Innovation, patents, and productivity in firms

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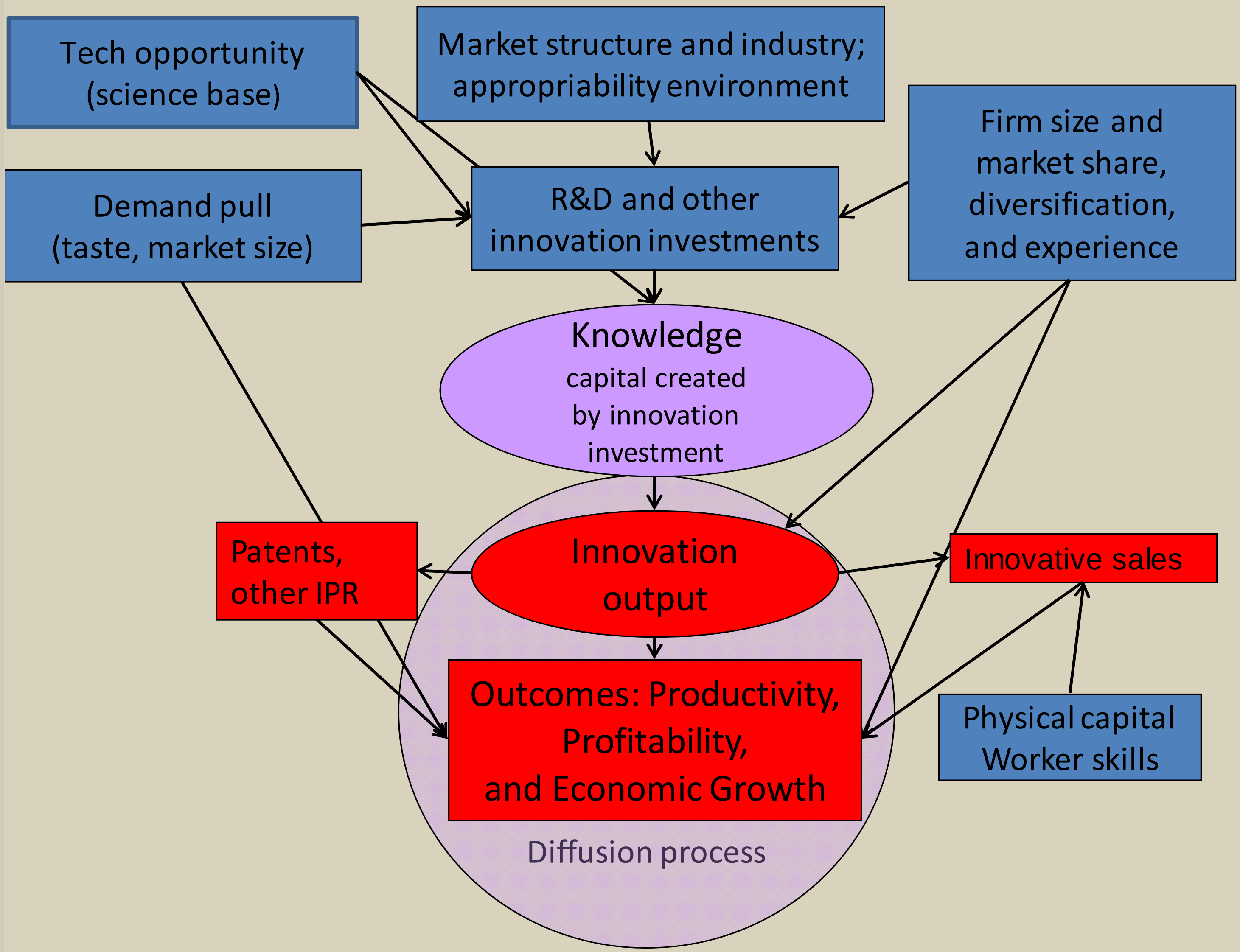
A big topic – begin with definitions

- Innovation: "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations." (*Oslo Manual,* OECD 2005, third edition, p. 46)
- Patents: the right to exclude others from practicing an invention for a limited amount of time, in return for disclosing the invention to the public.
- Productivity: the amount of output that can be obtained from a given set of inputs.
  - TFP = total factor productivity (controls for all inputs)
  - Labor productivity = output per person or person-hour

Stylized picture of innovation in the private sector



Focus of this presentation on the boxes in red

Introduction

- What are the mechanisms connecting innovation and patents?
  - Innovation based on novel invention encouraged by the patent system (limited monopoly)
  - => patents may serve as indicators of certain kinds of innovation
- 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 and firms on technology frontier
  - Exit of less efficient firms

Two questions

1. What is the relationship between innovation and total factor productivity (TFP)?
2. Does the patent system increase innovative activity?

This talk reviews what economists know about the answers to these two questions.

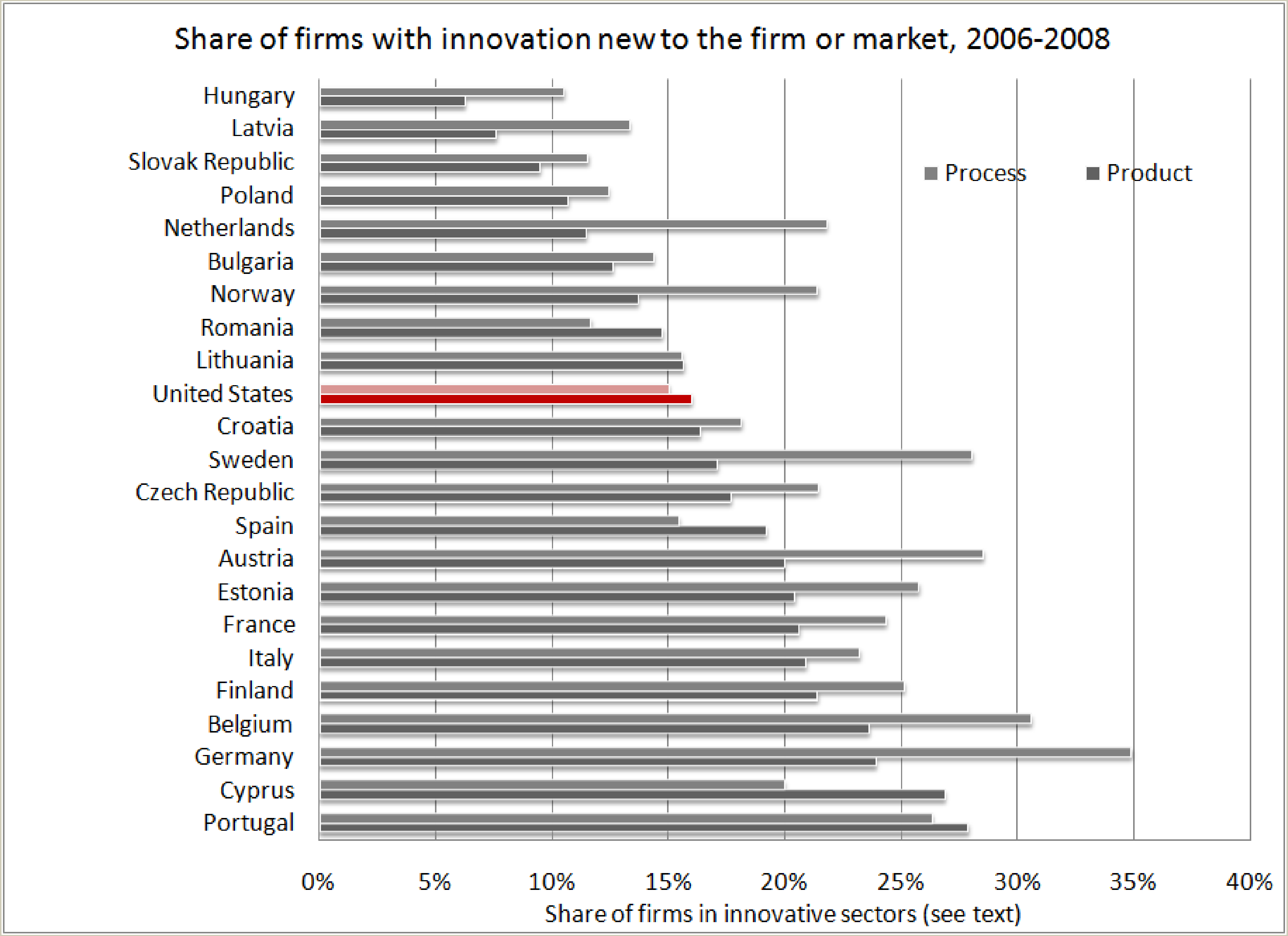
Note: topic is broad and omissions inevitable.

Problem 1: Measuring innovation

- Large literature using R&D (capital) 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 weaknesses, especially outside manfacturing sector.
- Now we have more direct measures – do they help?

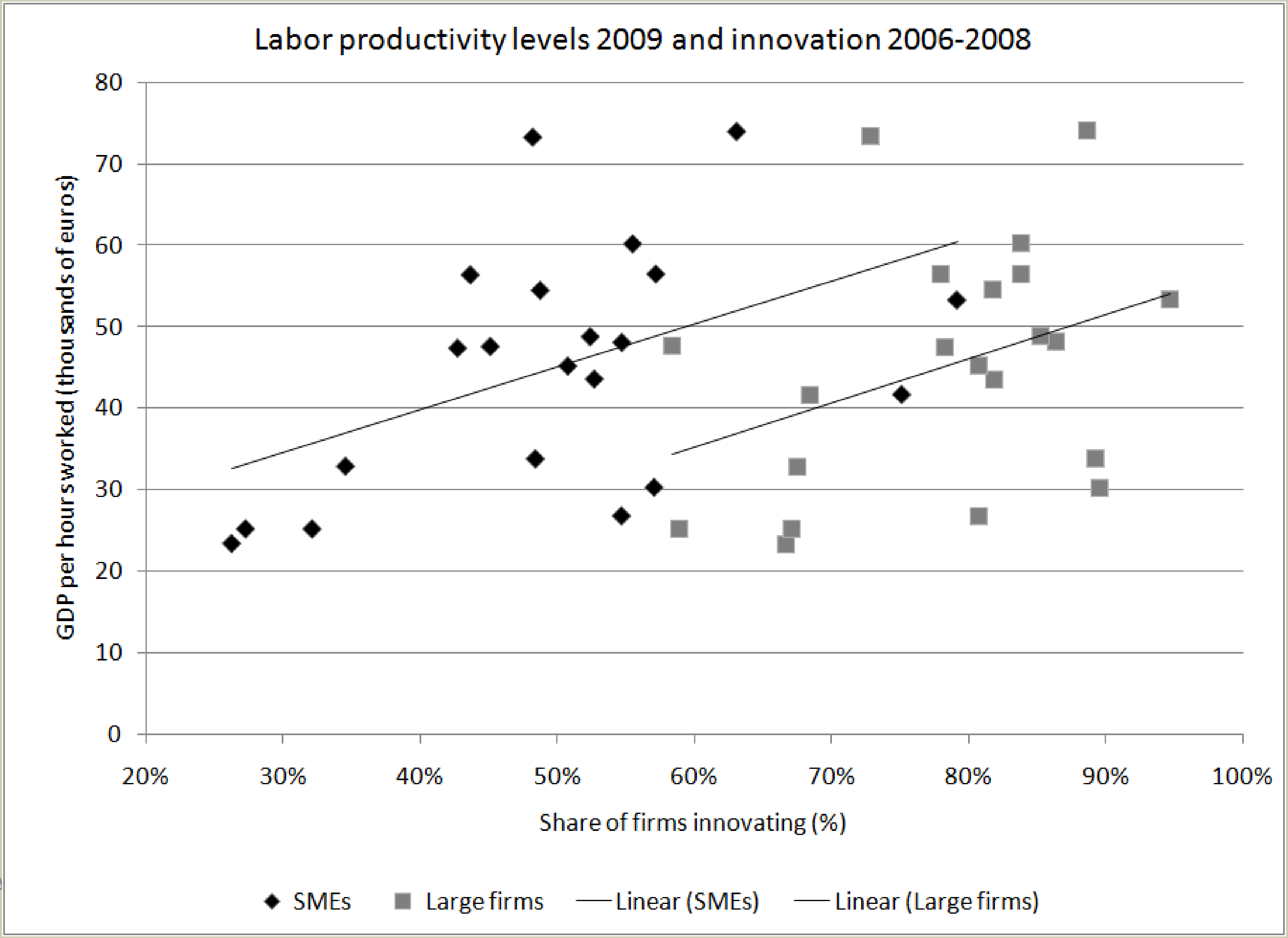
Innovation surveys contain…..

- Data on innovation:
  - Product or process new to firm/market (yes/no)
  - Share of sales during past 3 years from new products
  - Later surveys have expenditures on various kinds of innovation investments (answers can be missing or noisy)
- Data on productivity:
  - Often sales per worker (labor productivity)
  - Sometimes TFP (adjusted for changes in capital)
  - Issues arising from deflation and level of aggregation
- Next two figures add US data to graphs produced by OECD in *Measuring Innovation*



Where is Canada? Difficult to say exactly, but process ~ 17%; product ~18-25%

There is a rough relationship between share of innovating firms and aggregate labor productivity



Problem 2: Measuring TFP

- Two approaches:
  - Growth accounting – use shares going to labor, capital, etc. to estimate their productivity, subtract from output to get residual
  - Regression – output on labor, capital, materials, etc to obtain coefficient estimates; compute residual
- Measurement issues:
  - Quality adjustment for input variables – affects allocation of productivity gains
  - Usual data gives sales deflated by industry-level deflator, but innovative activity may affect firm output quality (and possibly market power)

Reviewing the evidence

- Focus here on micro evidence using CDM model (Crepon Duguet Mairesse 1998)
  - Some non-R&D firms innovate and some R&D firms do not innovate (during a 3-year period)
  - Data is usually cross-sectional, so simultaneity between R&D, innovation, and productivity
  - Model attempts to accommodate these features of the data

A brief overview of the CDM model

- Three blocks of equations
  1. equations explaining the “R&D” decision and the amount of R&D performed
  2. Innovation output equations (KPF) with R&D as input
  3. Productivity equation, in which innovation output indicators appear as explanatory variables

Estimation is recursive using single equation blocks, or simultaneous (no feedback)

What have we learned from applying the CDM model to CIS data?

- estimated for ~15-20 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, and R&D tends to predict productivity better
- Backup slides summarize results in tables.

TFP on innovative 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 market power – profits may increase, but revenue productivity does not (*see algebra in backup slides*)

TFP level results with dummies

- Product dummy supports innovation sales share result, although noisier.
- Process innovation:
  - With product innovation included, process innovation often negative or zero
  - Without product innovation, process innovation positive for productivity
- Substantial correlation between product and process innovation, especially when they are instrumented.
  - Possibly misleading results in some of the literature

Aggregation

- How does individual firm relationship aggregate up to macro-economy?
- Foster, Haltiwanger, and Syverson (2008) – distinguish revenue and quantity productivity, but include exit & entry effects
  - Revenue productivity tends to understate the contribution of entrants to productivity growth (because their prices are lower)
  - Demand variation is a more important determinant of firm survival than efficiency in production (consistent with productivity impacts)

Entry and exit

- Aghion et al. (2009); Gorodnichenko et al. (2010)
  - Competition and entry encourages innovation unless the sector is very far behind
- Djankov (2010) survey:
  - stronger entry regulation and/or higher entry costs are associated with fewer new firms, greater existing firm size and growth, lower TFP, less investment, and higher profits
- Bartelsman et al. (2010), and subsequent research:
  - Size-productivity more highly correlated within industry if regulation is "efficient"
  - Evidence on Eastern European convergence
- Full set of links between innovation, competition, entry, and productivity growth not yet explored.

Adding patents to the picture

- Do patents provide an incentive for innovative activity?
- Simple economic view:
  - Trade off limited-term right to exclude (monopoly) in return for incentive to innovate (and reveal the innovation)
    - Good for innovation
    - Bad for competition
- But……

Patent system as viewed by a "two-handed" economist

Effects on	Positive	Negative
Innovation	creates an incentive for R&D and innovation investments	impedes the combination of new ideas & inventions; raises transaction costs; inhibits cumulative invention
Competition	facilitates entry of new or small firms with limited assets; enables vertical disintegration	creates short-term "monopolies", which may become long-term in network industries

Patents may inhibit innovation

- The patent thicket – problem of contracting when many inputs are essential
  - High transaction costs lead to breakdown
  - Negotiations fail due to holdup potential
  - Discourages entry (increases sunk costs)
- Large numbers of patents in a given area, impossibility of adequate search
  - Ex post holdup by patentholder after costs are sunk
  - Given litigation costs, even “invalid” patents can be enforced
  - Increases the risk of innovation

Patents may help competition

- Increase dynamic competition by facilitating entry
  - Useful for securing financing in knowledge-intensive industries (where there are few tangible assets)
  - Downside – search for salvage value has led to PAE/NPE activity in the US, made profitable by holdup potential
- Can lead to competition-enhancing vertical disintegration by facilitating trade in technology (specialization; interface standardization)
  - Chemicals - Arora, Fosfuri, Gambardella
  - Semiconductor design firms – Hall & Ziedonis

When do patents encourage innovation?

- Theory
  - When one product = one patent
  - When one product = many patents? – not clear
  - When one invention builds on another? – not clear
- Empirical evidence
  - Historical investigations of changes in patent systems
  - Firm surveys
  - Cross country rehgressions

Historical evidence

- 19th century (variation across Europe/US)
  - Moser (2005) - little effect on overall innovation, but change in focus
  - Lerner (2001) - increase in patenting by foreigners but no increase by firms within country or in Britain (that is, no increase in innovation)
- 20th century
  - Park and Ginarte – 60 countries, 1960-90. Strength of IPR (including coverage of pharmaceuticals) positive for R&D in developed countries
  - Branstetter & Sakakibara – increasing patent scope in Japan (1988) did not increase R&D
  - Baldwin et al – Canadian innovation survey. Innovation causes patenting, but patenting does not seem to increase innovation

Survey evidence

- Industrial R&D managers in the US
  - Yale survey (Levin, Klevorick, Nelson, and Winter 1983)
  - Carnegie-Mellon survey (Cohen, Nelson, and Walsh 1994)
- EU innovation surveys
  - 1993 CIS for Norway, Germany, Luxembourg, the Netherlands, Belgium, Denmark, and Ireland – 2,849 R&D-performing firms (reported in Arundel 2001)

→ patents *not* the most important means of securing returns to innovation

- Only ~10% of respondents rate them first or second
- Exceptions: pharmaceuticals, specialty chemicals, medical instruments, auto parts

A useful taxonomy

- "discrete" product industries
  - food, textiles, chemicals including oil and plastics, pharmaceuticals, metals, and metal products
  - patents used to exclude, and sometimes for licensing; also to prevent litigation
- "complex" product technologies
  - machinery, computers, software, electrical equipment, electronic components, instruments, and transportation equipment
  - patents used in negotiations (cross licensing and other), and to prevent litigation
- In general, patents more important for appropriability in discrete product industries
- Strategic uses (cross licensing, negotiations) greater in "complex" product industries

Summary

1. What is the relationship between innovation and total factor productivity (TFP)?
   – Positive for the most part, but the available innovation measures are very noisy, so precise answers are not possible.
2. Does the patent system increase innovative activity?
   – The role of patents in encouraging innovation is ambiguous
     - Positive on balance in discrete product industries
     - Neutral or negative in complex product industries
     - BUT considerable heterogeneity within industry
   – Patents may actually help competition if they facilitate entry or leapfrogging

BACKUP SLIDES

Productivity

Conventional setup:

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

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 (as here)

Revenue productivity

If firms have market power and idiosyncratic prices, we observe real revenue r, not output q, with $r = p+q$ (all in logs)

Add demand: $q_{it} = \eta p_{it}$, $\eta<0$

Then the revenue productivity relationship is

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

Note that if demand is inelastic ($0>\eta>-1$), revenue falls with increased output, although profit may rise

Adding innovation

Add two terms:

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

This yields the following revenue function:

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

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

Process improvement ($\gamma(\eta+1)/\eta$) can be negative

Some papers estimating the CDM model and variants

- Crepon, Duguet, Mairesse 1998
- Duguet 2006
- Loof et al 2001
- Janz et al 2003
- Loof and Heshmati 2003
- Criscuolo and Haskel 2003
- Huergo and Jaumandreu 2004
- Benavente 2006
- Jefferson, Bai et al 2006
- Loof and Heshmati 2006
- Van Leeuwen and Klomp 2006
- Parisi et al 2006
- Griffith et al 2006
- Mairesse et al 2009
- Polder et al 2009
- Mairesse and Robin 2010
- Hall et al 2011

Level vs growth

- CDM is in terms of productivity *levels* primarily for data availability reasons
- It seems more natural to think of innovative activity as affecting productivity growth
- Some work along these lines, but matching across surveys usually leaves a very selected sample, possibly not representative

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.

Productivity-innovation relationship in TFP levels

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)

Productivity-innovation relationship in TFP growth rates

Sample	*Time period*	*Elasticity wrt Innov sales share*	*Product innovation dummy*	*Process innovation dummy*
Argentinian mfg sector	1992-2001		0.09 (0.08)	0.18 (0.08)**
Dutch mfg sector	1994-1998	0.009 (0.001)***		-1.2 (0.7)*
Dutch mfg sector	1996-1998	0.0002*** #		
French mfg sector	1986-1990		0.022 (0.004)***	
German mfg sector	2000-2003	0.04 (0.02)**		0.14 (0.08)* @
Italian mfg sector	1992-1997		0.12 (0.09)	0.04 (0.12)
Spanish mfg sector	1990-1998		0.015 (0.004)***	
Swedish mfg sector	1996-1998	0.07 (0.03)**		
Swedish service sector	1996-1998	0.08 (0.03)***		
UK mfg sector	1994-1996	-0.02 (0.02)		0.02 (0.01)*
UK mfg sector	1998-2000	0.07 (0.03)**		-0.04 (0.02)**

Source: author's summary from Appendix Table 1.

elasticity with respect to innovation expenditure per sales.

@ elasticity with respect to cost reduction per employee.