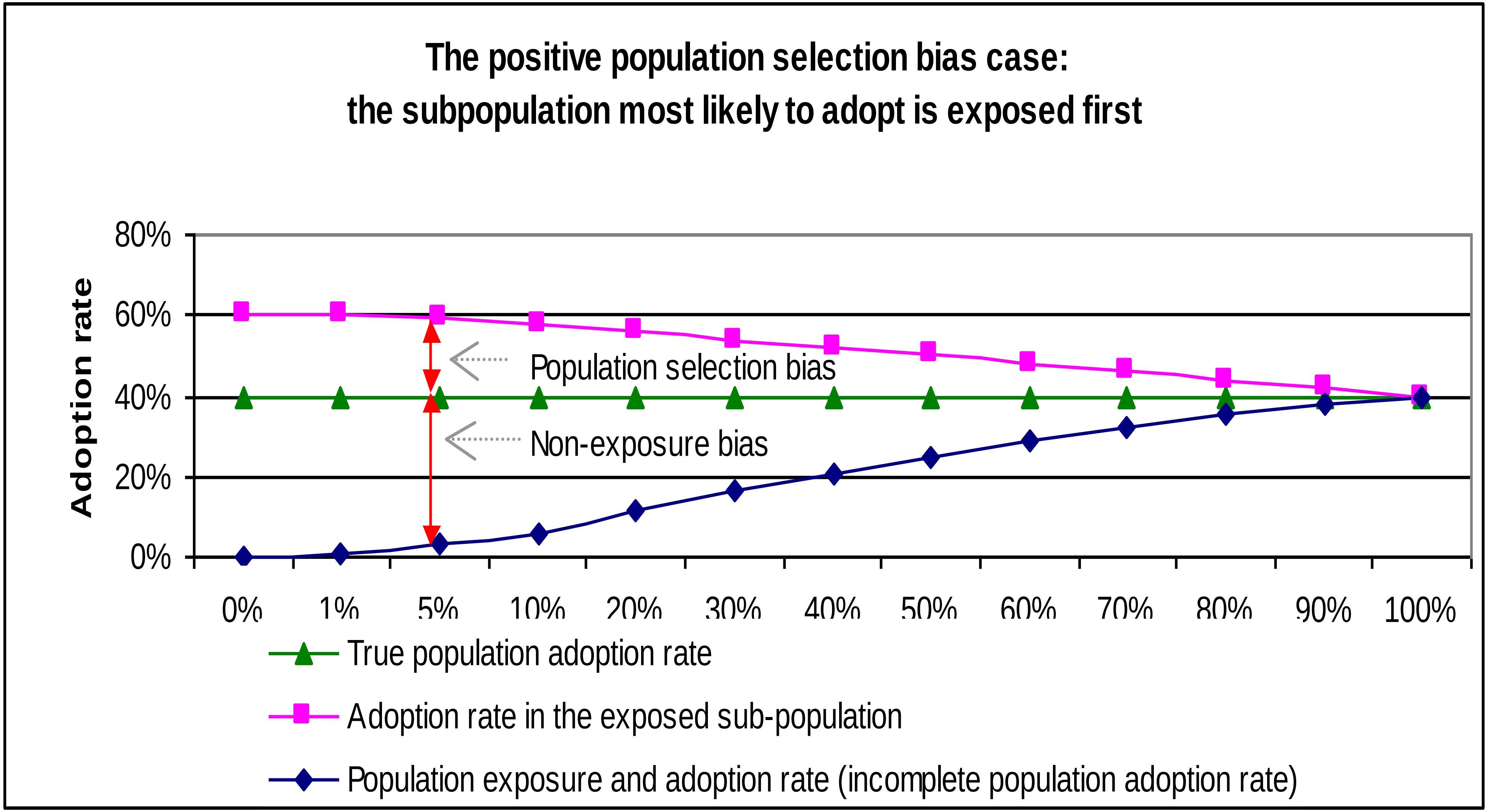
$$(z, x, \varepsilon) \;\rightarrow\; g(z, x, \varepsilon)$$

$\oplus$ adopter type
$\otimes$ non-adopter type

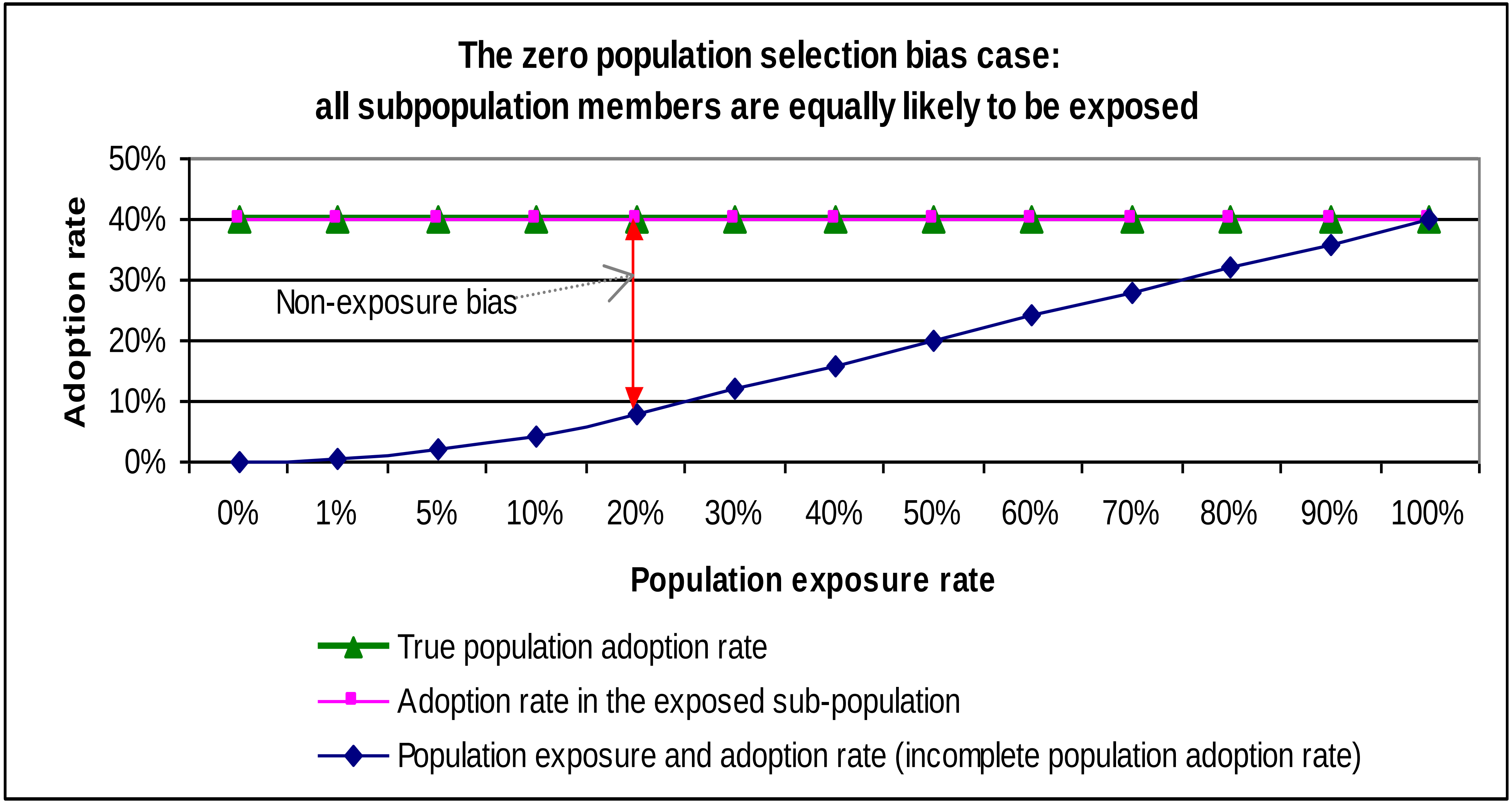
● exposed
○ non-exposed

x,z = observed covariates
u,v, ε = unobserved covariates

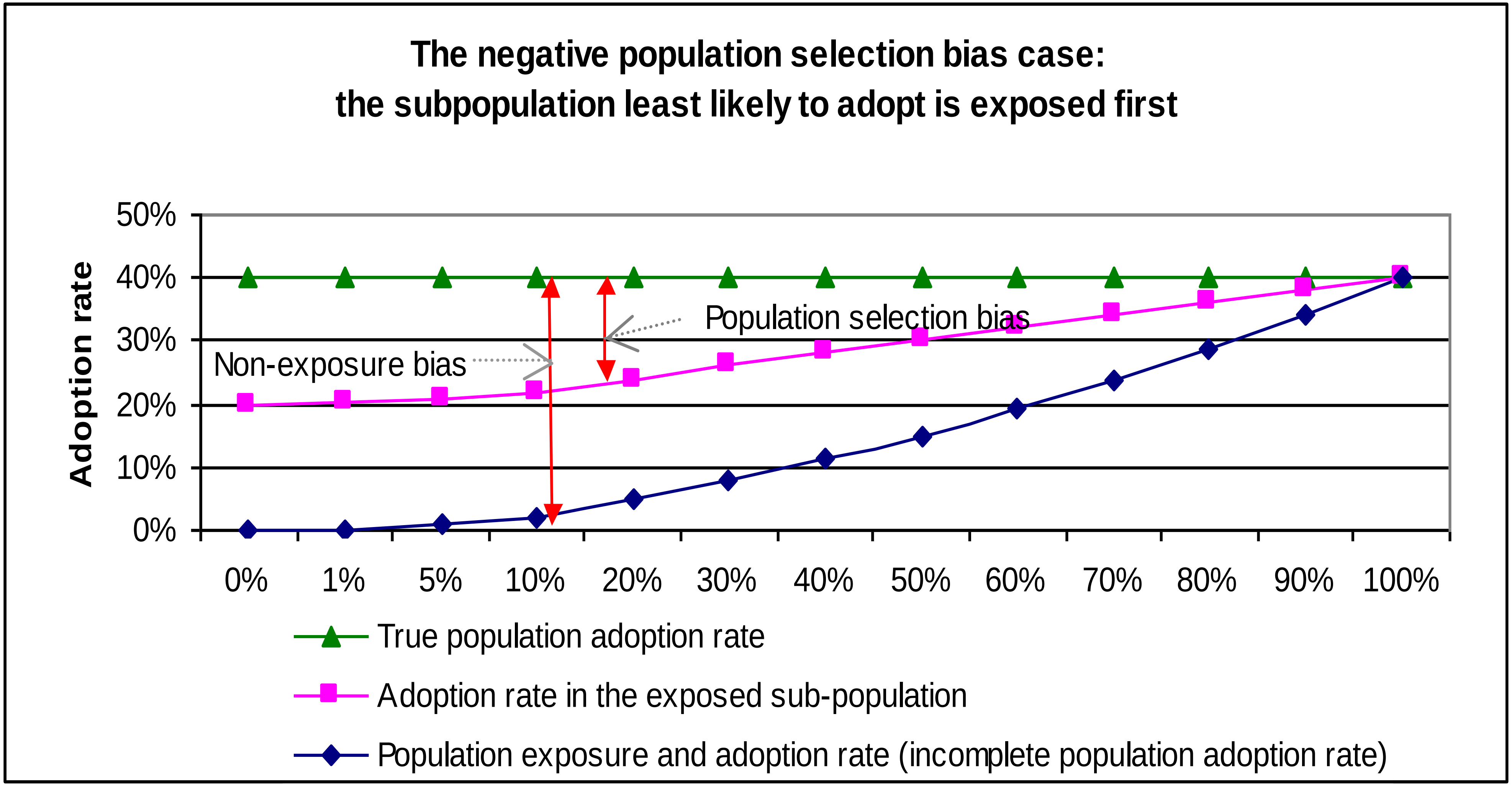
Population adoption rates and biases as function of exposure rate



Population adoption rates and biases as function of exposure rate



Population adoption rates and biases as function of exposure rate



Random Sampling from the partially exposed population

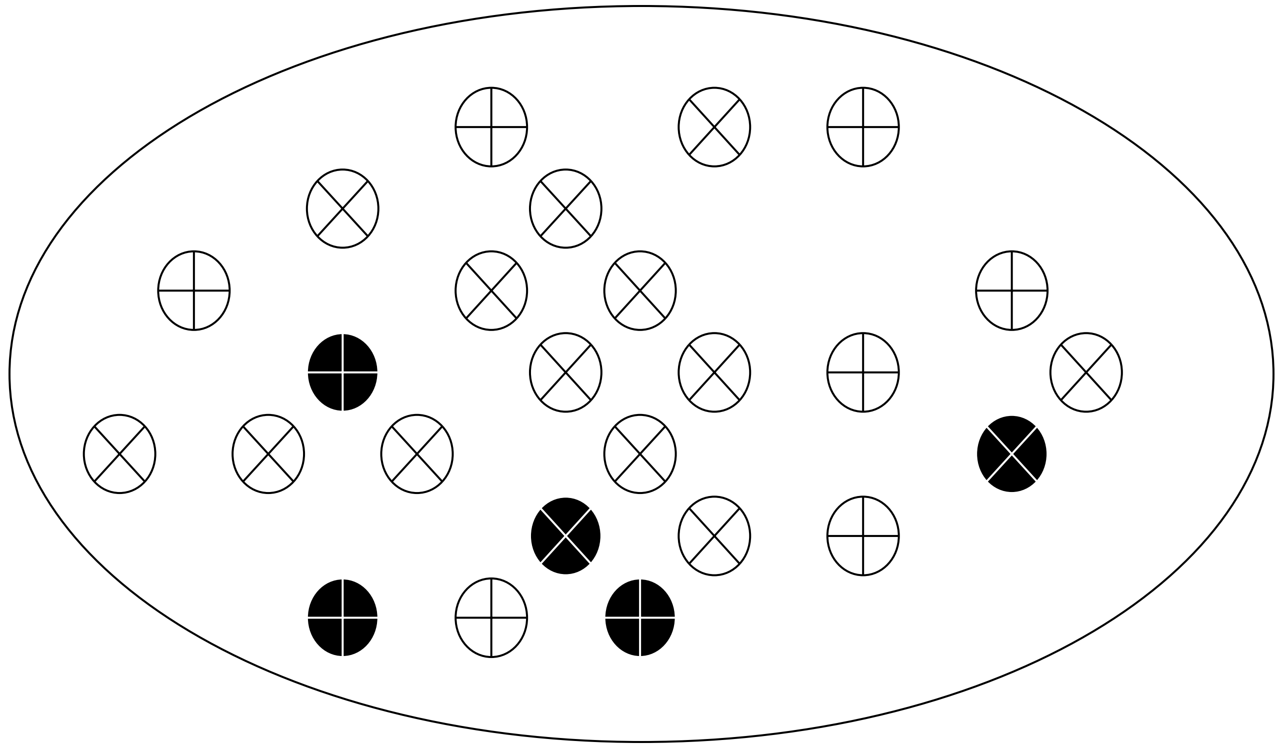
Sample size =25

adopter type (10)
non-adopter type (15)
exposed (5)

Sample exposure rate = 20%

Sample adoption rate =**12%**

Sample adoption rate among the exposed: = **60%**



The Adoption Estimation Problems

- How can the structural population adoption parameter be estimated?

  i.e. how to estimate the 40% in the example

- How can the structural adoption function be estimated?

  i.e. how to estimate the function

$$f : R^K \times R^L \mapsto \{\oplus \ \otimes\}$$

$$(x, u) \rightarrow f(x,u)$$

Adoption outcomes as results of treatment/policy intervention

- Treatment/Policy intervention =
  - exposure to the technology
- The two counterfactual states:
  - being exposed to the technology
  - not being exposed to the technology
- The two counterfactual outcomes:
  - adoption outcome under exposure
  - adoption outcome under non-exposure

The Average Treatment Effect (ATE) Estimation framework

- ATE: *average treatment effect*

  measures the effect of a “treatment” on a person randomly selected in the population

- ATT: average treatment effect on the treated

  measures the average effect of a “treatment” on the treated subpopulation

- ATU: *average treatment effect* on the untreated

  measures the average effect of a “treatment” on the untreated subpopulation

ATE estimation of structural population adoption parameters

The ATE Estimation framework

- *W = exposure status (observed)*

  W=1 exposure

  W=0 non-exposure

- Y_1 = Potential adoption outcome when exposed
- Y_0 = Potential adoption outcome when not exposed
- $Y = w\, Y_1 + (1\text{-}w)\; Y_0$ = *observed adoption outcome*

The ATE Estimation framework

- $Y_{1i} - Y_{0i}$ = treatment effect for farmer i
- $E(Y_1 - Y_0)$ = Average treatment effect (ATE)
- $E(Y_1 - Y_0 \mid w=1)$ = Average treatment effect in the treated subpopulation (ATT)
- $E(Y_1 - Y_0 \mid w=0)$ = Average treatment effect in the non-treated subpopulation (ATU)

The ATE Estimation framework

Potential adoption outcome Y_0 = 0 for all W

- ATE= $E(Y_1)$ = adoption rate
- $ATT=E(Y_1 \mid w=1)$ = adoption rate among exposed
- $ATU=E(Y_1 \mid w=0)$ = adoption rate among non-exposed

$Y = wY_1$ = *observed adoption outcome*

- $E(Y) = E(w\, Y_1)$ = *joint exposure and adoption rate (JEA)*

  $= P(w=1) \times E(Y_1 \mid w=1)$

The ATE Estimation framework

Other population adoption parameters

- *Adoption gap (NEB) = JEA – ATE*
- *Population selection bias (PSB)= ATT-ATE*

The ATE Estimation framework

We observe Y_1 only for w=1

⇨

- Cannot estimate ATE=$E(Y_1)$ *by sample average* (missing Y_1 values for w=0)
- *Can estimate ATT=*$E(Y_1 \mid w=1)$ consistently by sample average among exposed

The ATE Estimation framework: Identification

How can ATE and ATU be identified and estimated if we don't observe Y_1 for w=0?

Answer: The Conditional Independence (CI) and common support assumptions (e.g.Rosenbaum and Rubin,1983):

- *w is independent of Y_1 and Y_0 conditional of X*
- $0 < Prob(W = 1|X) < 1$

The ATE Estimation framework: Identification

$$ATE = E(y_1) = E\left(\frac{y}{p(x)}\right) \qquad (1)$$

(2)

Where p(x)=P(w=1|x) is the conditional probability of exposure (the propensity score)

The ATE Estimation framework

Two alternative methods of estimation of ATE:

- *<u>Method 1</u>: semiparametric (based on Eq 1):*

  Step 1: Estimate p(x) by a nonparametric method or by probit or logit

  Step 2: Use the predicted propensity score values p(x) to compute the sample analogue of formula in Eq 1

The ATE Estimation framework

Two alternative methods of estimation of ATE:

- *<u>Method 2</u>: Parametric (based on Eq 2):*
  - *Step 1: Estimate a parametric model of E(y | x) using a random sample <u>restricted to the exposed sub-population</u>*
  - *Step 2: form the predicted values E(y|x) for the f<u>ull</u> sample (exposed and non exposed) and takes average across all observations*

Implementation of the *adoption* command

Structure of the adoption command

Adoption is essentially a wrapper of Stata estimation commands with some additional standard errors computation

1-Parse user inputs

1-Identification, 2-Parameters, 3-Estimation methods,
4-Parametric functional form

2- Estimate propensity score (the exposure function) by probit or logit and store in e(b) and e(V)

3- Call estimation routine that estimate the parametric structural adoption function using Stata estimation commands.

- Adjust covariance matrix in case of Two steps estimation (following MacFadden and Newey, 1994).
- Save results in e(b) and e(V)

4- Call routine that estimate the ATE adoption parameters (ATE, ATT, and ATU) with their standard errors

Syntax

The general syntax of the command is as follows:

adoption depvar [expvar] [if] [in] [weight] [using filename] [, options]

depvar is the observed dichotomous adoption variable

expvar exposure variable

Syntax

Options

zexposure ([probit|Logit =]zvar) zvar is the varlist of independent variables of exposure variable (expvar)

ate([sp| stata|model=]xavar) option for the choice of the ATE estimation method: semi-parmertric (sp) or parametric method. **xavar** is varlist of independent variables for the parametric method.

opexp(stata option) options of the Stata probit or logit command to be used in the exposure model (noconstant : suppress constant term of the regression model , Robust : synonym for vce(robust), etc.)

Syntax

Options

opatepara(stata option) options of the Stata internal parametric model (regress, nls, etc..) to be used in the parametric ATE estimation methods.

atestata (stata command syntax) Option for using an existing Stata estimation command as it would be used in the stata command window

classic(varlist=xeavar|xavar) Estimation of classic adoption model with joint exposure and adoption independent variables (**xeavar**) or adoption variable (**xavar**)

Syntax

Options

SE/Robust

vce(vcetype) vcetype may be robust, bootstrap, or jackknife

robust synonym for vce(robust)

cluster(varname) adjust standard errors for intragroup correlation

Reporting

level(#) set confidence level; default is level(95)

Syntax

adoption postestimation

1. Post estimation commands specific to the stata estimation commands used internally by adoption (e.g. probit, reg, nls, etc..):
   estimates restore model name

2. Prediction of adoption rates for subpopulations (ATE, ATT and ATU):
   adoption [if *exp]*

3. Marginal effects of exposure, adoption and joint exposure and adoption at observed values and mean of observed values.
   mfxadoption [if *exp*], options

Example: NERICA adoption in Cote d'Ivoire

- *Observed sample adoption rate*

```
. adoption aner00

ATE ESTIMATION OF THE POPULATION ADOPTION PARAMETERS...

.... ESTIMATION BY SAMPLE AVERAGE AS IF EXPOSURE WERE UNIVERSAL ....

SUMMARY of MODELS AND PARAMETERS ESTIMATED
```

name	command	depvar	npar	title
adoption	adoption	aner00	1	*Observed sample adoption incidence rate*

```
Observed sample adoption incidence rate
                                            Number of obs:       N  =    1509
                                            Number of adopters: Na =      53
```

aner00	parameter	Robust Std. Err.	z	P>|z|	[95% Conf. Interval]	
Na/N	.0351226	.0047405	7.41	0.000	.0258313	.0444139

Example: NERICA adoption in Cote d'Ivoire

- *Semi-parametric Method*

ATE ESTIMATION OF THE POPULATION ADOPTION PARAMETERS...

... ESTIMATION BY THE SEMIPARAMETRIC WEIGHTING METHOD....

SUMMARY of MODELS AND PARAMETERS ESTIMATED

name	command	depvar	npar	title
adoption	adoption	aner00	9	*ATE semiparmetric estimation of population adoption incidence rates*
exposure	probit	kner	21	*probit regression of the probability of exposure (propensity score)*

ATE semiparmetric estimation of population adoption incidence rates

Number of obs: N = 1261
Number of exposed: Ne = 124
Number of adopters: Na = 46

aner00	parameter	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
ate	.2244926	.0639927	3.51	0.000	.0990692	.3499159
ate1	.3709677	.0504818	7.35	0.000	.2720252	.4699103
ate0	.2085182	.0684713	3.05	0.002	.0743169	.3427194
jea	.036479	.0049641	7.35	0.000	.0267495	.0462085
gap	-.1880136	.0617382	-3.05	0.002	-.3090182	-.067009
psb	.1464752	.0592475	2.47	0.013	.0303523	.2625981
Observed						
Ne/N	.0983347	.0083886	11.72	0.000	.0818933	.1147761
Na/N	.036479	.0052816	6.91	0.000	.0261272	.0468308
Na/Ne	.3709677	.0537106	6.91	0.000	.2656969	.4762386

Example: NERICA adoption in Cote d'Ivoire

– *parametric Method*

... ESTIMATION OF POPULATION ADOPTION PARAMETERS ...

SUMMARY of MODELS AND PARAMETERS ESTIMATED

name	command	depvar	npar	title
adoption	adoption	aner00	9	*ATE parametric (Probit) estimation of population adoption incidence rates*
exposure	probit	kner	21	*probit regression of the probability of exposure (propensity score)*
parametric	probit	aner00	14	*ATE Probit regression (restricted to the exposed subsample)*
classic	probit	aner00	23	*Classic Probit regression (joint exposure and adoption)*

ATE parametric (Probit) estimation of population adoption incidence rates

Number of obs: N = 1261
Number of exposed: Ne = 124
Number of adopters: Na = 46

aner00	parameter	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
ATE						
ate	.3072747	.0480065	6.40	0.000	.2131837	.4013656
ate1	.3723981	.0371878	10.01	0.000	.2995115	.4452848
ate0	.3001724	.051408	5.84	0.000	.1994144	.4009303
jea	.0366196	.0036568	10.01	0.000	.0294524	.0437869
gap	-.270655	.0463529	-5.84	0.000	-.3615049	-.1798051
psb	.0651235	.044326	1.47	0.142	-.0217539	.1520009
Observed						
Ne/N	.0983347	.0083886	11.72	0.000	.0818933	.1147761
Na/N	.036479	.0052816	6.91	0.000	.0261272	.0468308
Na/Ne	.3709677	.0537106	6.91	0.000	.2656969	.4762386

Example: NERICA adoption in Cote d'Ivoire

- *Parametric Method*

Coefficients estimates of estimated parametric models

Variable	exposure	parametric	classic
vpvs	.91835685***	1.904404**	.86175005***
canaderv	-.20362235		.24240977
ccidtgvv	-.21234504		-2.1049415***
coldorgv	1.5686352***		1.8813963***
nknerv	.50895438***		1.1459965***
nktrav	.03981253***		-.01527343
nknauv	-.12715179*		-.33521354***
nkwauv	.06774571		.0412896
pvstpast	.09937416	.90556827*	.39801704
plateau	.89257809***	.48174778	.06795873
lx5totar	.15726343	-.13022016	.28978154*
hhsize96	.00620782		-.02552549
origvil	.24058739		-.42360128*
age	.00274973	-.01323842	-.02637045***
actsec	.28015257*	.45288544	.14766215
anscol	.03895033*	-.04720465	-.02459032
woman	.29474026	-.01661318	-.04732435
bete	-.99144975***	1.1178406**	-.60412819
senoufo	1.1956274	-1.218619	-1.4912903***
forest	.91145078	-2.9286214**	-3.9803813***
ccidtgiv		.97605853	.77421446
coldorg		.19508971	.2999906
hhsize		.0516281	.02931401
_cons	-6.1913474***		
N	1261	124	1261
r2_p	.3656829		
chi2	296.41958	47.35847	535.93065
df_m	20	14	23
ll	-257.08614	-64.963349	-140.71391
aic	556.17228	157.9267	327.42781

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

Example: NERICA adoption in Cote d'Ivoire

- *Parametric Method*

Marginal effects of exposure, adoption and joint exposure and adoption at mean of observed values

Variable	dfx_exposure	dfx_adoption	dfx_atejea	dfx_classic
vpvs	.03993268*	.58767655***	.02865662*	.0025498
canaderv	-.00604327		-.00131611	.00043029
ccidtgvv	-.00598074		-.00130249	-.00421657
coldorgv	.12669467**		.02759164**	.02587919
nknerv	.01549178*		.00337381	.00187732
nktrav	.00121183*		.00026391	-.00002502
nknauv	-.0038703		-.00084288	-.00054913
nkwauv	.00206207		.00044908	.00006764
pvstpast	.00332064	.3231725*	.00539729	.00117151
plateau	.0199939*	.12959869	.00542493	.00010616
lx5totar	.00478685	-.03833309	.00059596	.00047471
hhsize96	.00018896		.00004115	-.00004181
origvil	.00628965		.00136976	-.00111246
age	.0000837	-.00389701	-.00002717	-.0000432
actsec	.00901048	.13589854	.00385133	.00025211
anscol	.00118559	-.0138957	.00009633	-.00004028
woman	.01020286	-.00487944	.00214453	-.00007551
bete	-.01717925*	.39152842**	-.00241683	-.00059967
senoufo	.05852211	-.31706811*	.00277032	-.00314528
forest	.0310087	-.75016573***	-.00192179	-.10040788***
ccidtgiv		.35192686	.00409943	.00428456
coldorg		.06124992	.00071347	.00079161
hhsize		.01519784	.00017703	.00004802
N	1261	1261	1261	1261

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

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Conclusions

- ✓ *Adoption surveys need to collect information on individual awareness of the technologies*
- ✓ *When diffusion is incomplete, sample adoption rates and the classical adoption model are about joint adoption and exposure*
- ✓ *When diffusion is incomplete, ATE estimation provides reliable information on population potential adoption rates, gaps and determinants*

Ways Forward

- Extend *adoption* to account for when the new technology is not universally available to the population.

- Use margins to estimate ATE, ATT and ATU instead of using predict and computing standard errors manually.

- Implement other ATE estimation methods (matching, Doubly robust, MTE, etc..)

Wishes to Stata

- Make Stata estimation commands, *suest* and *margins* aware of two-step estimation when done manually (e.g. declaration through an option)

  → Automatic adjustment of standard errors (e.g. McFadden and Newey 1994)

- Make accessing estimated coefficients sub vectors of e(b) possible and usable in operations and commands like margin:

  i.e. extend _b[varname] to allow for _b[varlist]

- More non-parametric regression commands

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THANK YOU !