INNOVATION, PRODUCTIVITY, (AND GROWTH)

Bronwyn H. Hall
University of Maastricht and UC Berkeley

Innovation and productivity

- 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 manfacturing sector.
  - Most surveys of the service sector find many innovating firms, few R&D-doers
- Now we have more direct measures – do they help?

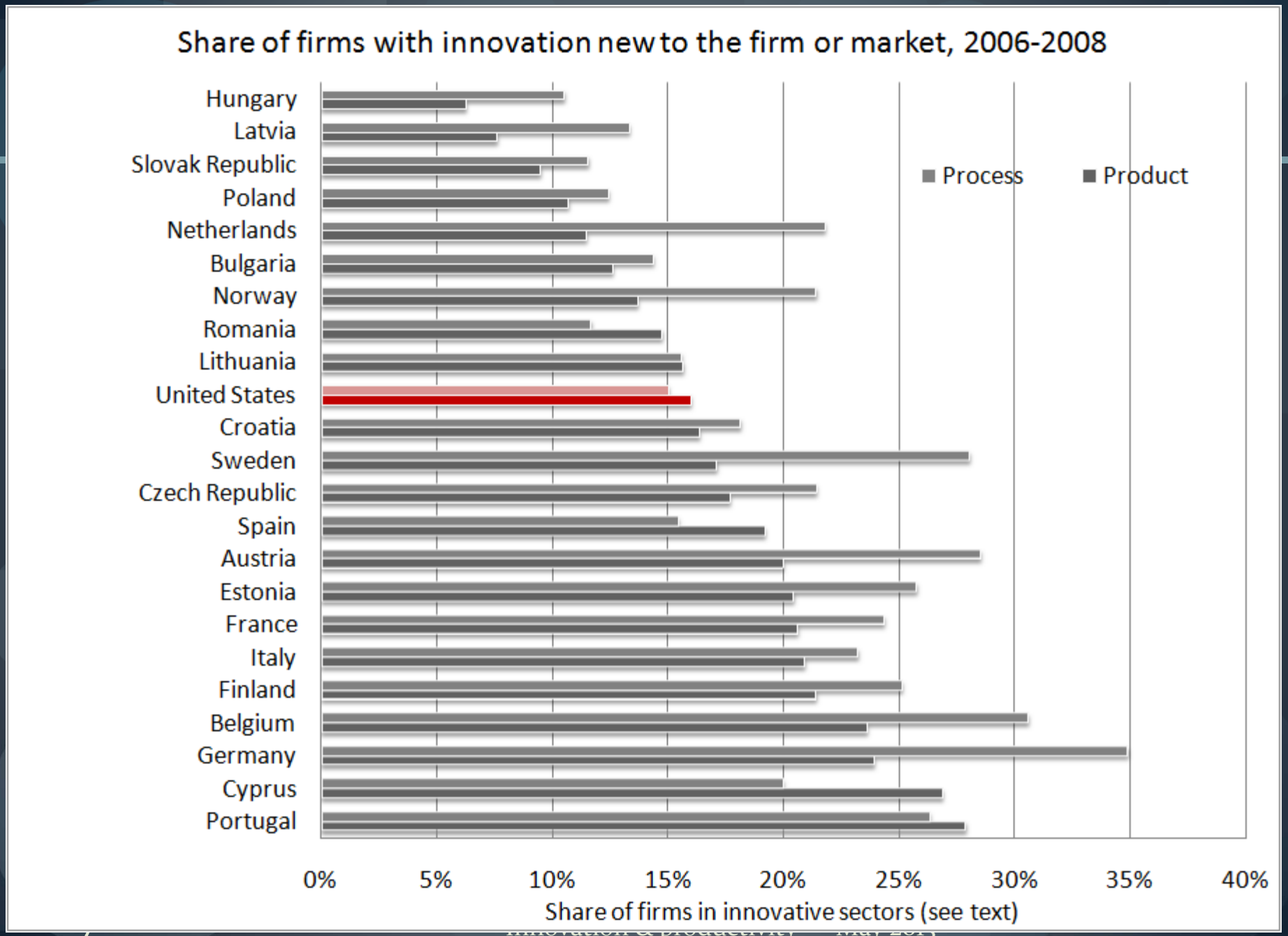
Innovation surveys contain.....

- 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
Process
Product
0%
5%
10%
15%
20%
25%
30%
35%
40%
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

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

q = 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)

Revenue productivity

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

$$r = p + q \qquad \text{(all in logs)}$$

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

This yields the following revenue function:

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

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 $\gamma - \varphi > 0$ (recall $\eta < 0$)

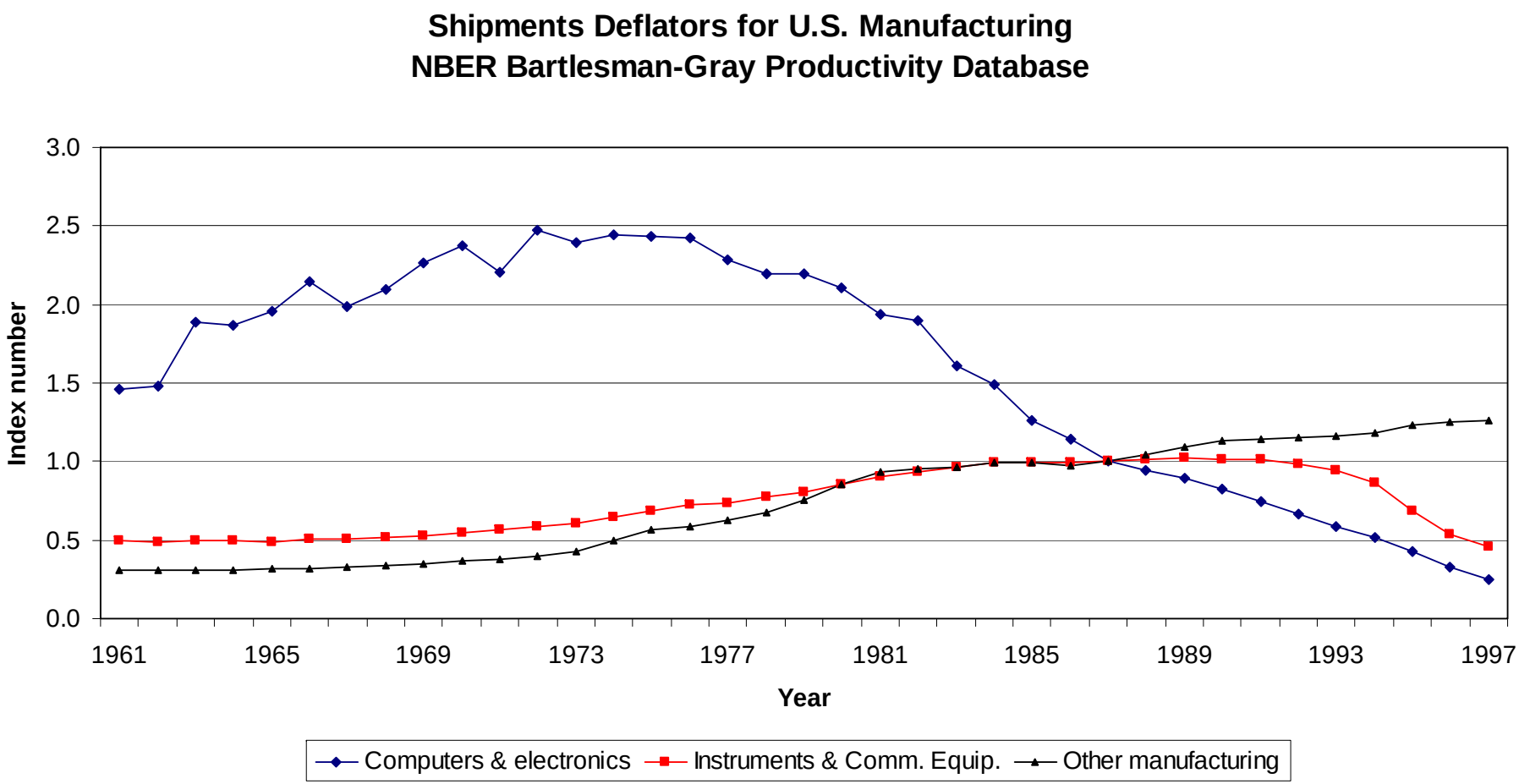
That is, if efficiency enhancement effect outweighs product improvement effect

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

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



Estimated R&D Elasticity – U.S. Manufacturing Firms

	Revenue	Quantity	Price
Period	Dep. Var = Log Sales	Dep. Var = Log Sales deflated	Difference
1974-1980	-.003 (.025)	.102 (.035)	-0.099
1983-1989	.035 (.030)	.131 (.049)	-0.096
1992-1998	.118 (.031)	.283 (.041)	-0.165

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 (γ-φ > 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→innovation→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.

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

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
- Source: Hall (2011), *Nordic Economic Policy Review*

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)***	
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)***
German K-intensive mfg sector	1998-2000	0.27 (0.10)***	-0.14 (0.07)**
Irish firms #	2004-2008	0.11 (0.02)***	0.33 (0.08)***
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)

Source: author's summary from Appendix Table 1.

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

TFP levels on innov sales share

- 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

Productivity-innovation using dummies

Sample	*Time period*	*Product innovation dummy*	*Process innovation dummy*
Argentinian mfg sector	1998-2000	-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	1998-2000	0.08 (0.03)**	
French mfg sector	1998-2000	0.06 (0.02)***	0.07 (0.03)**
French mfg sector	1998-2000	0.05 (0.09)	0.41 (0.12)***
French mfg sector	2002-2004	-0.08 (0.13)	0.45 (0.16)***
French service sector	2002-2004	0.27 (0.52)	0.27 (0.45)
German mfg sector	1998-2000	-0.05 (0.03)	0.02 (0.05)
Irish firms #	2004-2008	0.45 (0.08)***	0.33 (0.08)***
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)

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
- 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