INNOVATION, PRODUCTIVITY, (AND GROWTH)

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Many papers looking at this link using data from the Community Innovation Survey and other similar surveys

My goal here:
- Provide a framework for interpreting results
- Draw some conclusions about how we might improve the data/analysis
- Thoughts on macro implications
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
- Entry of more efficient firms
- Entry of firms on technology frontier
- Exit of less efficient firms
Measuring innovation

- Large literature using R&D (capitalized) as a proxy 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.
  - Most surveys of the service sector find many innovating firms, few R&D-doers
- Now we have more direct measures – do they help?
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

• **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 info: Mairesse and Mohnen (2010)
Raw data

- Next slide – share of process and product innovators in selected sectors:
  - Manufacturing, telecommunications, computer services and software publishing, finance, and some technical professional services
  - As close as we can get to matching OECD coverage to US coverage
  - Suggests the difficulty in measuring innovation with a dummy
Share of firms with innovation new to the firm or market, 2006-2008

- Hungary
- Latvia
- Slovak Republic
- Poland
- Netherlands
- Bulgaria
- Norway
- Romania
- Lithuania
- United States
- Croatia
- Sweden
- Czech Republic
- Spain
- Austria
- Estonia
- France
- Italy
- Finland
- Belgium
- Germany
- Cyprus
- Portugal

Share of firms in innovative sectors (see text)
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 is problematic
- Present an alternative analysis - derived from Griliches and Mairesse 1984
Conventional productivity equation

\[ q_{it} = \alpha_i + \alpha c_{it} + \beta l_{it} \quad i = \text{entity}, t = \text{time} \]

\( q = \log \text{value added (sometimes just output)} \)
\( c = \log \text{tangible capital} \)
\( l = \log \text{labor input} \)
\( a_{it} = \text{TFP (total factor productivity)} \)

Coefficients \( \alpha, \beta \) measured as shares (growth accounting) or by regression (econometric)
Revenue productivity

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

$$r_{it} = \text{constant} + \frac{\eta + 1}{\eta} (a_{it} + \alpha c_{it} + \beta l_{it})$$

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

This yields the following revenue function:

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

Product improvement ($-\varphi/\eta$) always positive

Process improvement ($\gamma(\eta + 1)/\eta$) could be small or even negative
Implication for prices

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

Then

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

If demand elasticity is constant, price falls with innovation if \( \gamma - \varphi > \alpha \) (recall \( \eta < \alpha \))

That is, if efficiency enhancement effect outweighs product improvement effect

Impact of innovation on price greater the more inelastic is demand, c.p.
An example of price impact

- U.S. deflators for the computer hardware industry and the communications equipment industry are hedonic (account for quality change)
  - see next slide
- Deflate firm sales by these 2-digit deflators instead of one overall deflator
- Result: true productivity is substantially higher than revenue productivity, because of hedonic price declines in the computer/electronics sector
- Benefits of “Moore’s Law”
Hedonic Price Deflator for Computers

Shipments Deflators for U.S. Manufacturing
NBER Bartlesman-Gray Productivity Database

Index number

Year


Computers & electronics
Instruments & Comm. Equip.
Other manufacturing
Estimated R&D Elasticity – U.S. Manufacturing Firms

<table>
<thead>
<tr>
<th>Period</th>
<th>Revenue Dep. Var = Log Sales</th>
<th>Quantity Dep. Var = Log Sales deflated</th>
<th>Price Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-1980</td>
<td>-.003 (.025)</td>
<td>.102 (.035)</td>
<td>-0.099</td>
</tr>
<tr>
<td>1983-1989</td>
<td>.035 (.030)</td>
<td>.131 (.049)</td>
<td>-0.096</td>
</tr>
<tr>
<td>1992-1998</td>
<td>.118 (.031)</td>
<td>.283 (.041)</td>
<td>-0.165</td>
</tr>
</tbody>
</table>

GMM-system estimation with lag 3 & 4 instruments. Sample sizes: 7156, 6507, and 6457 observations

**Conclusion:** much of the R&D in computing hardware went to lower prices for consumers \((\gamma - \varphi > 0)\)
What do the data say?

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
- Data is usually cross-sectional, so simultaneity between R&D, innovation, and productivity
- Sequential model: R&D $\rightarrow$ innovation $\rightarrow$ productivity
CDM model

• Proposed originally by Crépon, Duguet and Mairesse (CDM, 1998)

• Relationship among
  • innovation input (mostly, but not limited to, R&D)
  • innovation output (process, product, organizational)
  • productivity levels (sometimes growth rates)

• Closer look at the black box of the innovation process at the firm level:
  • unpacks the relationship between innovation input and productivity by looking at the innovation output
The model parts

1. The determinants of R&D choice: whether to do it and how much to do.

2. Knowledge production function with innovation variables as outcomes as a function of predicted R&D intensity.

3. Production function including the predicted innovation outcomes to measure their contribution to the firm’s productivity.

Need bootstrap s.e.s if sequentially estimated.
Only some firms report R&D; use standard selection model:

Selection eq

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

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.
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)
\( \Phi (.) = \) 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:

\[ y_i = \pi_1 k_i + \sum_{j} \pi_{2j} DI_{ij} + Z_i \varphi + \nu_i \]

\( y = \) 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
CDM model applied to CIS data

- Estimated for 15+ countries
- Confirmed 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 summarize results for regressions of individual firm TFP 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>French Hi-tech mfg #</td>
<td>1998-2000</td>
<td>0.23 (0.15)*</td>
<td>0.06 (0.02)***</td>
</tr>
<tr>
<td>French Low-tech mfg #</td>
<td>1998-2000</td>
<td>0.05 (0.02)***</td>
<td>0.10 (0.04)***</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>Irish firms #</td>
<td>2004-2008</td>
<td>0.11 (0.02)***</td>
<td>0.33 (0.08)***</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>

Source: author’s summary from Appendix Table 1.

# 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
  • Elasticities range from 0.04 to 0.29 with a typical standard error of 0.03
  • K-intensive and hi-tech firms have higher elasticities (=> equalized rates of return)
• Coefficient of process innovation dummy usually insignificant or negative, suggesting either inelastic demand or (more likely) measurement error in the innovation variables
<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>1998-2000</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>1998-2000</td>
<td>0.08 (0.03)**</td>
<td></td>
</tr>
<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>French mfg sector</td>
<td>1998-2000</td>
<td>0.05 (0.09)</td>
<td>0.41 (0.12)**</td>
</tr>
<tr>
<td>French mfg sector</td>
<td>2002-2004</td>
<td>-0.08 (0.13)</td>
<td>0.45 (0.16)**</td>
</tr>
<tr>
<td>French service sector</td>
<td>2002-2004</td>
<td>0.27 (0.52)</td>
<td>0.27 (0.45)</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>Irish firms #</td>
<td>2004-2008</td>
<td>0.45 (0.08)**</td>
<td>0.33 (0.08)**</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>
TFP level results with dummies

- Product dummy supports innovation sales share result, although noisier.
- There is substantial correlation between product and process innovation, especially when they are instrumented by R&D and other firm characteristics.
- 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
Summary

- Elasticity wrt innovative sales center on (0.09, 0.13)
  - higher for high tech and knowledge-intensive
  - 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)
- TFP growth rates
  - Similar results, somewhat lower and noisier
Discussion

- Innovation dummies at the firm level may be too noisy a measure to be useful.
  - Share of sales due to new products is more informative.
  - What measure would be useful (and reportable) for process innovation?
- Further exploration with innovation investment (instead of R&D) is warranted
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