R&D, innovation, and productivity

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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)

<table>
<thead>
<tr>
<th></th>
<th>Italian firms 1995-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-innovator</td>
</tr>
<tr>
<td>Does not do R&amp;D</td>
<td>77.9%</td>
</tr>
<tr>
<td>Does R&amp;D</td>
<td>22.6%</td>
</tr>
</tbody>
</table>

• 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.

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

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
Productivity-innovation relationship in TFP levels

<table>
<thead>
<tr>
<th>Sample</th>
<th>Time period</th>
<th>Elasticity with respect to innov sales share</th>
<th>Process innovation dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilean mfg sector</td>
<td>1995-1998</td>
<td>0.18 (0.11)*</td>
<td></td>
</tr>
<tr>
<td>Chinese R&amp;D-doing mfg sector</td>
<td>1995-1999</td>
<td>0.035 (0.002)***</td>
<td></td>
</tr>
<tr>
<td>Dutch mfg sector</td>
<td>1994-1996</td>
<td>0.13 (0.03)***</td>
<td>-1.3 (0.5)***</td>
</tr>
<tr>
<td>Finnish mfg sector</td>
<td>1994-1996</td>
<td>0.09 (0.06)</td>
<td>-0.03 (0.06)</td>
</tr>
<tr>
<td>French mfg sector</td>
<td>1986-1990</td>
<td>0.07 (0.02)***</td>
<td></td>
</tr>
<tr>
<td>German K-intensive mfg sector</td>
<td>1998-2000</td>
<td>0.27 (0.10)***</td>
<td>-0.14 (0.07)***</td>
</tr>
<tr>
<td>Norwegian mfg sector</td>
<td>1995-1997</td>
<td>0.26 (0.06)***</td>
<td>0.01 (0.04)</td>
</tr>
<tr>
<td>Swedish K-intensive mfg sector</td>
<td>1998-2000</td>
<td>0.29 (0.08)***</td>
<td>-0.03 (0.12)</td>
</tr>
<tr>
<td>Swedish mfg sector</td>
<td>1994-1996</td>
<td>0.15 (0.04)***</td>
<td>-0.15 (0.04)***</td>
</tr>
<tr>
<td>Swedish mfg sector</td>
<td>1996-1998</td>
<td>0.12 (0.04)***</td>
<td>-0.07 (0.03)***</td>
</tr>
<tr>
<td>Swedish service sector</td>
<td>1996-1998</td>
<td>0.09 (0.05)*)</td>
<td>-0.07 (0.05)</td>
</tr>
</tbody>
</table>

Innovative sales share and process innovation included separately in the production function:

- 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

<table>
<thead>
<tr>
<th>Sample</th>
<th>Time period</th>
<th>Product innovation dummy</th>
<th>Process innovation dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentinian mfg sector</td>
<td>1992-2001</td>
<td>-0.22 (0.15)</td>
<td></td>
</tr>
<tr>
<td>Brazilian mfg sector</td>
<td>1998-2000</td>
<td>0.22 (0.04)**</td>
<td></td>
</tr>
<tr>
<td>Estonian mfg sector</td>
<td>1998-2000</td>
<td>0.17 (0.08)**</td>
<td>-0.03 (0.09)</td>
</tr>
<tr>
<td>Estonian mfg sector</td>
<td>2002-2004</td>
<td>0.03 (0.04)</td>
<td>0.18 (0.05)**</td>
</tr>
<tr>
<td>French mfg sector</td>
<td>1998-2002</td>
<td>0.14 (0.04)**</td>
<td>0.02 (0.05)</td>
</tr>
<tr>
<td>French mfg sector</td>
<td>2002-2004</td>
<td>0.13 (0.01)**</td>
<td>-0.02 (0.01)</td>
</tr>
<tr>
<td>French service sector</td>
<td>2002-2004</td>
<td>0.17 (0.03)**</td>
<td>-0.01 (0.01)</td>
</tr>
<tr>
<td>German mfg sector</td>
<td>1998-2000</td>
<td>-0.05 (0.03)</td>
<td>0.02 (0.05)</td>
</tr>
<tr>
<td>Italian mfg sector</td>
<td>1995-2003</td>
<td>0.69 (0.15)***</td>
<td>-0.43 (0.13)***</td>
</tr>
<tr>
<td>Italian mfg sector SMEs</td>
<td>1995-2003</td>
<td>0.60 (0.09)***</td>
<td>0.19 (0.27)</td>
</tr>
<tr>
<td>Mexican mfg sector</td>
<td>1998-2000</td>
<td>0.31 (0.09)**</td>
<td></td>
</tr>
<tr>
<td>Spanish mfg sector</td>
<td>2002-2004</td>
<td>0.16 (0.05)***</td>
<td></td>
</tr>
<tr>
<td>Spanish mfg sector</td>
<td>1998-2000</td>
<td>0.18 (0.03)***</td>
<td>-0.04 (0.04)</td>
</tr>
<tr>
<td>Swiss mfg sector</td>
<td>1998-2000</td>
<td>0.06 (0.02)**</td>
<td></td>
</tr>
<tr>
<td>UK mfg sector</td>
<td>1998-2000</td>
<td>0.06 (0.02)**</td>
<td>0.03 (0.04)</td>
</tr>
</tbody>
</table>

Product and process innovation dummies included separately in the production function:

<table>
<thead>
<tr>
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<th>Time period</th>
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<th>Process innovation dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>French mfg sector</td>
<td>1998-2000</td>
<td>0.06 (0.02)***</td>
<td>0.07 (0.03)**</td>
</tr>
<tr>
<td>Irish firms</td>
<td>2004-2008</td>
<td>0.45 (0.08)***</td>
<td>0.33 (0.08)**</td>
</tr>
</tbody>
</table>

Source: Peters et al. 2014

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# Productivity-innovation using dummies

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<tr>
<td>German mfg sector</td>
<td>2006-2008</td>
<td>0.04 (0.02)**</td>
<td></td>
</tr>
<tr>
<td>German mfg sector</td>
<td>2006-2008</td>
<td>0.21 (0.07)**</td>
<td>0.09 (0.05)**</td>
</tr>
<tr>
<td>German service sector</td>
<td>2006-2008</td>
<td>0.18 (0.22)</td>
<td></td>
</tr>
<tr>
<td>German service sector</td>
<td>2006-2008</td>
<td>0.16 (0.06)**</td>
<td></td>
</tr>
<tr>
<td>Irish mfg sector</td>
<td>2006-2008</td>
<td>0.51 (0.30)**</td>
<td></td>
</tr>
<tr>
<td>Irish mfg sector</td>
<td>2006-2008</td>
<td>0.19 (0.28)</td>
<td></td>
</tr>
<tr>
<td>Irish service sector</td>
<td>2006-2008</td>
<td>0.05 (0.02)**</td>
<td></td>
</tr>
<tr>
<td>UK mfg sector</td>
<td>2006-2008</td>
<td>0.07 (0.03)**</td>
<td></td>
</tr>
<tr>
<td>UK mfg sector</td>
<td>2006-2008</td>
<td>0.04 (0.02)*</td>
<td></td>
</tr>
</tbody>
</table>

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)*

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)

<table>
<thead>
<tr>
<th></th>
<th>Product innovation</th>
<th>Process innovation</th>
<th>New-to-market prod innov</th>
<th>New to market proc innov</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted prob. of innovation</td>
<td>0.003 (0.051)</td>
<td>-0.107 (0.056)</td>
<td>0.048 (0.060)</td>
<td>-0.282 (0.180)</td>
</tr>
<tr>
<td>Prob. Innov. &amp; formal IP</td>
<td>0.114 (0.055)</td>
<td>0.074 (0.056)</td>
<td>0.157 (0.075)</td>
<td>0.173 (0.216)</td>
</tr>
<tr>
<td>Prob. Innov. &amp; informal IP</td>
<td>0.022 (0.041)</td>
<td>-0.051 (0.051)</td>
<td>0.059 (0.054)</td>
<td>-0.138 (0.157)</td>
</tr>
<tr>
<td>Prob. Innov. &amp; both</td>
<td>0.136 (0.031)</td>
<td>0.128 (0.029)</td>
<td>0.158 (0.038)</td>
<td>0.291 (0.105)</td>
</tr>
</tbody>
</table>

Using R&D spending

Using innovation spending

- 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
  
  \[
  \text{Growth} = \text{industry productivity trend in old products} + \text{growth due to process innovation in old products} + \text{growth due to output growth of old products} + \text{growth due to product innovation (net of substitution away from old products)}
  \]

- 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 Pottelsberghje 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 Pottelsberghje 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
Institutions and catch-up

  - 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
  — 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
  - 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

\[ r_{it} = a_{it} + \alpha c_{it} + \beta l_{it} \quad i = entity, t = time \]

- \( r = \log \text{value added (sometimes just output)} \)
- \( c = \log \text{tangible capital} \)
- \( l = \log \text{labor input} \)
- \( a_{it} = \text{TFP (total factor productivity)} \)
- Coefficients \( \alpha, \beta \) 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
  \[ r_{it} = \log R_{it} = \log P_{it} + \log Q_{it} \]
- Coefficients measure the sum of price and quantity impact from changes in capital, labor, and R&D or innovation

If firms have market power and idiosyncratic prices, we observe real revenue \( r \), not output \( q \):
\[ r = p + q \quad \text{(all in logs)} \]
Add a CES demand equation: \( q_{it} \sim \eta p_{it}, \eta < 0 \)
Then the revenue productivity relationship is
\[ r_{it} = \text{const} + \left( \frac{\eta + 1}{\eta} \right) (\alpha_{it} + \alpha c_{it} + \beta l_{it}) \sim \left( \frac{\eta + 1}{\eta} \right) q_{it} \]
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: $\gamma k_{it}$ in the production function, $\gamma > 0$
- product: $\phi k_{it}$ in the demand function, $\phi > 0$

This yields the following revenue function:

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

Product improvement from $k(-\phi/\eta)$ is always positive for revenue.
Process improvement from $k(\gamma(\eta+1)/\eta)$ could be small or even negative.

Implication for prices

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

Then

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

If demand elasticity is constant, price falls with innovation if $\gamma - \phi > 0$ (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:

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

• 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

\[ RDI_i = \begin{cases} 
1 & \text{if } RDI_i = w_i \alpha + \epsilon_i > \bar{c} \\
0 & \text{if } RDI_i = w_i \alpha + \epsilon_i \leq \bar{c}
\end{cases} \]

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

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

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,

$$DI_i \sim \phi \left( R_i D^* + X_i \delta + u_i \right)$$

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

$\Phi(.) =$ 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

Econometrics (3)

Production function:

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

$y =$ 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