Digging into the Technological Dimension of Environmental Productivity

Filippo Belloc [1] Edilio Valentini [2]

[1]U Siena, Dept. of Economics and Statistics

[2]U Chieti-Pescara, Dept. of Economic Studies

Urbino, Oct 2022

Introduction

- Within-product increase in environmental productivity (Q/E) documented in many OECD countries
- Dispersion of Q/E still very high
  - average 90-10 TFP ratio is 2:1 to 5:1 depending on the estimate
  - 90-10 Q/E ratio is $\sim$ 16:1
- Why it is important
  - microeconomic heterogeneity amplifies macroeconomic dynamics in response to aggregate shocks (e.g. exogenous increase in input price)
- What is behind such a huge Q/E dispersion?
  - technology diffusion (group-level) vs. technology usage (idiosyncratic)

This paper

- A novel mixture model approach to PF estimation applied to plant-level data on CO2 and physical output (EU OHA)
  - we estimate multiple E-PFs within narrowly defined sectors
  - we identify the frontier E-PF (locally optimal)
  - for each plant we obtain the probability of adopting each E-PF and the weighted E-TFP as a Solow residual
  - we simulate plant-level counterfactuals (output gains) by removing E-PF and E-TFP dispersion
- We match EU OHA data with parent companies in Orbis (BVD)
  - we quantify the growth margins of Q/E for different firms

Preview of results

- Existing technologies have large unexploited potentials
  - most sectors have 2+ E-PFs
  - 70% to 80% of firms adopt sub-optimal technologies
  - adopting the frontier E-PF yields $\sim$ 75% Q/E gain (155% if also E-TFP gaps are eliminated)
- We document large differentials across types of firms
  - larger, listed, multi-plant and international firms adopt better E-PFs
  - intangible-intensive, older firms show better E-TFP
- Policy insights
  - green innovation policies should be coupled with technology diffusion
  - better avoiding one-size-fits-all initiatives

Related literatures

- Q/E and environmental technologies in regulated firms
  - environmental regulation caused improvements in Q/E (Shapiro and Walker, AER 2018; Najjar and Cherniwchan, RESTAT 2020) and encouraged low-carbon innovation (Calel and Dechezlepretre, RESTAT 2016), without driving technology diffusion (Calel, AEJ: EP 2020)
- Environmental consequences of managerial quality
  - adoption of green technologies may be prevented by managerial inertia (Porter and van der Linde, JEP 1995; Ambec and Barla, EL 2002) and better managed firms are less energy intensive (Bloom et al., EJ 2010; Martin et al., JEEM 2012; De Haas et al., CEPR DP 2021)
- Productivity estimation and TFP dispersion
  - broad methodological literature on TFP estimation and its drivers (Syverson, JEL 2011), but few works on estimating multiple production functions (Battisti et al., RED 2020) and quantity-based productivity (de Roux et al., NBER WP 2021)

Outline

Data

Data

- $\sim$ 2000 ETS plants in EU OHA (Phase 1 to Phase 3)
- Plant-level physical output retrieved from the inverse allowance allocation rule of ETS Phase 3 (2013-2020) correction factors

$$A_{i,t,s} = \tilde{e}_s \, \lambda_{s,t} \, \vartheta_t \, Q_{i,s} \tag{1}$$

where $Q_{i,s}$ = median of the activity level in Phase 1 (2005-2008)

- Environmental productivity calculated as

$$\frac{Q_{i,s}}{E_{i,s}} \tag{2}$$

with $E_{i,s}$ = median tons of CO_2-equivalent emissions in Phase 1

- Emission intensity is $e_{i,s} = \frac{E_{i,s}}{Q_{i,s}}$

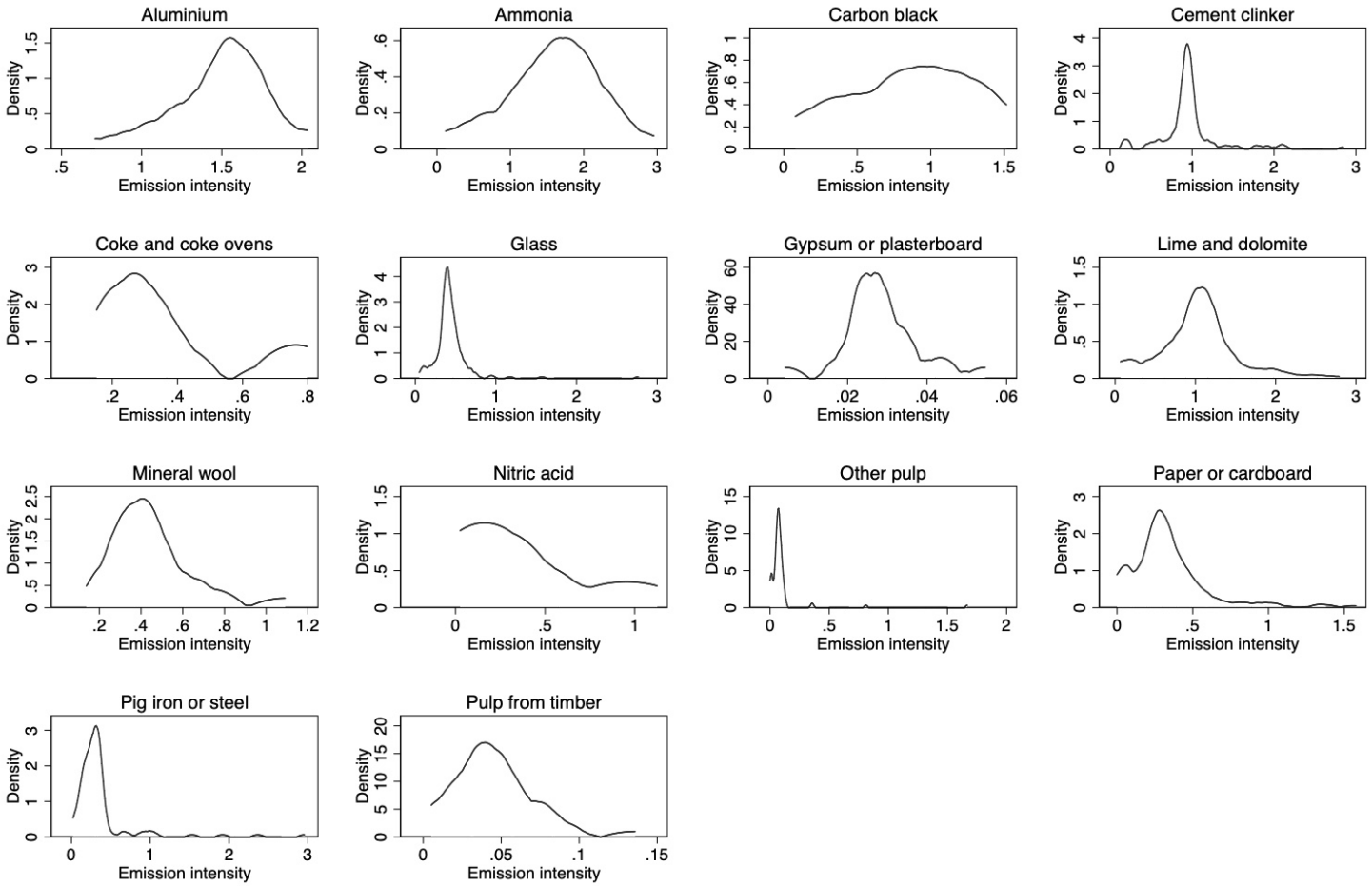
Descriptive statistics

Table 1: List of product-sectors and main variables

Sector	Allowances [tons co2]	Product quantity [tons]	Emissions [tons co2]	Benchmark emission intensity	Actual Emission intensity
	plant-level (avg. phase 3)	plant-level (med. phase 1)	plant-level (med. phase 1)	product-level (phase 3)	plant-level (phase 1)
Aluminium	138298	103889	97649	1.514	1.462
Ammonia	636403	447388	661550	1.619	1.509
Carbon black	89354	93844	75442	1.954	0.944
Cement clinker	472033	611220	508705	0.876	0.690
Coke and coke ovens	577486	2295911	1204695	0.286	0.283
Glass	41287	123562	53772	0.380	0.397
Gypsum, plasterboard	28382	983379	24218	0.032	0.031
Lime and dolomite	105082	118131	119894	1.013	0.946
Mineral wool	33143	101154	40892	0.682	0.507
Nitric acid	100535	378757	65721	0.302	0.307
Other pulp	35601	603412	32792	0.067	0.118
Paper or cardboard	40444	160178	38632	0.286	1.069
Pig iron or steel	623390	2178677	469086	0.325	0.401
Pulp from timber	61717	1799437	70135	0.039	0.036

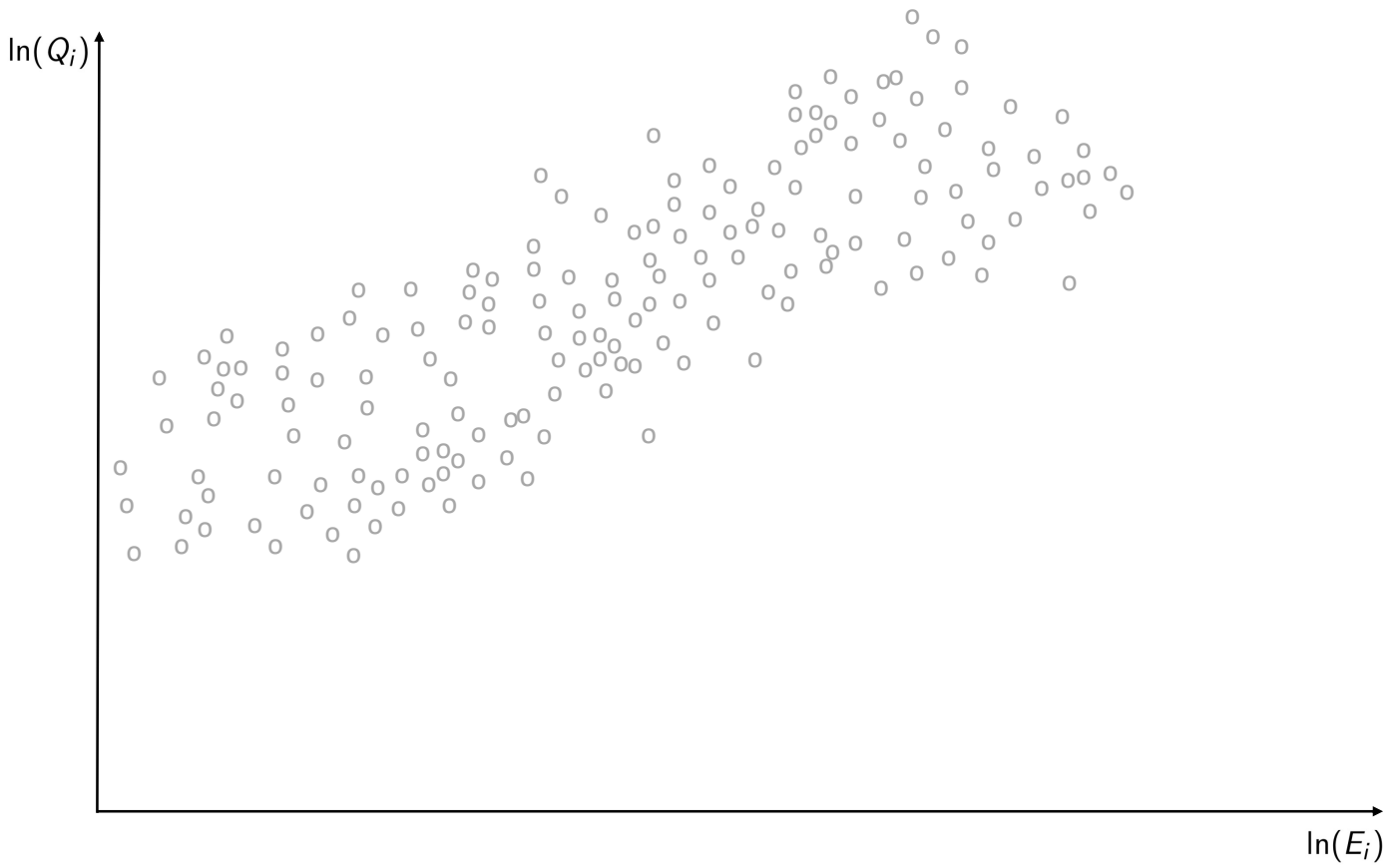
E/Q distributions

Figure 1: Distribution of emission intensity within sectors

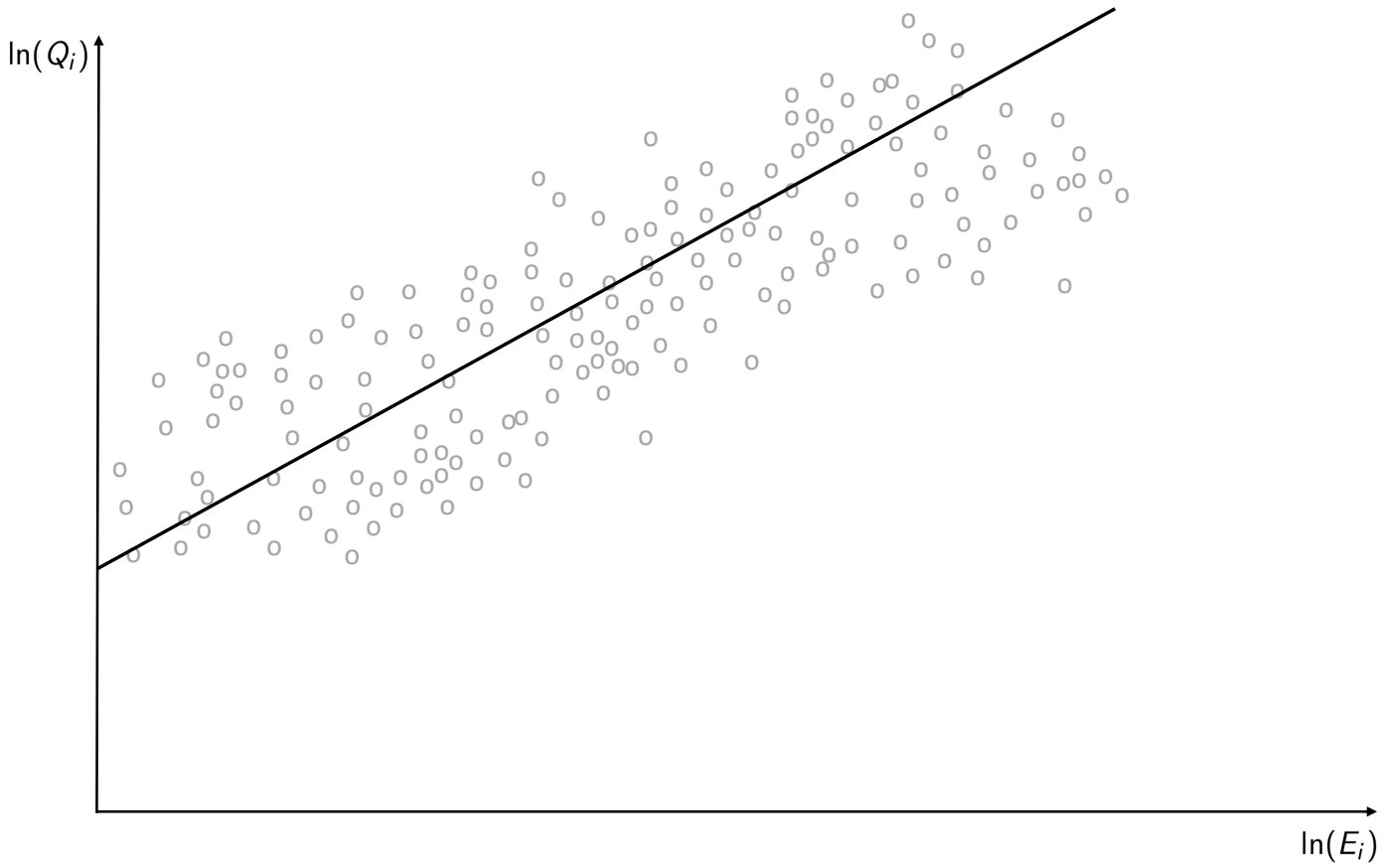


E-PF estimation

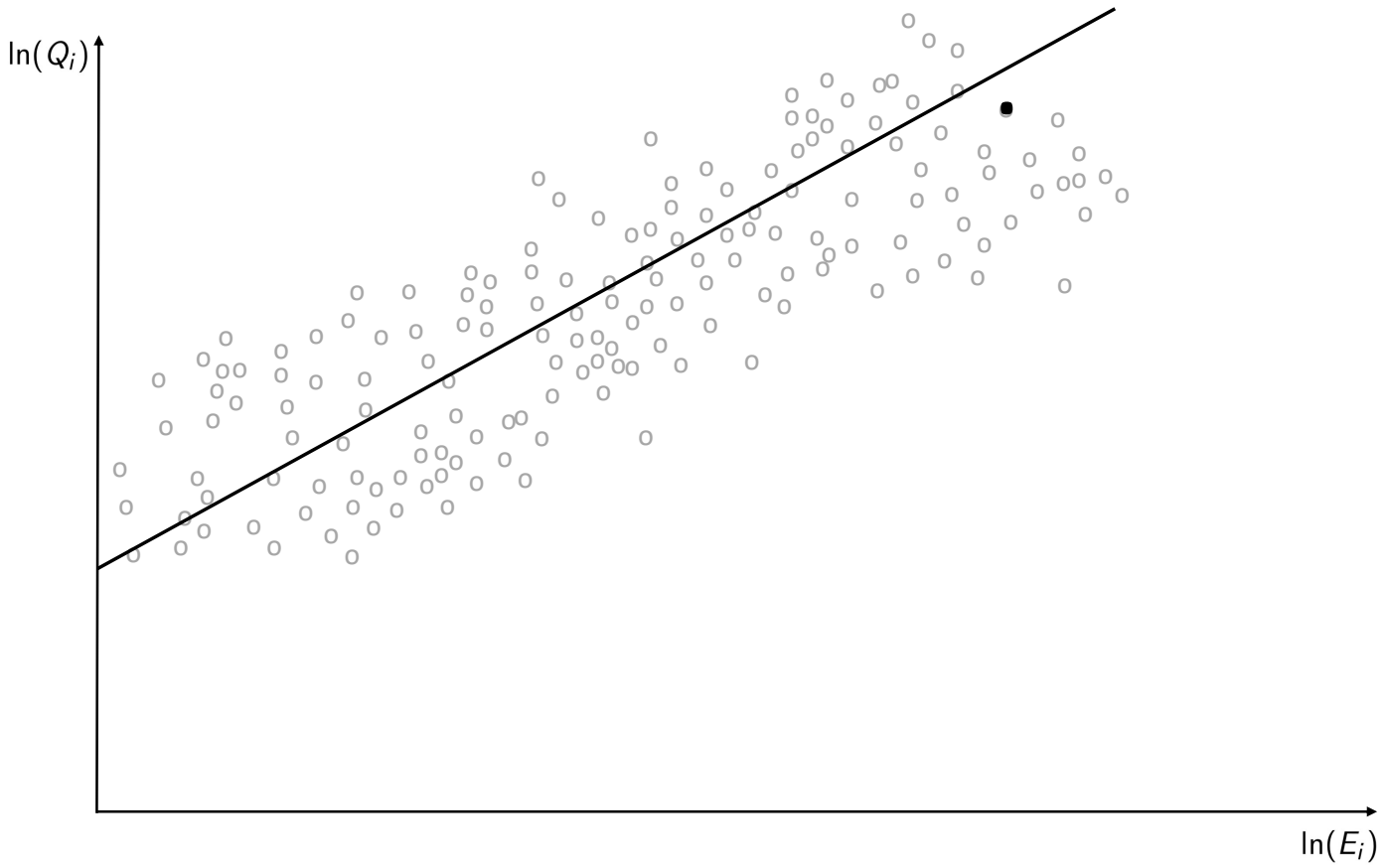
Multiple E-PFs framework: a graphical example



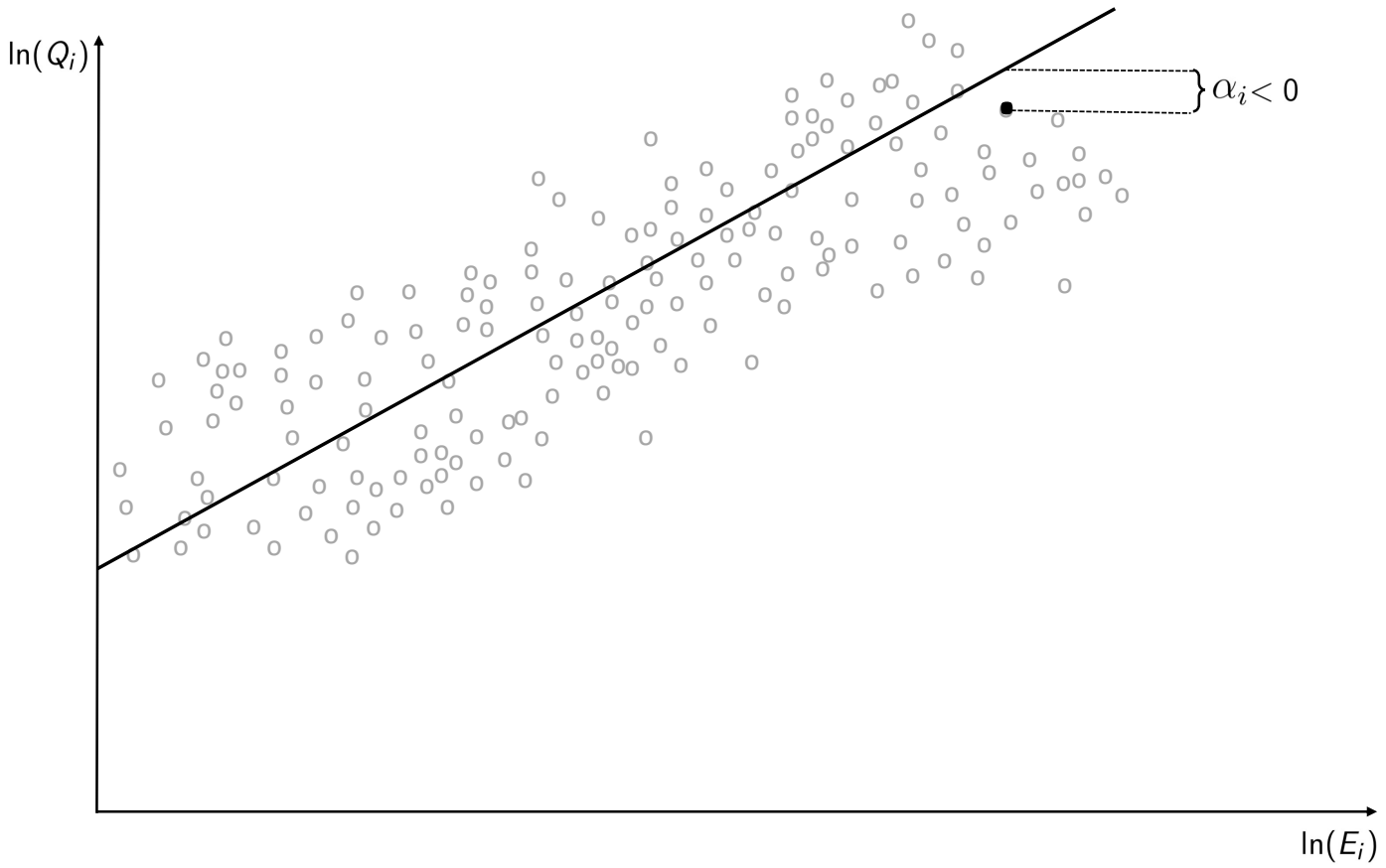
Multiple E-PFs framework: a graphical example



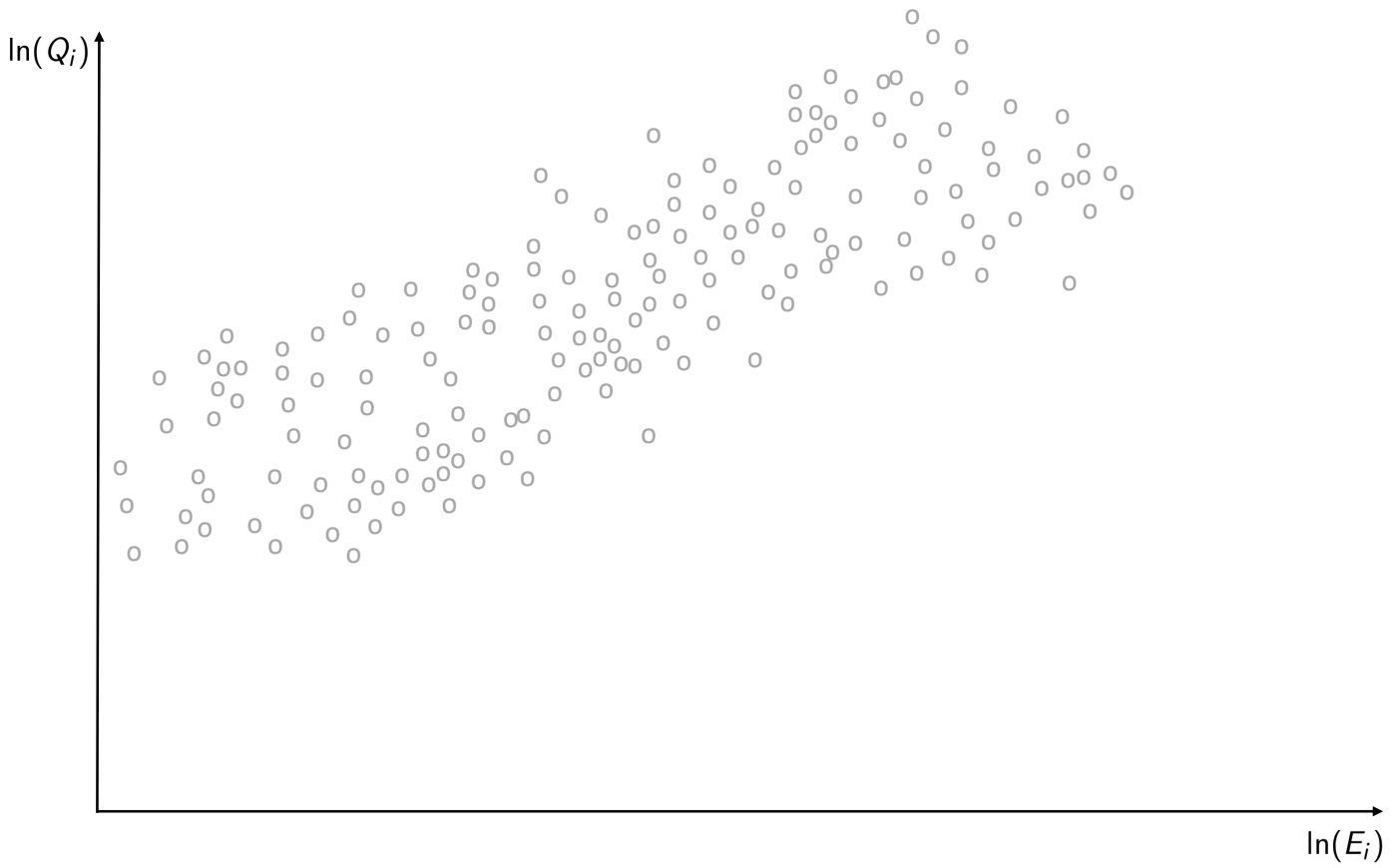
Multiple E-PFs framework: a graphical example



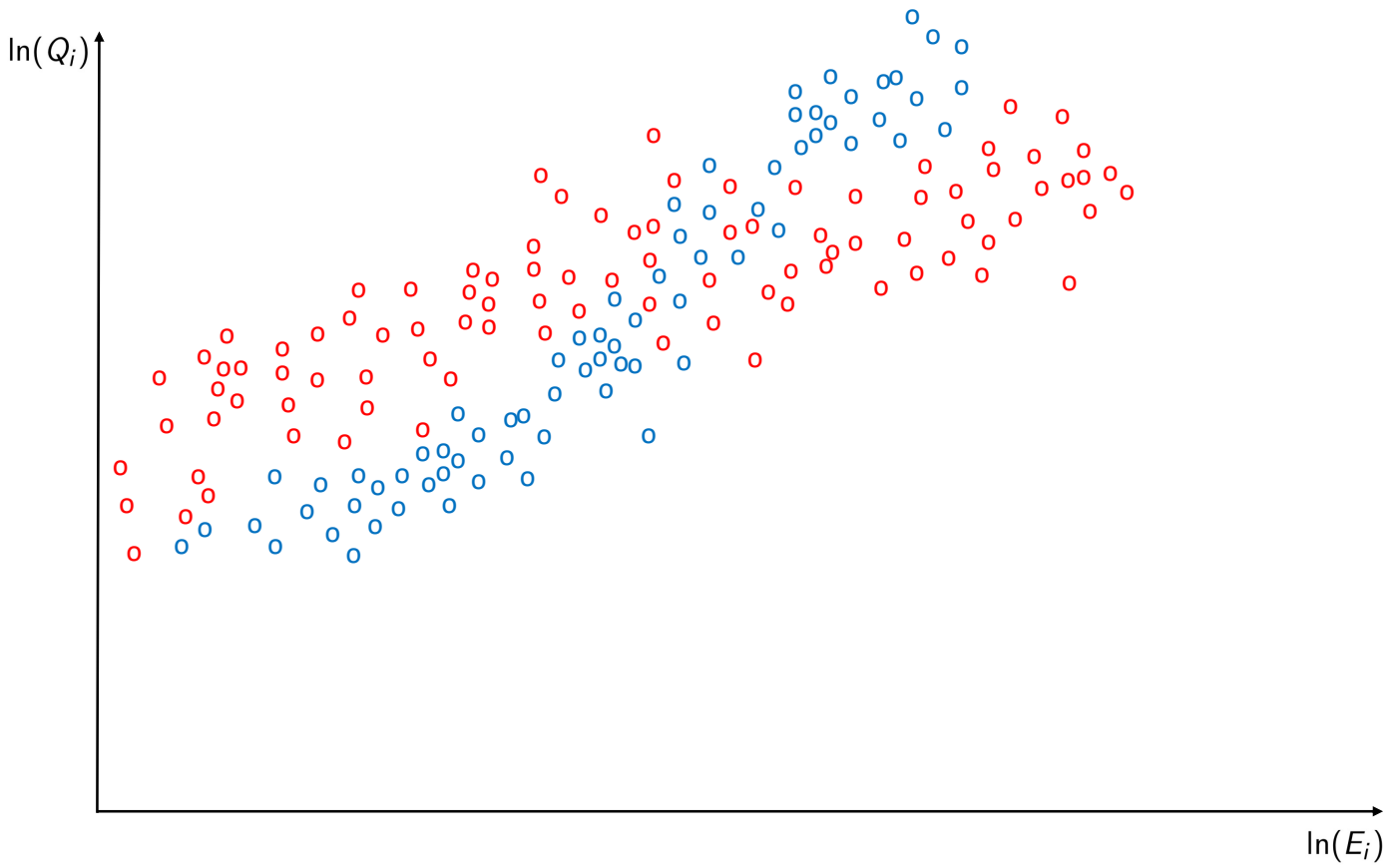
Multiple E-PFs framework: a graphical example



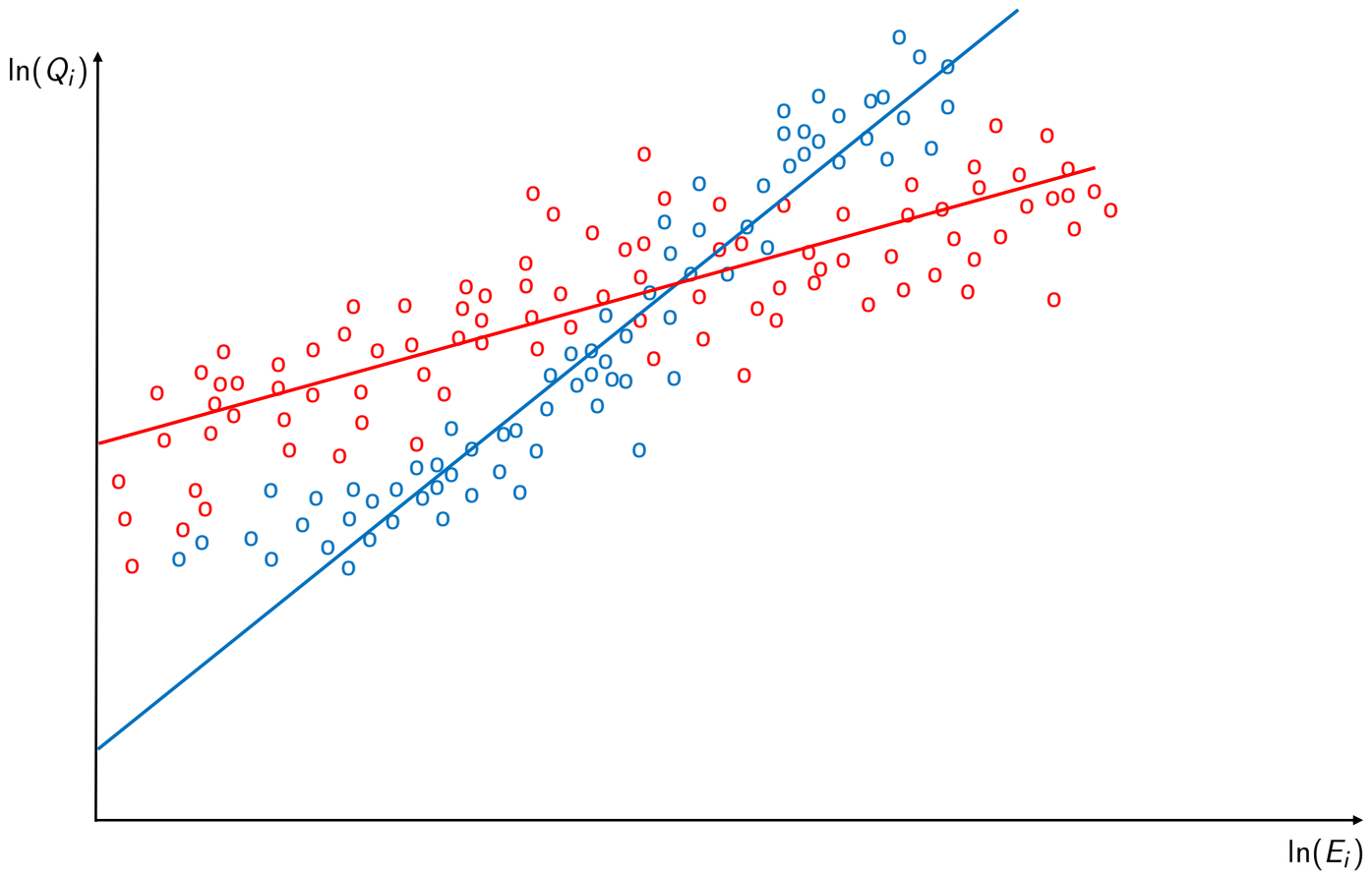
Multiple E-PFs framework: a graphical example



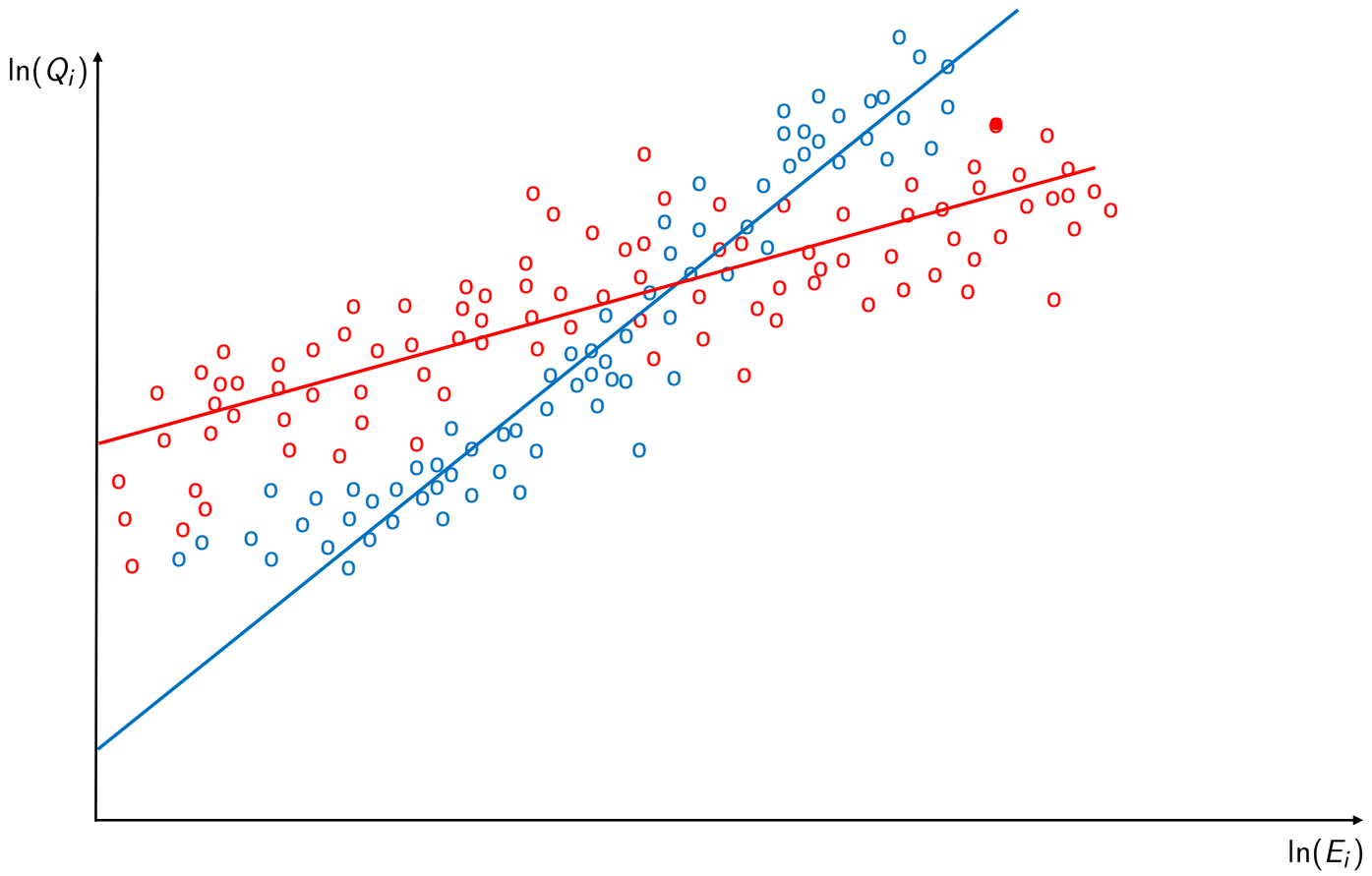
Multiple E-PFs framework: a graphical example



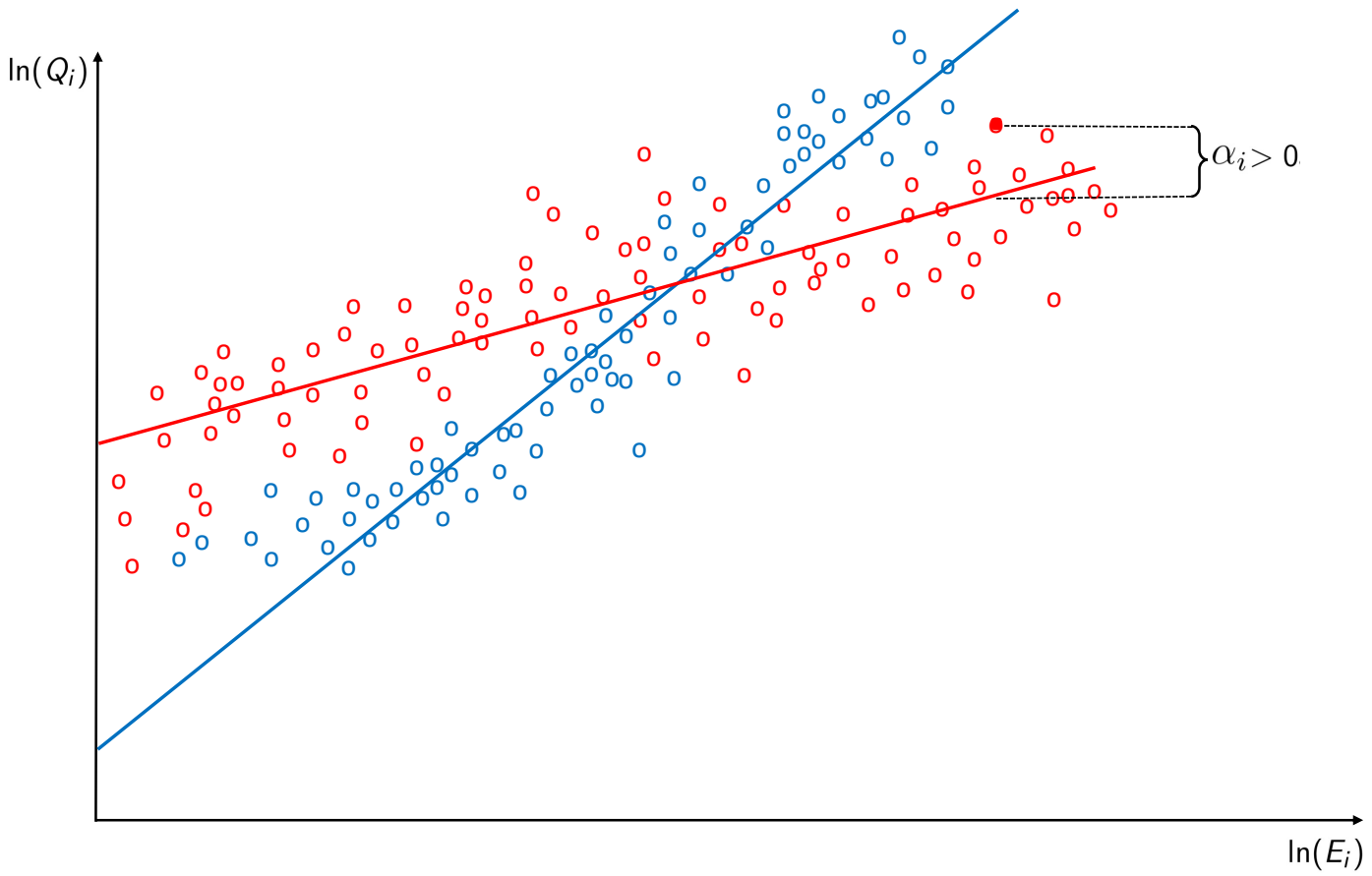
Multiple E-PFs framework: a graphical example



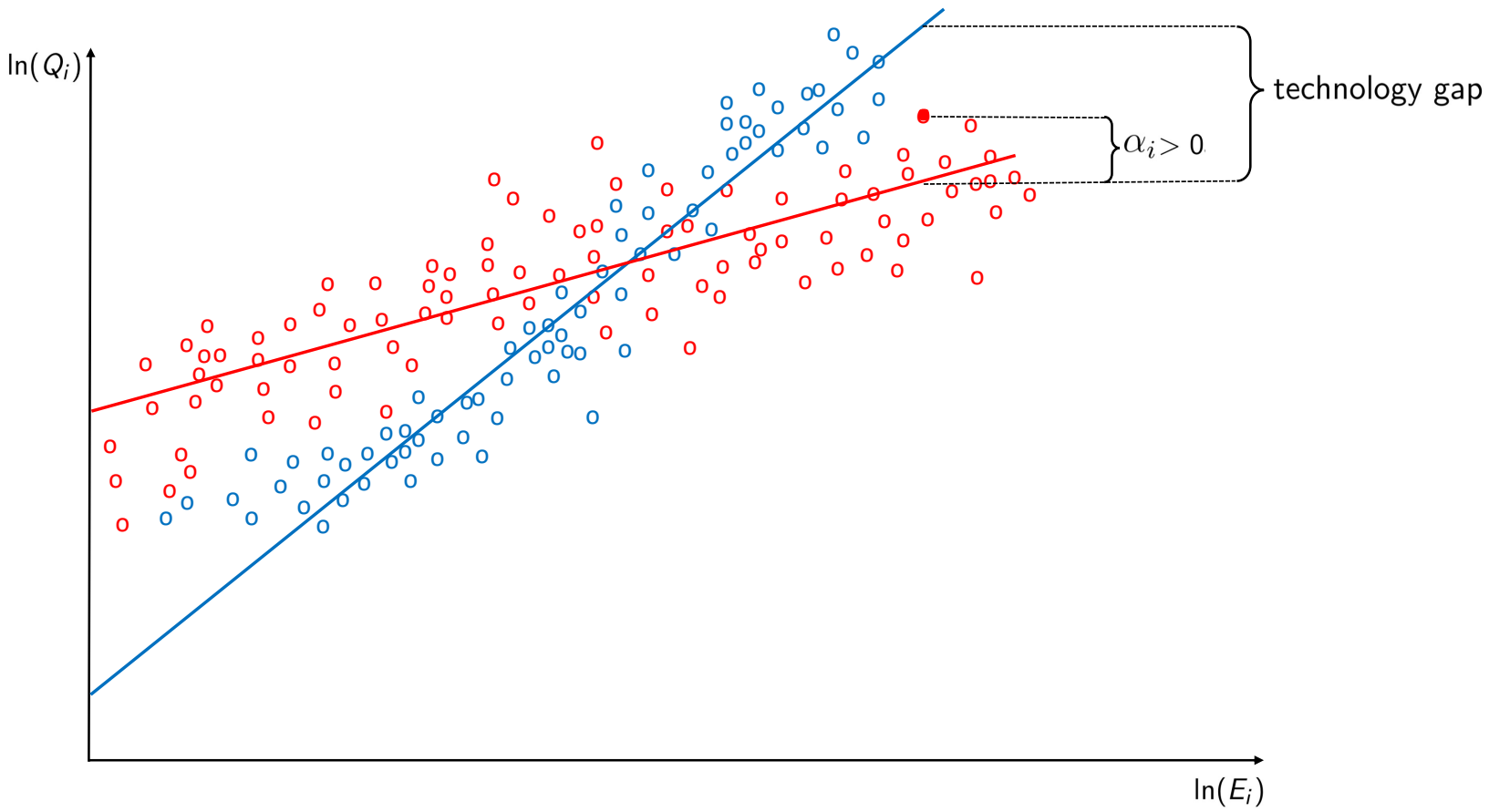
Multiple E-PFs framework: a graphical example



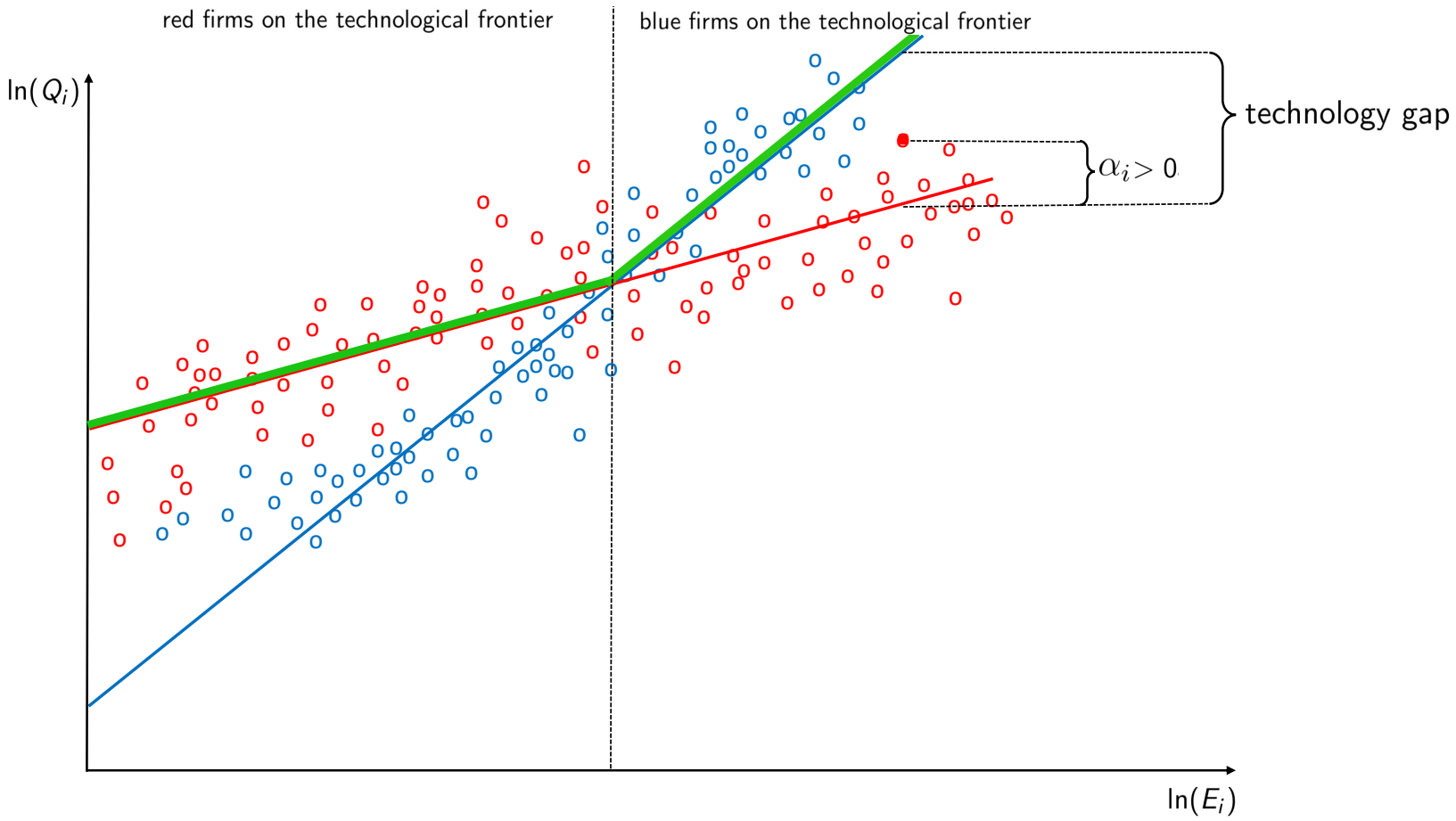
Multiple E-PFs framework: a graphical example



Multiple E-PFs framework: a graphical example



Multiple E-PFs framework: a graphical example



Empirical strategy

- The E-PF of firm i is

$$\ln(Q_i) = \overbrace{\alpha_{i,\tau}}^{\text{E-TFP}} + \overbrace{\alpha_\tau + \beta_\tau}^{\tau\text{-tech coeffs}} \ln(E_i) \tag{3}$$

estimated with a finite mixture model (WLS + EM) under the assumption that

$$f\left(\ln(Q_i)|\mu, \sigma^2\right) = \sum_{\tau=1}^{\mathcal{T}} \pi_\tau f_\tau \left(\ln(Q_i)|\mu_\tau, \sigma_\tau^2\right) \tag{4}$$

- Optimal number of E-PFs ($\tilde{\mathcal{T}}$) selected based on BIC minimization
- Locally optimal E-PF (τ^*): $\ln(\hat{Q}_{i,\tau^*})|E_i > \ln(\hat{Q}_{i,\tau})|E_i \;\; \forall \tau \neq \tau^*$
- E-TFP ($\alpha_{i,\tau}$): $\ln(Q_i) - \sum_{\tau=1}^{\tilde{\mathcal{T}}} \tilde{p}_{i,\tau} \ln(\hat{Q}_{i,\tau})$

Selection of $\tilde{\mathcal{T}}$

Table 2: BIC values from the sector-by-sector mixture model estimation

Sector	$\text{BIC}_{\mathcal{T}=1}$	$\text{BIC}_{\mathcal{T}=2}$	$\text{BIC}_{\mathcal{T}=3}$	$\text{BIC}_{\mathcal{T}=4}$	$\text{BIC}_{\mathcal{T}=5}$	$\text{BIC}_{\mathcal{T}>5}$	BIC_{min}	$\tilde{\mathcal{T}}$
Aluminium	55.476	78.963	n.c.	n.c.	n.c.	n.c.	55.476	1
Ammonia	11.373	n.c.	n.c.	n.c.	n.c.	n.c.	11.373	1
Carbon black	11.953	6.694	n.c.	n.c.	n.c.	n.c.	6.694	2
Cement clinker	199.759	51.661	43.964	n.c.	n.c.	n.c.	43.964	3
Coke and coke ovens	19.193	25.188	21.160	n.c.	n.c.	n.c.	19.193	1
Glass	279.792	182.605	174.329	163.654	145.700	n.c.	145.700	5
Gypsum or plasterboard	16.323	13.717	n.c.	n.c.	n.c.	n.c.	16.323	2
Lime and dolomite	283.474	204.808	212.997	189.685	n.c.	n.c.	189.685	4
Mineral wool	32.714	37.133	30.905	n.c.	n.c.	n.c.	30.905	3
Nitric acid	40.613	17.581	n.c.	n.c.	n.c.	n.c.	17.581	2
Other pulp	293.492	n.c.	n.c.	n.c.	n.c.	n.c.	293.492	1
Paper or cardboard	894.623	631.598	n.c.	n.c.	n.c.	n.c.	631.598	2
Pig iron or steel	315.812	271.033	n.c.	n.c.	n.c.	n.c.	271.033	2
Pulp from timber	86.536	83.353	n.c.	n.c.	n.c.	n.c.	83.353	2

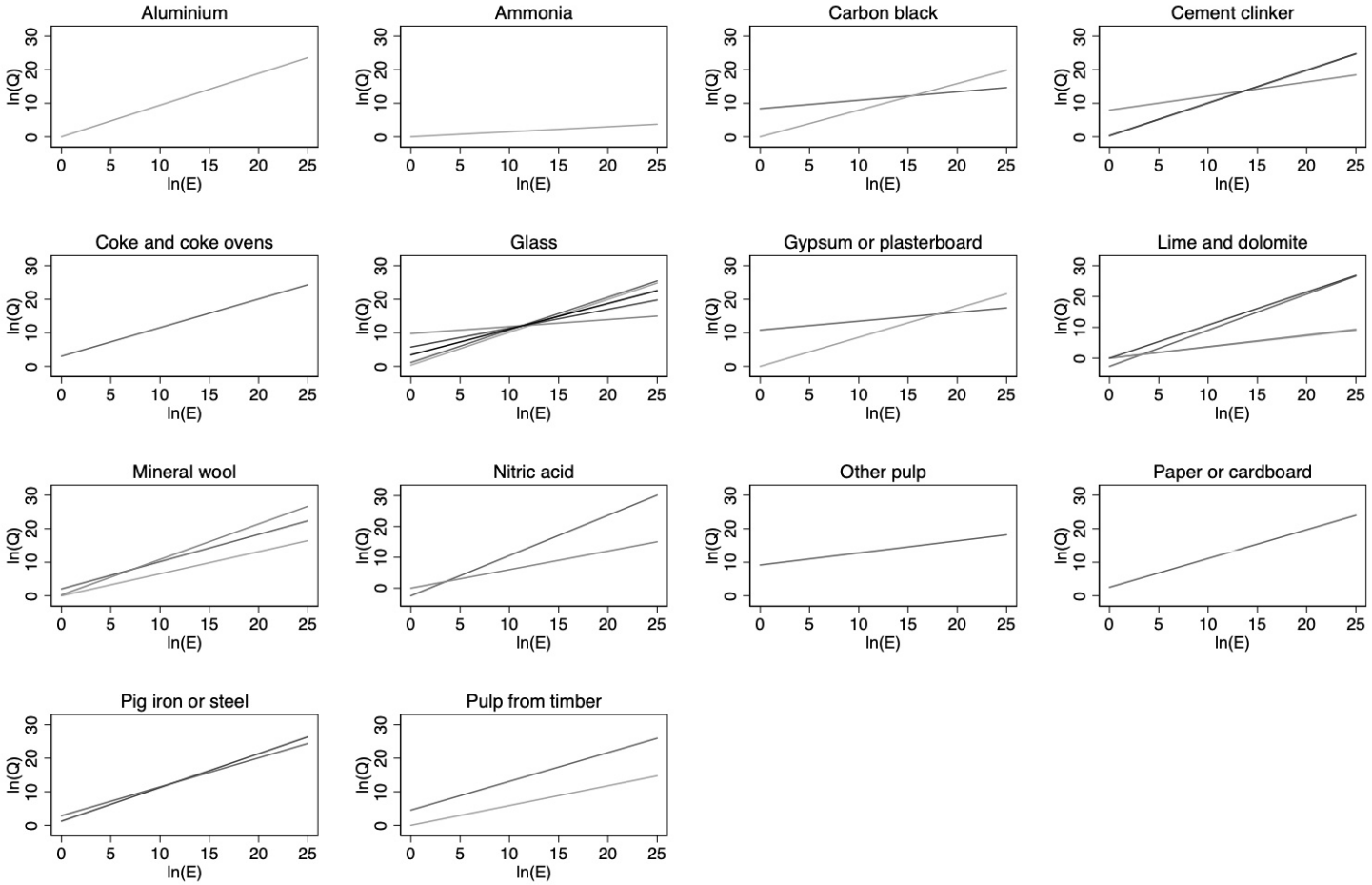
Technology coefficients

Table 3: E-PF parameters from the sector-by-sector mixture model estimation

Sector	E-PF$_1$	E-PF$_2$	E-PF$_3$	E-PF$_4$	E-PF$_5$
Aluminium	$\beta_1 = 0.944$				
	$\alpha_1 = 0.000$				
Ammonia	$\beta_1 = 0.151$				
	$\alpha_1 = 0.000$				
Carbon black	$\beta_1 = 0.250$	$\beta_2 = 0.793$			
	$\alpha_1 = 8.407$	$\alpha_2 = 0.000$			
Cement clinker	$\beta_1 = 0.974$	$\beta_2 = 0.419$	$\beta_3 = 0.975$		
	$\alpha_1 = 0.284$	$\alpha_2 = 7.956$	$\alpha_3 = 0.384$		
Coke and coke ovens	$\beta_1 = 0.852$				
	$\alpha_1 = 3.020$				
Glass	$\beta_1 = 0.973$	$\beta_2 = 0.980$	$\beta_3 = 0.208$	$\beta_4 = 0.561$	$\beta_5 = 0.766$
	$\alpha_1 = 1.141$	$\alpha_2 = 0.358$	$\alpha_3 = 9.760$	$\alpha_4 = 5.748$	$\alpha_4 = 3.424$
Gypsum or plasterboard	$\beta_1 = 0.264$	$\beta_2 = 0.864$			
	$\alpha_1 = 10.819$	$\alpha_2 = 0.000$			
Lime and dolomite	$\beta_1 = 1.170$	$\beta_2 = 0.367$	$\beta_3 = 0.373$	$\beta_4 = 1.069$	
	$\alpha_1 = -2.620$	$\alpha_2 = 0.003$	$\alpha_3 = 0.082$	$\alpha_4 = 0.048$	
Mineral wool	$\beta_1 = 0.811$	$\beta_2 = 0.658$	$\beta_3 = 1.057$		
	$\alpha_1 = 2.066$	$\alpha_2 = 0.000$	$\alpha_3 = 0.272$		
Nitric acid	$\beta_1 = 1.306$	$\beta_2 = 0.602$			
	$\alpha_1 = -2.485$	$\alpha_2 = 0.000$			
Other pulp	$\beta_1 = 0.359$				
	$\alpha_1 = 9.203$				
Paper or cardboard	$\beta_1 = 0.857$	$\beta_2 = 0.065$			
	$\alpha_1 = 2.542$	$\alpha_2 = 12.441$			
Pig iron or steel	$\beta_1 = 0.860$	$\beta_2 = 1.004$			
	$\alpha_1 = 2.877$	$\alpha_2 = 1.236$			
Pulp from timber	$\beta_1 = 0.856$	$\beta_2 = 0.590$			
	$\alpha_1 = 4.548$	$\alpha_2 = 0.000$			

Estimated E-PFs

Figure 2: Within-sector estimated E-PFs



Technology adoption

Table 4: Technology-sector distributions (%)

Sector	$\tau = \tau_1$	$\tau = \tau_2$	$\tau = \tau_3$	$\tau = \tau_4$	$\tau = \tau_5$	$\tau = \tau^*$
Aluminium	100					100
Ammonia	100					100
Carbon black	74.04	25.95				54.25
Cement clinker	35.58	7.05	57.35			18.31
Coke and coke ovens	100					100
Glass	60.958	7.61	3.42	22.20	5.79	19.88
Gypsum or plasterboard	56.44	43.55				51.42
Lime and dolomite	6.79	24.27	4.55	64.37		6.10
Mineral wool	16.79	25.51	57.69			27.07
Nitric acid	54.48	45.50				41.98
Other pulp	100					100
Paper or cardboard	86.36	13.63				14.53
Pig iron or steel	33.29	66.70				41.26
Pulp from timber	60.88	39.11				37.89
All sectors pooled						31.85
All sectors with $\tilde{\mathcal{T}} \geq 2$ pooled						21.12

Within-technology E-TFP dispersion

- We compare $\text{Var}(\alpha_{i,\tau^*})$ and $\text{Var}(\alpha_{i,\tau\neq\tau^*})$, where

$$\alpha_{i,\tau^*} = \ln(Q_i) - \tilde{p}_{i,\tau^*} \ln(\hat{Q}_{i,\tau^*}) \quad \text{and}$$
$$\alpha_{i,\tau\neq\tau^*} = \ln(Q_i) - \sum_{\tau\neq\tau^*} \tilde{p}_{i,\tau} \ln(\hat{Q}_{i,\tau}) \tag{5}$$

Table 5: E-TFP variance conditional on technology

Sector	$\text{Var}(\alpha_{i,\tau^*})$	$\text{Var}(\alpha_{i,\tau\neq\tau^*})$
Aluminium	0.063	–
Ammonia	0.122	–
Carbon black	0.026	0.017
Cement clinker	0.003	0.057
Coke and coke ovens	0.222	–
Glass	0.002	0.020
Gypsum or plasterboard	0.002	0.010
Lime and dolomite	0.001	0.043
Mineral wool	0.004	0.015
Nitric acid	0.050	0.084
Other pulp	0.846	–
Paper or cardboard	0.052	0.193
Pig iron or steel	0.315	0.200
Pulp from timber	0.158	0.436

Counterfactuals

Gains from eliminating EP dispersion

- Increase in Q/E by adopting τ^* (E-TFP equal)

$$\text{E-PF } \textit{gain} = \ln(\hat{Q}_{i,\tau^*}) - \sum_{\tau=1}^{\tilde{\mathcal{T}}} \tilde{p}_{i,\tau} \ln(\hat{Q}_{i,\tau}) \tag{6}$$

- Increase in Q/E by having top-5% E-TFP (E-PF equal)

$$\text{E-TFP } \textit{gain} = \alpha^* - \alpha_{i,\tau} \tag{7}$$

- Total EP distance from the "frontier installation"

$$\textit{Total gain} = \text{E-TFP } \textit{gain} + \text{E-PF } \textit{gain} \tag{8}$$

Sectoral gains from eliminating EP dispersion

Table 6: Potential gains (%): sectoral averages

Sector	E-PF *gain*	E-TFP *gain*	*Total gain*
Aluminium	0.000	0.595	0.595
	(0.000)	(0.219)	(0.219)
Ammonia	0.000	0.429	0.429
	(0.000)	(0.349)	(0.349)
Carbon black	0.102	0.386	0.488
	(0.148)	(0.211)	(0.267)
Cement clinker	0.478	0.578	1.057
	(0.612)	(0.249)	(0.666)
Coke and coke ovens	0.000	0.571	0.571
	(0.000)	(0.471)	(0.471)
Glass	0.534	0.332	0.867
	(0.589)	(0.154)	(0.608)
Gypsum or plasterboard	0.122	0.169	0.292
	(0.169)	(0.113)	(0.217)
Lime and dolomite	1.037	0.452	1.489
	(0.928)	(0.210)	(0.997)
Mineral wool	0.521	0.267	0.788
	(0.534)	(0.132)	(0.568)
Nitric acid	1.159	0.571	1.730
	(1.420)	(0.347)	(1.484)
Other pulp	0.000	1.692	1.692
	(0.000)	(0.834)	(0.834)
Paper or cardboard	1.754	0.883	2.637
	(1.153)	(0.481)	(1.194)
Pig iron or steel	0.102	1.259	1.362
	(0.125)	(0.638)	(0.664)
Pulp from timber	0.136	1.710	1.847
	(0.203)	(0.723)	(0.810)
All sectors pooled	0.755	0.800	1.555
	(0.999)	(0.640)	(1.128)

IV estimates

Q/E gains and parent firms (OHA-Orbis match)

Table 7: E-PF *gain*, E-TFP *gain* and parent firms' characteristics

	[1] E-PF *gain*	[2] E-TFP *gain*	[3] E-PF *gain*	[4] E-TFP *gain*
Firm age	0.000	-0.001**	-0.000	-0.001
	(0.001)	(0.000)	(0.001)	(0.001)
Firm size	-1.444**	-0.419	-1.896***	-0.406
	(0.609)	(0.290)	(0.626)	(0.295)
Multi-plant firm	-0.434***	-0.020	-0.382***	-0.042
	(0.093)	(0.053)	(0.094)	(0.054)
Intangibles intensity	-0.000	-0.001**	-0.000	-0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Listed firm	-0.348*	-0.002	-0.254	-0.106
	(0.177)	(0.106)	(0.194)	(0.117)
International ultimate owner	-0.196**	-0.130**	-0.198**	-0.097*
	(0.091)	(0.052)	(0.095)	(0.056)
Constant	1.169***	0.947***	0.763***	1.334***
	(0.089)	(0.052)	(0.243)	(0.148)
Country FE	No	No	Yes	Yes
F	8.56	3.61	4.72	2.48
Pr.> F	0.000	0.001	0.000	0.000
# of obs.	493	554	493	554

Conclusions

Recap

- We study the cross-plant differences in Q/E
  - the extent they are due to technology adoption vs technology usage
  - the gains from upgrading on both margins
- We propose a mixture model approach to E-PF estimation
  - entirely data-driven (free to determine the # of technologies)
  - only requiring information on Q and E (available for large-scale samples)
- We document cross-plant technology differentials
  - only 21% of plants use frontier technologies
  - but technology usage most important in many sectors
  - E-PF and E-TFP differ systematically across plant types
- Policy insights
  - diffusion of improved technologies is important (not only innovation!)
  - technology standards may work well for some firms but not for others

Thank you!

Filippo Belloc
U of Siena
filippo.belloc@unisi.it
https://sites.google.com/site/filippobelloc/

Correction factors

Table 8: CSCF and CLEF

Year	ϑ_t (CSCF)	$\lambda_{s,t}$ (CLEF) sectors at risk of carbon leakage	$\lambda_{s,t}$ (CLEF) sectors not at risk of carbon leakage
2013	0.94272151	1	0.8000
2014	0.92634731	1	0.7286
2015	0.90978052	1	0.6571
2016	0.89304105	1	0.5857
2017	0.87612124	1	0.5143
2018	0.81288476	1	0.4429
2019	0.79651677	1	0.3714

back

Endogeneity bias

- Possible endogeneity of $\ln(E_i)$ as in standard TFP contexts
- We integrate the mixture model in Eq. (3) with a 1st stage

$$E_i = \gamma_1 + \gamma_2 A_{i,2005} + \epsilon_i \tag{9}$$

where $A_{i,2005}$ = allowances allocated with "grandfathering" in 2005 (allocated based on historical, predetermined emissions)

Table 9: 1st stage OLS correlation between E_i (med. 2005-08) and $A_{i,2005}$

γ_1	γ_2	R^2	F	Pr.$> F$
7526.502* (3979.685)	0.916*** (0.005)	0.953	23883.36	0.000

IV estimates of E-PF and E-TFP gains

Table 10: Potential gains (%): sectoral averages

Sector	E-PF *gain*	E-TFP *gain*	*Total gain*
Ammonia	0.000	0.447	0.447
	(0.000)	(0.357)	(0.357)
Carbon black	0.332	0.138	0.471
	(0.270)	(0.087)	(0.290)
Cement clinker	0.181	1.305	1.487
	(0.275)	(0.430)	(0.442)
Coke and coke ovens	0.000	0.931	0.931
	(0.000)	(0.491)	(0.491)
Glass	0.671	0.516	1.187
	(0.732)	(0.251)	(0.803)
Gypsum or plasterboard	0.000	0.313	0.313
	(0.000)	(0.238)	(0.238)
Lime and dolomite	0.619	0.552	1.172
	(0.808)	(0.248)	(0.898)
Mineral wool	0.922	0.483	1.406
	(0.804)	(0.278)	(0.781)
Nitric acid	0.000	2.412	2.412
	(0.000)	(1.596)	(1.596)
Other pulp	0.639	1.207	1.846
	(0.665)	(0.427)	(0.875)
Paper or cardboard	0.375	1.454	1.829
	(0.477)	(0.661)	(0.951)
Pig iron or steel	0.852	0.979	1.832
	(1.182)	(0.536)	(1.330)
Pulp from timber	2.079	2.217	4.297
	(1.370)	(0.748)	(1.246)
All sectors pooled	0.554	1.062	1.617
	(0.797)	(0.691)	(1.101)

back

Differentials between baseline and IV estimates

Figure 3: Difference between baseline and IV-based E-PF *gain* and E-TFP *gain*