Innovation Complementarity and Scale of Production

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Motivation

- Management applications of lattice-based theoretical models have focused their attention on the following issues:
  - Finding out the source of the observed correlation among firms' own strategies.
  - Evaluating the "externalities" that some particular incentives may have in other areas of the firm.
  - Designing the proper organizational structure of firms.

- In this paper we:
  - Estimate a model of production, product, and process innovation decision in the Spanish tile industry.
  - Develop a structural model that allows to distinguish whether the observed correlation among strategies is due to:
    - Complementarities.
    - Unobserved firms' heterogeneity.
  - Ignore strategic complementarities.

- Building blocks:
  - Athey and Schmutzler (1995).
  - Athey and Stern (1998).
  - A large selection of unworthy empirical papers.
    - Simplistic econometric methods.
    - Testing cannot distinguish between:
      - Complementarity.
      - Unobserved heterogeneity.
      - Missing variables.
      - Misspecification of the econometric model.

- Findings:
  - Managerial ability is responsible for realizing the potential benefits of simultaneous adoption of innovations.
  - Technology eases product innovation for smaller firms.
  - Larger firms could also profit more from process innovation but unobserved market conditions reduces this return.

The Spanish Ceramic Tile Industry

- Second largest in the world.
- Clustered in a small area on the east of Spain.
- Data covers the initial 7 years of Spain’s EU membership (1986-1992).
- Suffered from technological backwardness in the early 1980s.
  - It was able to compete only based on low wages.
- Major innovation became available in the 80s.

- The single-firing furnace:
  - vs. product specific firing furnace.
  - vs. full/half cycle double firing furnace.

  - Major innovation.
    - Required a major restructuring of the firm.
    - Energy efficient.
    - Automated process.
    - Integrated design and production of multiple varieties.
    - Allowed the production of new high-quality products:
      - Low water absorption.
      - Large tile dimensions.
      - Non-squared shapes.
      - Large selection of colors and design.

- Motivating story:
  - Economic growth (1985-1992) leads to wage increases.
  - Access to European markets allows for potentially large markups.
  - Increasing returns to process innovation.
  - Technology facilitates new designs.
  - Management realizes the potential profits of new products.

INNOVATION CHOICES AND SCALE OF PRODUCTION

	N	Freq. (%)	Mean scale	S.D. scale
Whole Sample				
Both	88	20.4	5.29	2.20
Only product	62	14.4	5.02	2.13
Only process	68	15.7	5.56	1.75
None	214	49.5	5.47	1.80
All firms	432		5.38	1.94
Large Scale Sample				
Both	63	21.1	6.37	0.78
Only product	39	13.1	6.20	0.76
Only process	46	15.4	6.42	0.86
None	150	50.3	6.30	0.84
All firms	298		6.32	0.82
Small Scale Sample				
Both	25	18.7	2.58	2.29
Only product	23	17.2	3.00	2.19
Only process	22	16.4	3.77	1.78
None	64	47.8	3.53	1.95
All firms	134		3.30	2.08

- Supermodularity of the profit function in production, product, and process innovation leads to complementarity relationships among these choice variables and to empirical association among strategies.

UNCONDITIONAL ASSOCIATION OF STRATEGIES

	Whole Sample	Large Scale Sample	Small Scale Sample
PRODUCT, PROCESS	0.321 [0.000]	0.350 [0.000]	0.253 [0.000]
PRODUCT, OUTPUT	−0.024 [0.454]	−0.001 [0.983]	−0.178 [0.000]
PROCESS, OUTPUT	0.036 [0.260]	0.066 [0.042]	−0.057 [0.078]
N	432	298	134

Model

$$\pi(\boldsymbol{x}; \boldsymbol{Z}) + \pi(\boldsymbol{x}'; \boldsymbol{Z}) \leq \pi(\boldsymbol{x} \vee \boldsymbol{x}'; \boldsymbol{Z}) + \pi(\boldsymbol{x} \wedge \boldsymbol{x}'; \boldsymbol{Z}).$$

$$\pi(\boldsymbol{x}_i; \boldsymbol{Z}_i) = R(x_{di}, x_{yi}; \boldsymbol{Z}_{ri}) - C(x_{ci}, x_{yi}; \boldsymbol{Z}_{ci}) - K(x_{di}, x_{ci}; \boldsymbol{Z}_{ki}).$$

$$R(1, x_{yi}; \boldsymbol{Z}_{ri}) \geq R(0, x_{yi}; \boldsymbol{Z}_{ri}).$$

$$C(1, x_{yi}; \boldsymbol{Z}_{ci}) \leq C(0, x_{yi}; \boldsymbol{Z}_{ci}).$$

Specification:

$$
\begin{aligned}
R(x_{di}, x_{yi}; Z_{ri}) &= \alpha_d x_{di} + \alpha_y x_{yi} + \delta_{dy} x_{di} x_{yi} \\
&+ \theta'_{dr} z_{ri} x_{di} + \theta'_{yr} z_{ri} x_{yi} + \psi'_{dr} \zeta_{ri} x_{di} + \psi'_{yr} \zeta_{ri} x_{yi} - (\gamma_r/2) x_{yi}^2, \\
C(x_{ci}, x_{yi}; Z_{ci}) &= \beta_c x_{ci} + \beta_y x_{yi} - \delta_{cy} x_{ci} x_{yi} \\
&- \theta'_{cc} z_{ci} x_{ci} - \theta'_{yc} z_{ci} x_{yi} - \psi'_{cc} \zeta_{ci} x_{ci} - \psi'_{yc} \zeta_{ci} x_{yi} - (\gamma_c/2) x_{yi}^2, \\
K(x_{di}, x_{ci}; Z_{ki}) &= \eta_d x_{di} + \eta_c x_{ci} - \delta_{dc} x_{di} x_{ci} \\
&- \theta'_{dk} z_{ki} x_{di} - \theta'_{ck} z_{ki} x_{ci} - \psi'_{dk} \zeta_{ki} x_{di} - \psi'_{ck} \zeta_{ki} x_{ci},
\end{aligned}
$$

- Firm's Environment:

$$Z_{ri} = (z'_{ri}, \zeta'_{ri})', \; Z_{ci} = (z'_{ci}, \zeta'_{ci})', \text{ and } Z_{ki} = (z'_{ki}, \zeta'_{ki})'$$

- After transformations…

$$\pi(x_{di}, x_{ci}) = (\kappa_{di} + \epsilon_{di})x_{di} + (\kappa_{ci} + \epsilon_{ci})x_{ci} + \delta x_{di}x_{ci} + \pi_{0i}.$$

$$\begin{aligned}
\kappa_{yi} &= \theta_{yi} + \epsilon_{yi}, \\
\kappa_{di} &= \theta_{di} + \delta_{dy}^2/2 + \delta_{dy}\kappa_{yi}, \\
\kappa_{ci} &= \theta_{ci} + \delta_{cy}^2/2 + \delta_{cy}\kappa_{yi}, \\
\pi_{0i} &= \kappa_{yi}^2/2, \\
\delta &= \delta_{dc} + \delta_{dy}\delta_{cy},
\end{aligned}$$

$$\begin{aligned}
\theta_{di} &= \theta_d(z_{ri}, z_{ki}) = \theta_{d0} + \boldsymbol{\theta}'_{dr} z_{ri} + \boldsymbol{\theta}'_{dk} z_{ki}, \\
\theta_{ci} &= \theta_c(z_{ci}, z_{ki}) = \theta_{c0} + \boldsymbol{\theta}'_{cc} z_{ci} + \boldsymbol{\theta}'_{ck} z_{ki}, \\
\theta_{yi} &= \theta_y(z_{ri}, z_{ci}) = \theta_{y0} + \boldsymbol{\theta}'_{yr} z_{ri} + \boldsymbol{\theta}'_{yc} z_{ci},
\end{aligned}$$

$$\begin{aligned}
\epsilon_{di} &= \psi'_{dr}\zeta_{ri} + \psi'_{dk}\zeta_{ki}, \\
\epsilon_{ci} &= \psi'_{cc}\zeta_{ci} + \psi'_{ck}\zeta_{ki}, \\
\epsilon_{yi} &= \psi'_{yr}\zeta_{ri} + \psi'_{yc}\zeta_{ci}.
\end{aligned}$$

- Model features:
  - Returns to each strategy distinguish between observable and unobservable sources.
  - Supermodularity of the profit function only depends on parameters δ_{dc}, δ_{dy}, and δ_{cy}, but not on the correlation of unobserved environmental variables.
  - Returns to each strategy exclude some set of environmental variables.
  - Unobserved heterogeneity leads to strategy association
  - Correlation among strategies may also be caused by observable environmental variables common to different strategy returns θ_d, θ_c, or θ_y.

- Estimation based on innovation profiles.

  - To innovate both in product and process:

$$\pi(1,1) > \pi(0,1) \implies \kappa_{di} + \epsilon_{di} + \kappa_{ci} + \epsilon_{ci} + \delta + \pi_{0i} > \kappa_{ci} + \epsilon_{ci} + \pi_{0i},$$
$$\pi(1,1) > \pi(1,0) \implies \kappa_{di} + \epsilon_{di} + \kappa_{ci} + \epsilon_{ci} + \delta + \pi_{0i} > \kappa_{di} + \epsilon_{di} + \pi_{0i},$$
$$\pi(1,1) > \pi(0,0) \implies \kappa_{di} + \epsilon_{di} + \kappa_{ci} + \epsilon_{ci} + \delta + \pi_{0i} > \pi_{0i}.$$

$$\epsilon_{di} > -\kappa_{di} - \delta$$
$$\epsilon_{ci} > -\kappa_{ci} - \delta$$
$$\epsilon_{ci} + \epsilon_{di} > -\kappa_{di} - \kappa_{ci} - \delta$$

- Innovation profiles:

UNOBSERVED HETEROGENEITY AND CHOICE OF INNOVATION PROFILE

$$S_i(1,1): \begin{cases} \epsilon_{di} > -\kappa_{di} - \delta \\ \epsilon_{ci} > -\kappa_{ci} - \delta \\ \epsilon_{ci} > -\kappa_{ci} - \kappa_{di} - \delta - \epsilon_{di} \ ^{a} \end{cases} \qquad S_i(1,0): \begin{cases} \epsilon_{di} > -\kappa_{di} \\ \epsilon_{ci} < -\kappa_{ci} - \delta \\ \epsilon_{ci} < -\kappa_{ci} + \kappa_{di} + \epsilon_{di} \ ^{b} \end{cases}$$

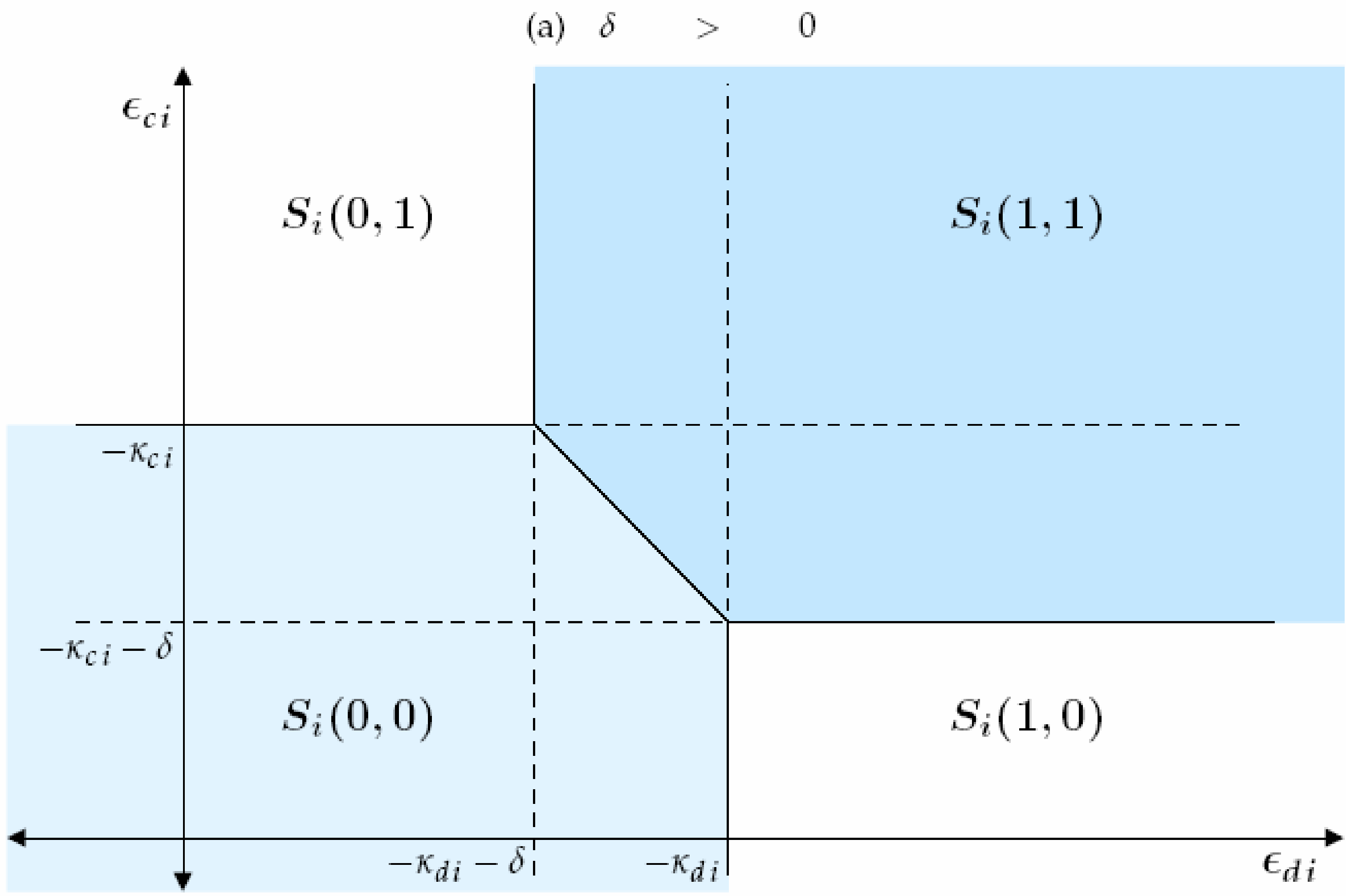
$$S_i(0,1): \begin{cases} \epsilon_{di} < -\kappa_{di} - \delta \\ \epsilon_{ci} > -\kappa_{ci} \\ \epsilon_{ci} > -\kappa_{ci} + \kappa_{di} + \epsilon_{di} \ ^{b} \end{cases} \qquad S_i(0,0): \begin{cases} \epsilon_{di} < -\kappa_{di} \\ \epsilon_{ci} < -\kappa_{ci} \\ \epsilon_{ci} < -\kappa_{ci} - \kappa_{di} - \delta - \epsilon_{di} \ ^{a} \end{cases}$$

These are the conditions that simultaneously fulfill all points pertaining to $S_i(d,c)$, the set of pairs $(\epsilon_{di}, \epsilon_{ci})$ for which the optimal decision on innovative profile is $(x_{di}, x_{ci}) = (d, c)$.

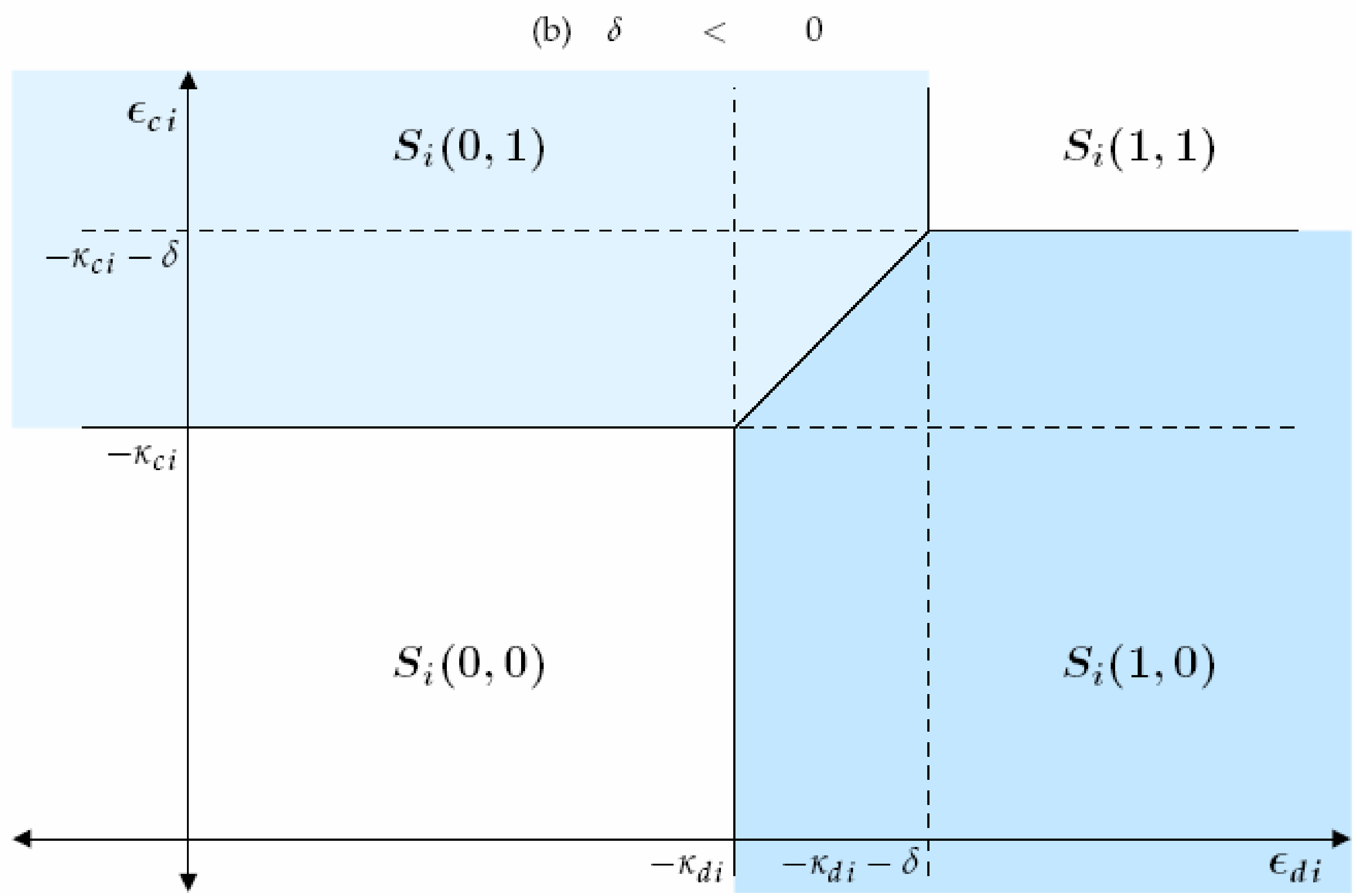
[a] This condition is not binding when $\delta \leq 0$.

[b] This condition is not binding when $\delta \geq 0$.

- Some added econometric difficulty (complements):



- Some added econometric difficulty (substitutes):



Behavioral Model

- Common effects:
  - Time trend (reputation, experience,…).
  - Entry and exit.
- Revenues (Z_r):
  - Exports, EU indicator, Trademarks.
- Production costs (Z_c):
  - Age of the firm.
- Adoption costs (Z_k):
  - Number of products.

		Model [I]	Model [II]	Model [III]	Model [IV]
θ_d	CONSTANT	−0.64 (0.16)***	−0.63 (0.16)***	−0.51 (0.21)**	0.90 (0.67)
	EX	−0.21 (0.35)	−0.29 (0.32)	−0.17 (0.35)	0.34 (0.36)
	EX · EU	0.88 (0.36)**	0.97 (0.33)***	0.99 (0.36)***	0.43 (0.53)
	TM	0.35 (0.15)**	0.36 (0.14)***	0.43 (0.15)***	0.39 (0.19)**
	TMHI	−0.03 (0.16)	−0.05 (0.15)	0.04 (0.17)	0.37 (0.18)**
	MPROD	0.07 (0.14)	0.07 (0.13)	0.08 (0.14)	0.03 (0.12)
	MPRODHI	0.38 (0.34)	0.43 (0.34)	0.20 (0.34)	0.69 (0.40)*
	TIME	−0.16 (0.14)	−0.17 (0.14)	−0.13 (0.14)	−0.08 (0.13)
	EXIT	−0.36 (0.27)	−0.35 (0.27)	−0.41 (0.28)	−0.62 (0.26)**
	ENTRY	0.33 (0.30)	0.33 (0.30)	0.24 (0.31)	0.01 (0.32)
θ_c	CONSTANT	−0.24 (0.28)	−0.35 (0.26)	−0.49 (0.30)	−0.56 (0.41)
	AGE	−0.03 (0.10)	0.01 (0.09)	−0.03 (0.10)	−0.20 (0.11)*
	MPROD	−0.02 (0.13)	−0.02 (0.13)	−0.03 (0.13)	−0.02 (0.11)
	MPRODHI	1.54 (0.41)***	1.59 (0.42)***	1.58 (0.43)***	1.30 (0.47)***
	TIME	−0.11 (0.14)	−0.12 (0.14)	−0.08 (0.14)	−0.13 (0.12)
	EXIT	−0.30 (0.27)	−0.29 (0.27)	−0.25 (0.27)	−0.12 (0.26)
	ENTRY	0.09 (0.32)	0.15 (0.32)	0.05 (0.33)	0.15 (0.29)
θ_y	CONSTANT	3.26 (0.38)***	3.33 (0.38)***	3.30 (0.38)***	3.29 (0.39)***
	EX	1.02 (0.44)**	1.04 (0.45)**	1.01 (0.44)**	1.05 (0.42)**
	EX · EU	−0.10 (0.48)	−0.11 (0.48)	−0.07 (0.48)	0.04 (0.48)
	TM	0.44 (0.19)**	0.44 (0.19)**	0.45 (0.19)**	0.48 (0.19)**
	TMHI	0.97 (0.22)***	0.97 (0.22)***	0.97 (0.22)***	0.90 (0.23)***
	AGE	0.52 (0.13)***	0.49 (0.13)***	0.52 (0.13)***	0.51 (0.13)***
	TIME	0.13 (0.19)	0.14 (0.19)	0.13 (0.19)	0.12 (0.19)
	EXIT	−1.00 (0.35)***	−1.01 (0.35)***	−1.01 (0.35)***	−1.02 (0.35)***
	ENTRY	−0.40 (0.44)	−0.44 (0.44)	−0.40 (0.44)	−0.39 (0.44)
δ_{dc}				0.52 (0.08)***	−0.50 (0.36)
δ_{dy}				−0.08 (0.03)***	−0.27 (0.14)**
δ_{cy}				0.01 (0.03)	0.19 (0.10)*
ρ_{dc}			0.55 (0.06)***		0.64 (0.26)**
ρ_{dy}			−0.15 (0.06)**		0.40 (0.29)
ρ_{cy}			−0.04 (0.06)		−0.40 (0.20)**
σ_y		1.75 (0.06)***	1.75 (0.06)***	1.75 (0.06)***	1.74 (0.06)***
$\ln L$		−1396.3	−1367.8	−1367.9	−1364.5
χ^2		132.7***	137.2***	136.3***	121.2***

Results

- Model specifications I-IV:
  - Non-existence of complementarity is always rejected.
  - The association among strategies cannot be attributed to a single source.
  - A specification that includes both, complementarity and unobserved heterogeneity dominates any other.
  - Restricted specifications pick up the wrong effect of the excluded source of association.

- Returns to each strategy:
  - Product innovation:
    - Trademarks (+, ++)
    - Multiproduction (++) — learning spillovers
    - Exit (-) — declining firm
  - Process innovation:
    - Age (-) — old fashion firms
    - Multiproduction (++) — scope economies
  - Scale of production:
    - Exports (+) — small firms mostly sell in the domestic market
    - Trademarks (+, ++) — small firms mostly sell unbranded products
    - Age (+) — newly created firms designed for lower scale
    - Exit (-) — declining firm

Source of association:

- Product – Process.
  - Unobserved heterogeneity: Managerial and organizational features of firms that are difficult to account for.
- Product – Scale.
  - Technological: Single-firing furnace is suitable for smaller minimum efficient scale of production.
- Process – Scale.
  - Technological: Larger firms benefit more from process innovation.
  - Unobserved heterogeneity: Lack of experience, poor manager background, or lack of access to markets.

In the Future…?

- Several additional strategies.
  - Continuous strategies. Straightforward.
  - Dichotomous strategies. Simulation methods vs. ML.

- Dynamic complementarities.
  - Richer panel data required.

- Integrating the “return” and “adoption” approaches.
  - Estimate our model simultaneously with the profit function imposing cross-equations restrictions.
  - Allows to identify the direct effect of observable characteristics on the revenue, production cost, and innovation cost functions.