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Efficiency Measurement in the Electricity and Gas Distribution sectors

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FIMA , second international conference 2008

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- To present and discuss the **application of mathematical and statistical methods** in the measurement of the company's **productive efficiency**
- Applied econometrics
- Applied microeconomics

- Introduction
- Research question
- Econometric models
- Empirical study

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A. Introduction

- In the last two decades the electricity and gas distribution sectors have experienced a wave of regulatory reforms
- Competition in production and new regulation instruments in the distribution (still a natural monopoly).
- For the design of these reforms **as well for business decisions,** the empirical understanding on different efficiency concepts (***scale efficiency, scope efficiency, and cost efficiency***) is relevant

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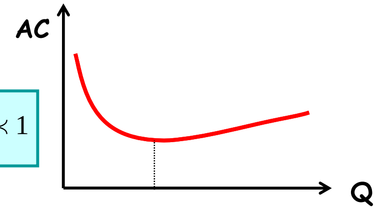
Importance of the empirical understanding

- **First,** the knowledge of the value of the economies of scale and the economies of scope provides information about
- the validity of the **natural monopoly argument**
- the definition of the **optimal size of service areas**.
- the **potential synergies through 'horizontal' integration**

Scale and scope efficiency

- *Economies of scale exists if*

$TC = f(Q)$ $CE = \frac{\partial C}{\partial Q}\frac{Q}{C} \prec 1$



- *Economies of scope exists* if
- $TC(Q_1,0) + TC(0,Q_2) > TC(Q_1,Q_2)$

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Empirical relevance

- **Second**, more and more in the application of incentive regulation schemes, regulators make use of cost efficiency indicators.

Country	Regulation Method	Explicit use of benchmarking
Netherlands	Yardstick	Yes
United Kingdom	Price-cap	Yes
Norway	Revenue-cap	Yes

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Price cap: $P_{t+1} = P_t(1+\Delta CPI - X + Z)$

growth rate of the total factor productivity (TFP) in the entire sector

decomposing the TFP growth into 3
1. techical progress
2. Scale efficiency
3. firm-specific efficiency

annual target change in productive efficiency for each individual company

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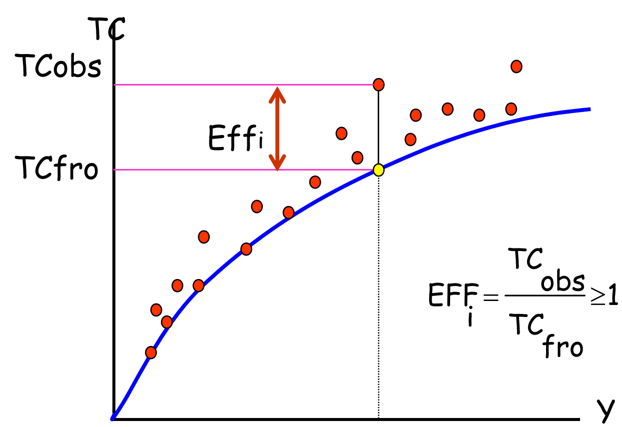
Cost frontier and cost inefficiency

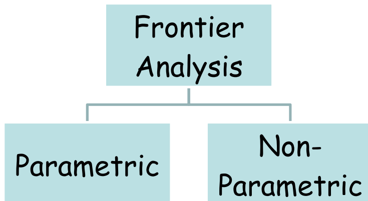


$EFF_i = \frac{TC_{obs}}{TC_{fro}} \geq 1$

Cost efficiency measures the ability of energy distribution companies to minimize costs

B. Research question

- In the literature we can distinguish two principal types of approaches to measure efficiency



A main problem is **the choice of the approach** and within each method the choice among several legitimate models.

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Two approaches

- Both approaches – *econometric* and *linear programming* – have their own advocates. At least in the scientific community neither one has emerged as dominant.
- The purpose of this presentation is not to stress the advantages and disadvantages of these two different approaches.

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Empirical evidence

- The empirical evidence in the electricity sector suggests that the results in terms of efficiency are sensitive to the approach used (**parametric** and **non parametric methods**).
- Jamasb and Pollit (2003), Estache et al. (2004) , Farsi and Filippini (2004, 2005) show that there are:

↳ **substantial variations in estimated efficiency scores** and rank orders across different approaches (parametric and non-parametric) and

↳ among different econometric models.

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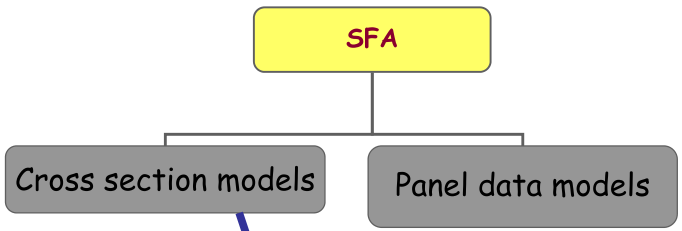
Unobserved heterogeneity

- Part of this discrepancy is related to the **unobserved heterogeneity across firms** (network characteristics and environmental factors).
- In the context of parametric methods, panel data can be helpful to **distinguish efficiency differences from unobserved heterogeneity**.
- .RESEARCH AREA

Parametric: Stochastic Frontier Methods

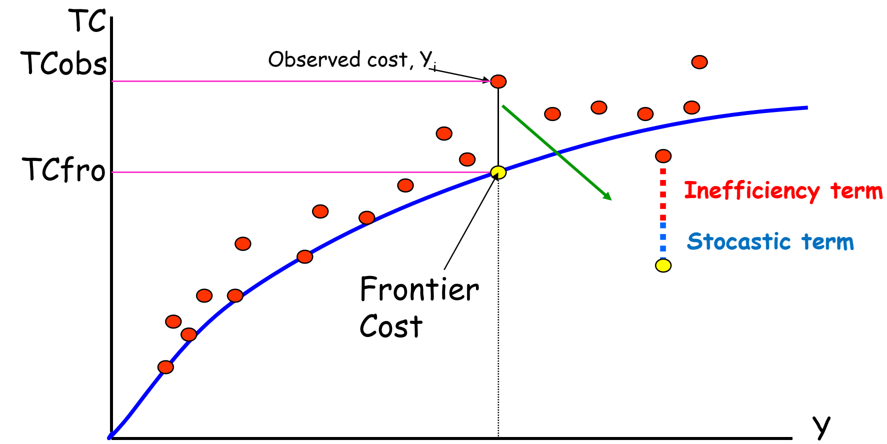


$$\ln C_i = \alpha_0 + \alpha_Q \ln Q_i + u_i + v_i \qquad u_i \geq 0$$

Inefficiency term

Stocastic term

Stocastic frontier



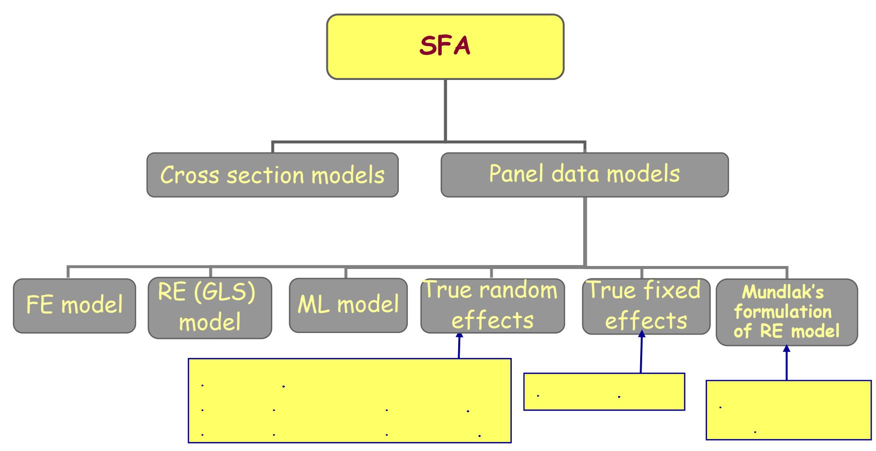
Econometric Modeling: two problems

$$\ln C_i = \alpha_0 + \alpha_Q \ln Q_i + u_i + v_i \qquad u_i \geq 0$$

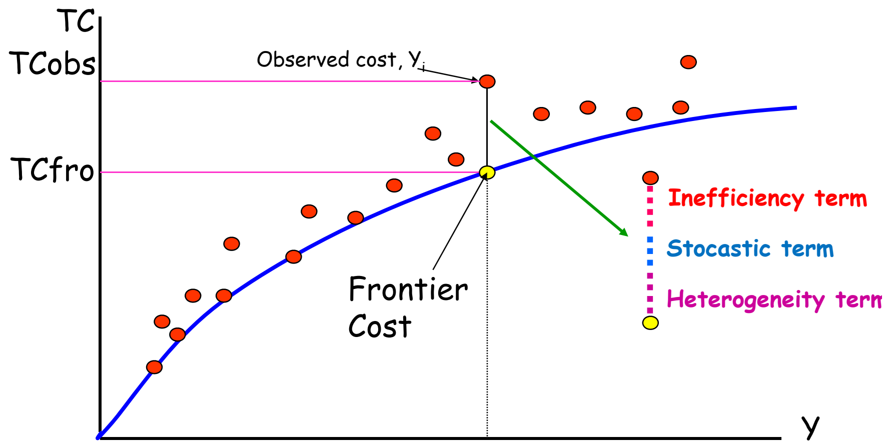
Excluded variables bias → Problem estimation economies of scale

Unobserved heterogeneity included in the efficiency term → Problem estimation cost inefficiency

Stochastic Frontier Methods



Unobserved heterogeneity,panel data and cost inefficiency



Stochastic cost frontier

$$\ln C_{it} = \alpha_0 + \alpha_Q \ln Q_{it} + \alpha_i + u_{it} + v_{it} \quad u_{it} \ge 0$$

C) Empirical Analysis

- This analysis explores the presence of economies of scale and scope as well cost inefficiency in the electricity, gas and water utilities.
- These issues have a crucial importance in the actual policy debates about
  - unbundling the integrated utilities into separate entities
  - Using regulation instruments combined with benchmarking stuides.

Previous studies of multi-utilities

	Mayo (1984)	Chappell and Wilder (1986)	Sing (1987)	Fraquelli et al. (2004)	Piacenza and Vannoni (2004)	Farsi et al. (2007b)
Data	Cross-section (1979, US)	Cross-section (1981, US)	Cross-section (1981, US)	Pooled (1994-96, Italy)	Pooled (1994-96, Italy)	Panel data (1997-2005, Switzerland)
Model	OLS	OLS	SUR	NLSUR	NLSUR	GLS, RCM
Output	Electricity and gas distribution	Electricity and gas distribution	Electricity and gas distribution	Electricity, gas and water distribution	Electricity, gas and water distribution	Electricity, gas and water
Factor prices	Labor, fuel	-	Labor, capital, fuel	Labor, other inputs	Labor, other inputs	Labor, capital, fuel
Other characteristics	-	-	Customer density	-	-	Customer density
Economies of scope	Exist only for small companies (+0.77%), for large companies diseconomies (up to -11.7%)	Exist over most of the output ranges, +12% for small, -10% for largest companies	Output combinations of both scope economies and diseconomies, no economies of scope for the mean output (-7.2%)	Exist, but significant only for companies producing less than the median output	Exist with all the models except with the translog cost function. For the median output between 16 and 64%	Exist over most of the output ranges, except for largest companies
Economies of scale	Product-specific economies of scale for gas over all outputs, for electricity only for small companies	Global and product-specific economies of scale exist	Product-specific economies of scale for electricity, diseconomies for gas	Exist, but significant only for companies producing less than the median output	All the models show economies of scale except the translog model	Global economies of scale exist over virtually all outputs

Model Specification

$$C = C(q^{(1)}, q^{(2)}, q^{(3)}, r, w^{(0)}, w^{(1)}, w^{(2)}, w^{(3)}, D_t)$$

- where C represents total costs; $q^{(1)}$, $q^{(2)}$, $q^{(3)}$ are respectively the distributed electricity, gas and water during the year, and $w^{(0)}$, $w^{(1)}$, $w^{(2)}$, $w^{(3)}$ are respectively the input factor prices for capital and labor services and the purchased electricity and gas; r is the customer density

Typical problems and typical trade-off

- Choice and definition of the variables ➔ problems with N
- Choice of the functional form ➔ quadratic/translog
- Choice of the econometric specification
- Pseudo panel data

Functional form

$$\ln\left(\frac{C_{it}}{w_{it}^{(0)}}\right) = \sum_m \alpha^m \ln q_{it}^{(m)} + \alpha^r \ln r_{it} + \sum_k \beta^k \ln \frac{w_{it}^{(k)}}{w_{it}^{(0)}} + \frac{1}{2}\sum_m \alpha^{mm} \left(\ln q_{it}^{(m)}\right)^2$$

$$+ \sum_{m(m\neq n)}\sum_n \alpha^{mn} \ln q_{it}^{(m)} \ln q_{it}^{(n)} + \frac{1}{2} \alpha^{rr}\left(\ln r_{it}\right)^2 + \sum_m \alpha^{rm}\ln q_{it}^{(m)} \ln r_{it}$$

$$+ \frac{1}{2}\sum_k \beta^{kk}\left(\ln\frac{w_{it}^{(k)}}{w_{it}^{(0)}}\right)^2 + \sum_{k(k\neq l)}\sum_l \beta^{kl}\ln\frac{w_{it}^{(k)}}{w_{it}^{(0)}}\ln\frac{w_{it}^{(l)}}{w_{it}^{(0)}} + \sum_t \delta^t D_t + \alpha^0 ,$$

Data: 237 observations from 34 companies from 1997 to 2005

Variable		Unit	Minimum	Median	Mean	Maximum
C	Total cost	Mio. CHF	11.20	41.10	77.60	503.00
$q^{(1)}$	Electricity distribution	GWh	38.78	126.89	293.23	2'023.59
$q^{(2)}$	Gas distribution	GWh	28.82	226.34	512.60	4'294.20
$q^{(3)}$	Water distribution	Mio. m^3	0.78	2.45	5.28	33.35
r	Customer density	Customers/ km^2	44.35	298.33	387.57	1'554.09
$w^{(0)}$	Capital price	CHF/ km	11'853	31'167	38'385	234'796
$w^{(1)}$	Labor price	CHF/ employee	77'789	106'466	107'851	146'816
$w^{(2)}$	Electricity price	CHF/ MWh	44.6	107.4	105.9	163.5
$w^{(3)}$	Gas price	CHF/ MWh	16.6	28.4	29.3	63.2

Economies of scale

Output Quartile	*Model I* GLS (Schmidt-Sickles)	*Model II* ML (Pitt-Lee)	*Model III* ML (Battese-Coelli)	*Model IV* True RE (Greene)
1st	1.06	1.09	1.20	1.10
2nd	1.09	1.07	1.14	1.07
3rd	1.15	1.05	1.09	1.06

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Conditions for Natural Monopoly (convexity and ray economies of scale)

- Overall, the above results indicate
  ↳ the existence of weak cost-complementarity and
  ↳ strong ray economies of scale.
- In line with Gordon et al. (2003) we consider this as a suggestive evidence of subadditivity (natural monopoly) for all practical purposes.

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Cost-inefficiency

	Model I GLS (Schmidt-Sickles)	*Model II* ML (Pitt-Lee)	*Model III* ML (Battese-Coelli)	*Model IV* True RE (Greene)
Mean	0.184	0.183	0.216	0.063
Std. Deviation	0.079	0.119	0.143	0.043
Minimum	0.000	0.013	0.014	0.010
1st Quartile	0.144	0.060	0.075	0.031
Median	0.202	0.207	0.214	0.050
3rd Quartile	0.251	0.275	0.303	0.082
Maximum	0.303	0.401	0.699	0.277

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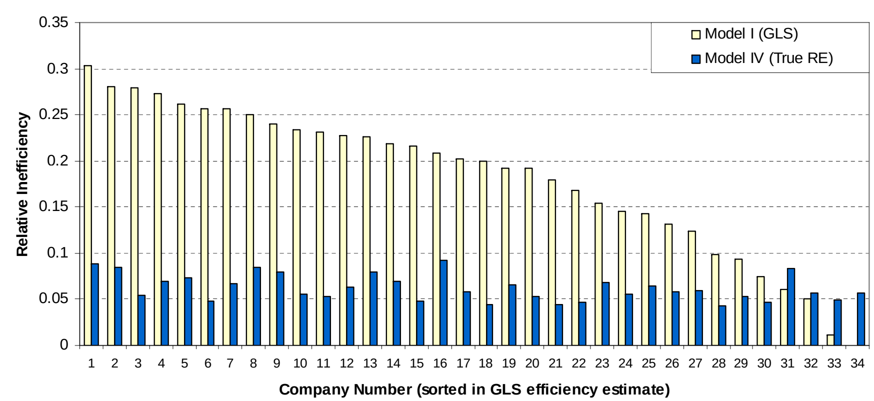
Distribution of inefficiency scores for individual firms



Pearson correlation matrix between inefficiency estimates

	Model I GLS (Schmidt-Sickles)	Model II ML (Pitt-Lee)	Model III ML (Battese-Coelli)	Model IV True RE (Greene)
I	1	0.863**	0.715**	0.124*
II		1	0.793**	0.140**
III			1	0.128**

Conclusions and policy implications (I)

- The multi-utility distribution utilities can be characterized as a natural monopoly.
- There are economies of scope which cannot be exploited if multi-utilities are unbundled horizontally.
- There are significant unexploited economies of scale that should be considered in any structural reform in the future.
- The analysis indicates certain cost-inefficiency in the sector, which motivates an incentive regulation of the utilities

Conclusions and research implications (II)

- ↳ in the context of parametric methods, panel data could be helpful to distinguish efficiency differences from unobserved heterogeneity.
- ↳ However, the results are not completely satisfactory.
- ↳ Further research on: choice of the functional form, definition of the variables and the econometric specification

THANK YOU FOR YOUR INTEREST !

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Regression results

	Model I		Model II		Model III		Model IV	
	GLS (Schmidt-Sickles)		ML (Pitt-Lee)		ML (Battese-Coelli)		True RE (Greene)	
α^1 (Electricity output)	0.505 **	(.053)	0.460 **	(.069)	0.418 **	(.063)	0.527 **	(.020)
α^2 (Gas output)	0.317 **	(.032)	0.298 **	(.041)	0.245 **	(.045)	0.258 **	(.012)
α^3 (Water output)	0.092 **	(.039)	0.178 **	(.053)	0.212 **	(.047)	0.146 **	(.015)
α^r (Customer density)	0.064 **	(.027)	0.043	(.038)	0.026	(.037)	0.007	(.009)
β^1 (Labor price)	0.242 **	(.057)	0.229 **	(.054)	0.236 **	(.058)	0.201 **	(.027)
β^2 (Electricity price)	0.326 **	(.059)	0.317 **	(.051)	0.333 **	(.052)	0.370 **	(.033)
β^3 (Gas price)	0.234 **	(.043)	0.243 **	(.039)	0.223 **	(.038)	0.215 **	(.024)
α^{11}	0.646 **	(.197)	0.368 *	(.221)	0.218	(.193)	0.231 **	(.086)
α^{22}	0.234 **	(.055)	0.154 *	(.080)	0.067	(.071)	0.093 **	(.023)
α^{33}	0.287 **	(.141)	0.042	(.176)	0.186	(.167)	0.089 *	(.052)
α^{rr}	0.019	(.061)	-0.063	(.095)	-0.233 **	(.089)	-0.146 **	(.026)
α^{12}	-0.273 **	(.086)	-0.182 *	(.105)	-0.048	(.091)	-0.099 **	(.041)
α^{13}	-0.327 **	(.149)	-0.124	(.158)	-0.214	(.148)	-0.133 **	(.058)
α^{23}	-0.002	(.059)	0.049	(.072)	0.051	(.068)	0.037	(.026)

The remaining coefficients are not listed.

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Example cost inefficiency (Farsi and Filippini 2004)

Company	Inefficiency Score			
	OLS	RE (GLS)	RE (ML)	FE
A	1.20	1.16	1.15	1.22
B	1.08	1.00	1.09	1.41
C	1.46	1.38	1.35	1.44
D	1.21	1.10	1.13	1.09
E	1.31	1.21	1.19	1.17

The companies are adopted based on the ranking obtained from the RE (GLS) model: A: median; D: 1st quartile;
B: most efficient; E: 3rd quartile.
C: least efficient;

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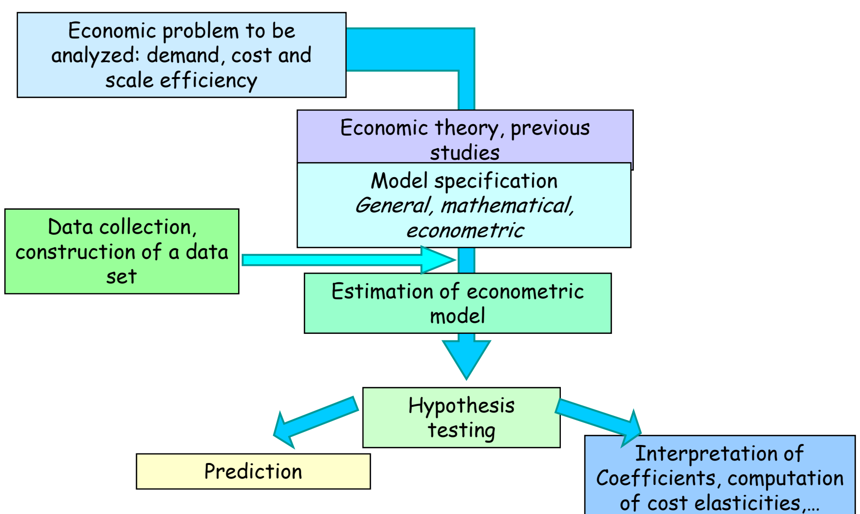
Anatomy of econometric modelling



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Econometric Modeling: total cost function

- $TC = f(Q_A, Q_B)$
- $Ln\, Q_A = \alpha_0 + \alpha_A LnQ_A + \alpha_B LnQ_B + \varepsilon$
- $Ln\, Q_A = 10.1 + 0.6\, LnQ_A + 0.3\, LnQ_B + \varepsilon$

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Econometric specifications

Stochastic term	*Model I* **GLS (Schmidt-Sickles)**	*Model II* **ML (Pitt-Lee)**	*Model II* **ML (Battese-Coelli)**	*Model IV* **True RE (Greene)**
Firm-specific effect α_i	$\alpha_i \sim iid\ (0, \sigma_\alpha^2)$	$\alpha_i \sim N^+(0, \sigma_\alpha^2)$	0	$\alpha_i \sim N(0, \sigma_\alpha^2)$
Time-varying inefficiency u_{it}	0	0	$u_{it} =$ $u_i \exp\{-\eta(t\text{-}T)\}$ $u_i \sim N^+(0, \sigma_u^2)$	$u_{it} \sim N^+(0, \sigma_u^2)$
Random noise v_{it}	$v_{it} \sim iid\ (0, \sigma_v^2)$	$v_{it} \sim N\ (0, \sigma_v^2)$	$v_{it} \sim N(0, \sigma_v^2)$	$v_{it} \sim N(0, \sigma_v^2)$
Inefficiency estimate	$\hat{\alpha}_i - \min\{\hat{\alpha}_i\}$	$E\left[\alpha_i \mid \hat{\omega}_{i1}, \hat{\omega}_{i2}, \ldots\right]$ with $\omega_{it} = \alpha_i + v_{it}$	$E\left[u_{it} \mid \hat{\varepsilon}_{it}\right]$ with $\varepsilon_{it} = u_{it} + v_{it}$	$E\left[u_{it} \mid \hat{r}_{it}\right]$ with $r_{it} = \alpha_i + u_{it} + v_{it}$