R&D, innovation, and productivity

Bronwyn H. Hall
University of California at Berkeley
NBER, IFS London, NIESR London, College de France, and MPI Munich

Questions

- Do R&D and innovation contribute to the productivity growth of firms, industries and countries?
- Do R&D and innovation contribute to the productivity growth of other firms, industries, and countries?
- What other factors in the environment matter for innovation?

Outline

- Innovation-productivity nexus
  - Brief digression on R&D vs innovation
- What is known about R&D and innovation in relation to productivity
  - Interpretive framework
  - Survey of key results
- Broader policy framework

Innovation and productivity

- What are the mechanisms connecting innovation and productivity?
  - Improvements within existing firms
    - Creation of new goods & services, leading to increased demand for firm's products
    - Process and organizational innovation leading to efficiency gains in production
  - Reallocation of resources towards "better" firms
    - Entry of more efficient or new product firms
    - Entry of firms on technology frontier
    - Exit of less efficient firms

Measuring innovation

- Large literature using R&D flows or stocks as proxies for innovation input
  - Hall, Mairesse, Mohnen 2010 survey, *inter alia*
- Smaller literature using patents as a proxy for intermediate innovation output
- Both measures have well-known weaknesses, especially outside the manufacturing sector.
- Recently more direct measures are available, thanks to CIS firm surveys
  - Most surveys of the service sector find many innovating firms, fewer R&D-doers

R&D vs innovation

- Not all innovative firms do formal R&D
- R&D-doing firms do not innovate every year (or even every 3 years)

Italian firms 1995-2006		
	Non-innovator	Innovator
Does not do R&D	77.9%	47.6%
Does R&D	22.6%	52.4%

- Especially true in the service sector:
  - Many innovations are not technological, such as new ways of organizing information flow, new designs, etc.
  - Many innovations rely on purchased technology, such as adoption of computer-aided processes, CRM software, etc.

R&D vs innovation spending

- UK firms on the CIS 1998-2006 – average breakdown of spending on innovative activities.
- Service sector firms spend more on new equipment and marketing and less on R&D.

	Manufacturing	Services & other
Acquisition of machinery & computer hardware/software	43.2%	47.0%
Internal R&D spending	25.1%	12.0%
Marketing expense	10.6%	16.5%
Training expense	5.4%	13.4%
Design expense	8.8%	4.2%
External R&D spending	4.2%	3.2%
Acquisition of external knowledge	2.6%	3.7%
Share with nonzero innov. spending	71.1%	54.7%

The shares shown are for firms that have some form of innovation spending reported.

What do we know?

- A great deal about
  - Contribution of R&D and innovation to firm-level productivity
  - Contribution of R&D and innovation to the productivity of other industries and countries
- Something about
  - Contribution of entry of more efficient and exit of less efficient firms to aggregate productivity growth
  - Contribution of R&D to quality improvement and therefore productivity growth (via lower prices)
- Less about
  - Contribution of R&D and innovation to welfare and to poorly measured but important outputs (health, environmental quality, etc)
  - Aggregate growth implications in detail
  - Distribution of the benefits from gains in productivity

Productivity-innovation model

- Innovation will affect both the price the firm can charge and the quantity it produces from a given set of inputs
- Output measure -- revenue (sales) -- incorporates the joint response of price*quantity to product and process innovation
- Labor demand responds both to increased efficiency (negatively) and to increased output (positively, due to output increases)
- Assume the following:
  - Imperfect competition (nonzero markup; downward sloping demand with constant elasticity)
  - Process innovation reduces cost (same inputs produce more)
  - Product innovation shifts demand curve out (higher willingness to pay for the improved good, or higher quality good for the same price)

Algebra for this analysis given in backup slides

Conclusions from analysis

- Product innovation unambiguously increases *revenue productivity* and *labor demand*
- Process innovation will increase *revenue productivity* and *labor demand* only if demand is elastic; even in this case impact is dampened unless there is perfect competition (output price taking)
- Allocation of the impact of innovation between price and quantity will depend on the type of price deflator used
  - the closer the deflator is to a true quality-adjusted price, the higher the *measured* innovation contribution to quality and price rather than quantity (with a corresponding *negative* effect on quantity).
  - However, estimates of the innovation impact on firm *revenue* are not affected by the choice of deflator.

Surveying results from the CDM model

R&D-Innovation-productivity relationship in the cross section

Innovation surveys contain…..

- Data on innovation:
  - Product or process new to firm/market (yes/no)
  - Share of sales during past 3 years from new products
  - More recent surveys have expenditures on various kinds of innovation investments; information on other types if innovation
- Data on productivity and employment:
  - Usually sales per worker (labor productivity)
  - Sometimes TFP (adjusted for changes in capital)
  - Issues arising from deflation and level of aggregation
    - of goods, and of enterprises

More information in Mairesse and Mohnen (2010)

What do the data say about this relationship?

- Results from a large collection of papers that used the CDM model for estimation (Crepon Duguet Mairesse 1998):
  - Innovation survey data reveals that some non-R&D firms innovate and some R&D firms do not innovate during the relevant period
  - Data is usually cross-sectional, so possible simultaneity between R&D, innovation, and productivity
    - productivity usually for the later year
  - Sequential model: R&D→innovation→productivity

Interpretive framework

- Innovation-productivity regressions use revenue productivity data
  - Include coarse sectoral dummies
  - Relative within-sector price changes not accounted for
  - Quality change not generally accounted for
- In the case of innovative activity, omitting price change at the firm level can be helpful, as it allows estimation of the contribution of innovation to demand as well as efficiency

The CDM model

1. The determinants of R&D choice: whether to do it and how much to do (generalized Tobit)
2. Innovation production function with innovation variables as functions of predicted R&D intensity (regression or probits)
3. Production function including the predicted innovation outcomes to measure their contribution to the firm's productivity.

Effectively a triangular simultaneous equations model, but nonlinear. (bootstrap s.e.s if sequentially estimated)

CDM model applied to CIS data

- Estimated for 20+ countries
- Confirms high rates of return to R&D found in earlier studies
- Like patents, innovation output statistics are much more variable ("noisier") than R&D,
  - R&D tends to predict productivity better, when available
- Next few slides - results summary
  - regressions of individual firm TFP or LP on innovation
- Sources: Hall (2011), *Nordic Economic Policy Review* and Hall and Mohnen (2013), *Eurasian Business Review, updated.*

Productivity-innovation relationship in TFP levels

Sample	*Time period*	*Elasticity with respect to innov sales share*	*Process innovation dummy*
Chilean mfg sector	1995-1998	0.18 (0.11)*	
Chinese R&D-doing mfg sector	1995-1999	0.035 (0.002)***	
Dutch mfg sector	1994-1996	0.13 (0.03)***	-1.3 (0.5)***
Finnish mfg sector	1994-1996	0.09 (0.06)	-0.03 (0.06)
French mfg sector	1986-1990	0.07 (0.02)***	
German K-intensive mfg sector	1998-2000	0.27 (0.10)***	-0.14 (0.07)**
Norwegian mfg sector	1995-1997	0.26 (0.06)***	0.01 (0.04)
Swedish K-intensive mfg sector	1998-2000	0.29 (0.08)***	-0.03 (0.12)
Swedish mfg sector	1994-1996	0.15 (0.04)***	-0.15 (0.04)***
Swedish mfg sector	1996-1998	0.12 (0.04)***	-0.07 (0.03)***
Swedish service sector	1996-1998	0.09 (0.05)*	-0.07 (0.05)
Innovative sales share and process innovation included separately in the production function:			
French Hi-tech mfg	1998-2000	0.23 (0.15)*	0.06 (0.02)***
French Low-tech mfg	1998-2000	0.05 (0.02)***	0.10 (0.04)***
Irish firms	2004-2008	0.11 (0.02)***	0.33 (0.08)***

TFP levels on innov sales share

- Robustly positive, supports the view that product innovation shifts the firm's demand curve out and increases revenue
  - Elasticities range from 0.04 to 0.29 with a typical standard error of 0.03
  - R&D-intensive and hi-tech firms have higher elasticities (consistent with equalized rates of return across sectors)
- Coefficient of process innovation dummy usually insignificant or negative, suggesting either inelastic demand and/or substantial measurement error in the innovation variables

Productivity-innovation using dummies

Table 2b: Results for the productivity-innovation relationship in TFP levels

Sample	*Time period*	*Product innovation dummy*	*Process innovation dummy*
Argentinian mfg sector	1992-2001	-0.22 (0.15)	
Brazilian mfg sector	1998-2000	0.22 (0.04***	
Estonian mfg sector	1998-2000	0.17 (0.08)**	-0.03 (0.09)
Estonian mfg sector	2002-2004	0.03 (0.04)	0.18 (0.05)***
French mfg sector	1998-2002	0.14 (0.04)***	0.02 (0.05)
French mfg sector	2002-2004	0.13 (0.01)***	-0.02 (0.01)
French service sector	2002-2004	0.17 (0.03)***	-0.01 (0.01)
German mfg sector	1998-2000	-0.05 (0.03)	0.02 (0.05)
Italian mfg sector	1995-2003	0.69 (0.15)***	-0.43 (0.13)***
Italian mfg sector SMEs	1995-2003	0.60 (0.09)***	0.19 (0.27)
Mexican mfg sector	1998-2000	0.31 (0.09)**	
Spanish mfg sector	2002-2004	0.16 (0.05)***	
Spanish mfg sector	1998-2000	0.18 (0.03)***	-0.04 (0.04)
Swiss mfg sector	1998-2000	0.06 (0.02)***	
UK mfg sector	1998-2000	0.06 (0.02)***	0.03 (0.04)
Product and process innovation dummies included separately in the production function:			
French mfg sector	1998-2000	0.06 (0.02)***	0.07 (0.03)**
Irish firms	2004-2008	0.45 (0.08)***	0.33 (0.08)***

Productivity-innovation using dummies

Sample	*Time period*	*Product innovation dummy*	*Process innovation dummy*
German mfg sector	2006-2008	0.04 (0.02)*	
German mfg sector	2006-2008		0.09 (0.05)**
German service sector	2006-2008	0.21 (0.07)***	
German service sector	2006-2008		0.16 (0.06)***
Irish mfg sector	2006-2008	0.18 (0.22)	
Irish mfg sector	2006-2008		0.24 (0.24)
Irish service sector	2006-2008	0.51 (0.30)*	
Irish service sector	2006-2008		0.19 (0.28)
UK mfg sector	2006-2008	0.05 (0.02)***	
UK mfg sector	2006-2008		0.07 (0.02)***
UK service sector	2006-2008	0.07 (0.03)**	
UK service sector	2006-2008		0.04 (0.02)*

Source: Peters et al. 2014

TFP level results with dummies

- Product dummy supports innovation sales share result, although much noisier.
- There is substantial correlation between product and process innovation, especially when they are instrumented by R&D and other firm characteristics.
  - Without instruments, innovation dummies frequently do not enter productivity equation at all.

NB: Correlated measurement error can lead to bias in both coefficients (upward for the better measured one and downward for the other) – see Hall (2004)
http://bronwynhall.com/papers/BHH04_measerr.pdf

UK results (1)

Hall and Sena (2017) – UK firm survey data matched to innovation surveys 1998-2006

Augmented CDM model:

1. The determinants of R&D or innovation spending (IS) choice: whether to do it and how much to do (generalized Tobit)
2. Innovation production function with innovation variables and IP importance variables as functions of predicted R&D or IS intensity (trivariate probits)
3. Production function including the predicted innovation outcomes to measure their contribution to the firm's productivity, along with IP variables

UK results (2)

Coefficients in the production function (estimated by OLS)	Product innovation		Process innovation		New-to-market prod innov		New to market proc innov	
Using R&D spending								
Predicted prob. of innovation	0.003	(0.051)	-0.107	(0.056)	0.048	(0.069)	-0.282	(0.180)
Prob. Innov. & formal IP	***0.114***	***-0.055***	0.074	-0.068	***0.153***	***-0.075***	0.173	-0.216
Prob. Innov. & informal IP	0.022	-0.041	−0.051	-0.051	0.059	-0.054	−0.138	-0.157
Prob. Innov. & both	**0.136**	**-0.031**	**0.128**	**-0.029**	**0.158**	**-0.038**	**0.291**	**-0.105**
Using innovation spending								
Predicted prob. of innovation	0.003	-0.051	-0.107	-0.056	0.048	-0.069	-0.282	-0.180
Prob. Innov. & formal IP	***0.120***	***-0.056***	0.074	-0.068	***0.155***	***-0.076***	0.163	-0.216
Prob. Innov. & informal IP	0.023	-0.041	-0.052	-0.051	0.052	-0.054	-0.159	-0.156
Prob. Innov. & both	**0.140**	**-0.031**	**0.129**	**-0.031**	**0.159**	**-0.038**	**0.286**	**-0.105**

- Results using IS almost the same as those using R&D
- Innovation probability postive for productivity only if firm thinks formal IP is important.

Employment impacts

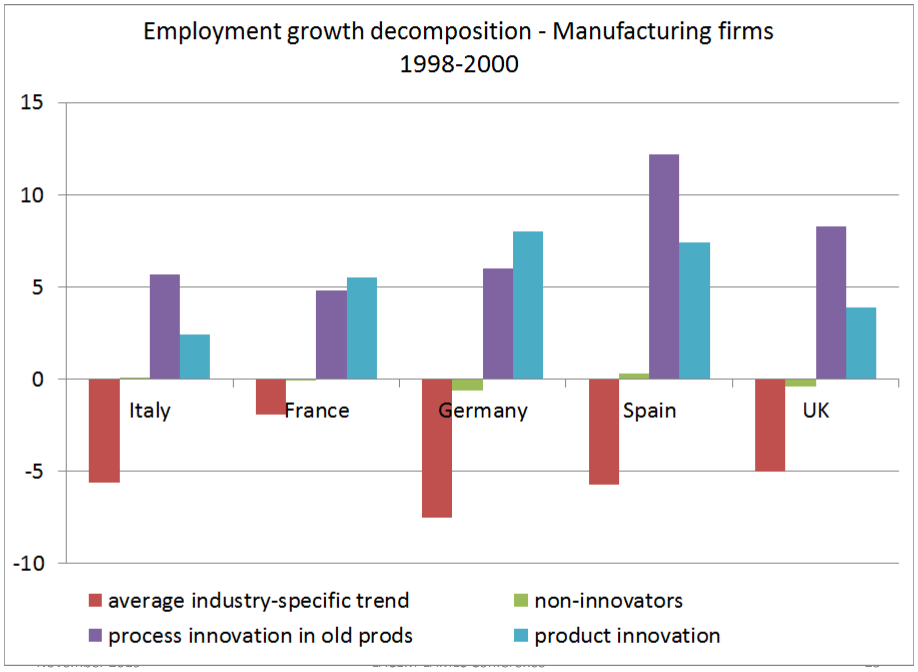
- Harrison et al (IJIO 2014) and Hall, Lotti, Mairesse (ICC 2008) - decompose employment growth as a function of process and product innovation

  Growth = industry productivity trend in old products

  + growth due to process innovation in old products

  + growth due to output growth of old products

  + growth due to product innovation (net of substitution away from old products)
- A reinterpretation of the labor productivity equation to focus on employment



Summary

- Elasticity wrt innovative sales centers on (0.09, 0.13)
  - higher for high tech and knowledge-intensive firms
  - Lower on average for low tech and developing countries, but also more variable
- With product innovation included, process innovation often negative or zero
- Without product innovation, process innovation positive for productivity
- When not instrumented, little impact of innovation variables in production function (unlike R&D)
  - See Mairesse & Mohnen (2005), Hall et al. (2012)
- Both process and product innovation are positive on average for firm employment growth in manufacturing,
  - at least during the late 1990s in Europe
- What if we had spending on innovation (rather than just R&D, a component of innovation spending)?

Product vs process R&D

- Can one distinguish between innovative activity directed toward
  - new/improved products (increased demand) vs.
  - new/improved processes (increased efficiency)?
- Work by Petrin, Warzynski, and Chan (2011, revised 2019)
  - Danish micro data on manufacturing
  - R&D at the product/process level within firm.
  - Allows estimation of the contribution of R&D to demand (quality improvement) and technical efficiency separately
- Results:
  - Product R&D increases product quality, marginal costs and lowers productivity.
  - Process R&D decreases marginal costs, increases productivity, but doesn't affect quality.
- *NB: breaks revenue productivity into price and quantity impacts*

Spillovers

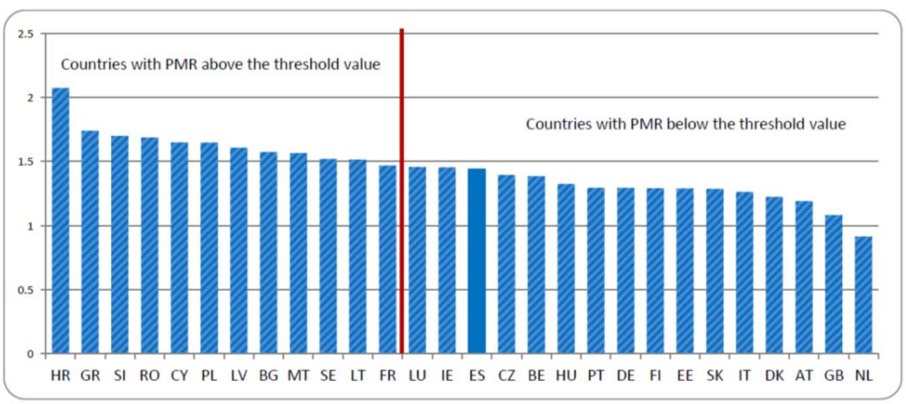
- Principal argument for R&D/innovation policy is the presence of unpriced spillovers to firms that are adjacent in industry, technology, or geographically.
- Lots of evidence that this is true (Kao et al 1999, Keller 1998, 2001, Coe and Helpman 1995). Some nuances:
  - For foreign R&D, export/import channel is important (Macgarvie 2004)
  - Spillovers from foreign R&D more important for smaller open economies than for countries like US, Japan, and Germany (Park 1995, van Pottelsberghe 1997)
  - Domestic spillovers usually larger than those from other countries (Branstetter 2001, Peri 2004)
  - Absorptive capacity of recipient country is important for making use of R&D spillovers (Guellec and van Pottelsberghe 2001)
  - Typical social rates of return are quite large, but very imprecisely determined

Institutions and innovation

- Some research on broader policies and innovation
- Barbosa and Faria (2011) – look at product/process innovation 2002-2004 in 10 European countries
  - Product and labor market regulation affects innovation intensity negatively
  - More developed credit markets foster innovation
  - Strengthening of intellectual property rights does not seem to stimulate innovation
- Ciriaci et al. (2016) – Above a threshold of PMR, EPL is negative for R&D location.

Product market regulation in 2013 and threshold value for EPL impact (EU 28)

- PMR measure from OECD includes 1) state control; 2) barriers to trade and investment; 3) barriers to entrepreneurship



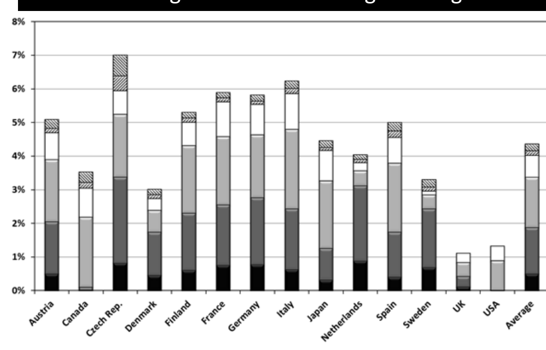
Allocative efficiency & regulation (AE)

- Can resources (capital and workers) move to their most productive use?
- Andrews & Cingano (2014) – controls for endogeneity of policies
  - Higher barriers to entry and creditor-friendly bankruptcy legislation tend to lower AE
  - Tighter employment protection lowers the efficiency of employment allocation
  - Stringent product & labor market regulation, bankruptcy legislation more disruptive to AE in innovative sectors

Cette, Lopez, Mairesse (2016)

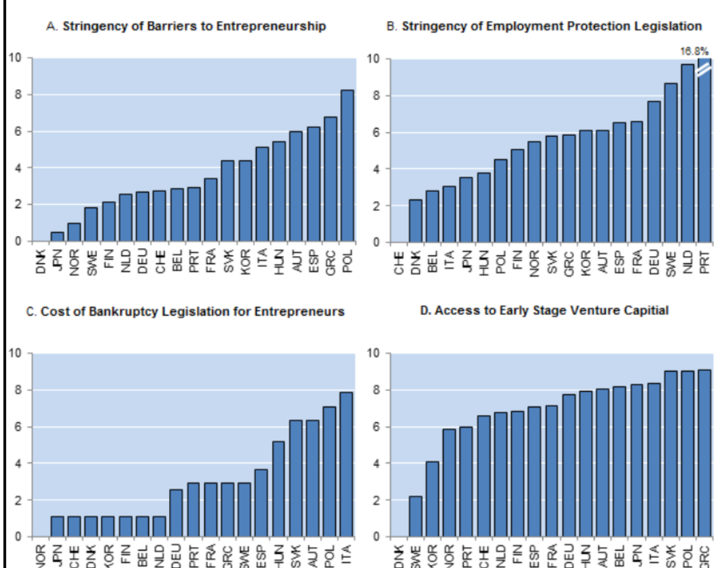
- Industry-country study for 14 OECD countries, 18 industries, both mfg and services
  - Impact of non-mfg regulation, harmonized tariffs and EPL on MFP is negative

Potential MFP gain from move to lightest regulation



Institutions and catch-up

- Andrews, Criscuolo, and Gal (2015) – study gap between firms on tech frontier and other firms in OECD countries
  - Productivity gaps between national frontier and global frontier firms smaller in countries where
    - education systems are of higher quality;
    - product market regulations are less cumbersome;
    - businesses and universities collaborate intensively;
    - markets for risk capital are more developed.
    - Mixed results on patent strength: lower gap in R&D intensive sectors, but not in more dynamic sectors
  - Country-industry results:
    - Lower PMR associated with higher MFP growth for firms in industries with high firm turnover rates,
    - Lower EPL associated with higher MFP growth for firms in industries with high job turnover rates,
    - Higher R&D collaboration between universities and firms is associated with higher MFP growth for laggard firms in K-intensive industries



Cross-country gains to aggregate labour productivity from reforms to best practice level of four policy variables that partly explain cross-country industry differences in the size of national frontier (NF) firms, relative to global frontier (GF) benchmark. Source: Andrews et al. (2015)

Thank you for listening

(a bit more on aggregate effects below)

Aggregation

- How does individual firm relationship aggregate up to macro-economy?
  - productivity gains in existing firms
  - exit and entry
- Aghion et al (2009); Gorodnichenko et al (2010)
  - Competition and entry encourages innovation unless the sector is very far behind
- Djankov (2010) survey – cross country
  - stronger entry regulation and/or higher entry costs associated with fewer new firms, greater existing firm size and growth, lower TFP, lower investment, and higher profits

Entry and exit

- Olley & Pakes, Haltiwanger & co-authors have developed decompositions that are useful
- Foster, Haltiwanger, and Syverson (2008) – US data
  - Distinguish between revenue and quantity, and include exit & entry
  - Revenue productivity understates contribution of entrants to real productivity growth because entrants generally have lower prices
  - Demand variation is a more important determinant of firm survival than efficiency in production (consistent with productivity impacts)

Future work?

- Full set of links between innovation, competition, exit/entry, and productivity growth not yet explored
- Bartelsman et al. (2010): Size-productivity more highly correlated within industry if regulation is "efficient"
  - Evidence on Eastern European convergence
  - Useful approach to the evaluation of regulatory effects without strong assumptions
- Similar analysis could assess the economy-wide innovation impacts

Interpretive framework

- Innovation-productivity regressions use revenue productivity data
  - Include coarse sectoral dummies
  - Relative within-sector price changes not accounted for
  - Quality change not generally accounted for
- In the case of innovative activity, omitting price change at the firm level can be helpful, as it allows estimation of the contribution of innovation to demand as well as efficiency
- Analysis of the implications of distinguishing productivity from revenue productivity
  - Based loosely on Griliches and Mairesse 1984

Conventional productivity equation

$$r_{it} = a_{it} + \alpha c_{it} + \beta l_{it} \qquad i = entity, t = time$$

r = log value added (sometimes just output)

c = log tangible capital

l = log labor input

a_{it} = TFP (total factor productivity)

Coefficients *α, β* measured as shares (growth accounting) or by regression (econometric)

R&D or innovation often added to this equation to measure productivity impacts

Revenue productivity

- Firm (enterprise) level: measure sales, value added, or revenue, the product of (relative) price and quantity, not quantity alone
- Equation in logarithms, so left hand side is sum of price and quantity

$$r_{it} \equiv \log R_{it} = \log P_{it} + \log Q_{it}$$

- Coefficients measure the sum of price and quantity impact from changes in capital, labor, and R&D or innovation

Revenue productivity

If firms have market power and idiosyncratic prices, we observe real revenue r, not output q:

$r = p+q$ (all in logs)

Add a CES demand equation: $q_{it} \sim \eta p_{it}$, $\eta<0$

Then the revenue productivity relationship is

$$r_{it} = \text{const} + \left(\frac{\eta+1}{\eta}\right)(a_{it} + \alpha c_{it} + \beta l_{it}) \sim \left(\frac{\eta+1}{\eta}\right) q_{it}$$

If imperfect competition ($\eta>-\infty$), revenue impact is dampened relative to output; if demand is inelastic ($0>\eta>-1$), revenue falls with increased output

Adding innovation

Add two terms involving knowledge stock:

process: γk_{it} in the production function, $\gamma>0$

product: φk_{it} in the demand function, $\varphi>0$

This yields the following revenue function:

$$r_{it} = C + \left(\frac{\eta+1}{\eta}\right)(a_{it} + \alpha c_{it} + \beta l_{it}) + \left(\frac{\gamma(\eta+1)-\varphi}{\eta}\right)k_{it}$$

Product improvement from k $(-\varphi/\eta)$ is always positive for revenue

Process improvement from k $(\gamma(\eta+1)/\eta)$ could be small or even negative

Implication for prices

Recall that $q_{it} = \eta p_{it} + \varphi k_{it}$

Then

$$p_{it} = \left(\frac{1}{\eta}\right)(a_{it} + \alpha c_{it} + \beta l_{it}) + \left(\frac{\gamma-\varphi}{\eta}\right)k_{it}$$

If demand elasticity is constant, price falls with innovation if $\gamma\text{-}\varphi > 0$ (recall $\eta<0$)

That is, if efficiency enhancement effect outweighs product improvement effect

Impact of innovation on price greater the more inelastic is demand, *c.p.*

Implication for employment

- Similar to that for output
- Short run profit maximization given ordinary and innovation capital yields labor demand as a function of capitals:

$$l_{it} \sim \left(\frac{\eta+1}{\eta(1-\beta)-\beta}\right)(a_{it}+\alpha c_{it})+\left(\frac{\gamma(\eta+1)-\varphi}{\eta(1-\beta)-\beta}\right)k_{it}$$

- Denominator is always negative =>
  - Process effect of *k* is negative for labor demand if demand is inelastic
  - Product effect of *k* always positive for labor demand

Econometrics (1)

Only some firms report R&D; use standard selection model:

Selection eq

$$RDI_i = \begin{cases} 1 & if \quad RDI_i = w_i\alpha + \varepsilon_i > \overline{c} \\ 0 & if \quad RDI_i = w_i\alpha + \varepsilon_i \leq \overline{c} \end{cases}$$

Conditional on doing R&D, we observe the level:

$$RI_i = \begin{cases} RD_i^* = z_i\beta + e_i & if \quad RDI_i = 1 \\ 0 & if \quad RDI_i = 0 \end{cases}$$

Assume joint normality => generalized tobit or Heckman selection model for estimation.

Econometrics (2)

Output of the KPF are various binary innovation indicators or the share of innovative sales. For example,

$$DI_i \sim \phi\left(RD_i^* \gamma + X_i \delta + u_i\right)$$

DI = Dummy for innovation (process, product, organizational)

Φ (.) = normal density

Why include the latent R&D variable *RD**?

1. Account for informal R&D effort that is often not reported
2. Instrument for errors in variables and simultaneity

Estimation is via multivariate probit

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Econometrics (3)

Production function:

$$y_i = \pi_1 k_i + \sum_j \pi_{2j} DI_{ij} + Z_i \varphi + v_i$$

y = log sales per employee

k = log capital stock per employee

DI are predicted probabilities of innovation from second step or predicted share of innovative sales (with logit transform)

Z includes size, age, industry, region, year, wave

Estimated by OLS

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