Prying open the "Black Box" of Innovation

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Prepared for the NABE teleconference "Preliminary Estimates of R&D's Role in GDP Growth"

October 20, 2006

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Today’s game plan

- Background and motivation for our research.
- Defining and measuring innovation.
- Examining the role of business R&D spending and other related activities.
- The importance of spillovers from academia.
- A theoretical model of product and process innovation.
- Empirical implementation.

Background and motivation

- Federal and state policy makers have become keenly interested in understanding the forces that affect innovation.
- Scarcity of tractable models to analyze impacts of various policy initiatives hampers this.
- Our work is a first attempt to model innovation as a function of multiple inputs, and link it to productivity growth.

What do we know about innovation?

- Key to growth in material living standards: output can (and does) grow faster than weighted growth in inputs.
- Why? Economists have spent 50 years trying to answer this question.
  - New ideas, infrastructure to turn these ideas into new products and processes. Easier to explain ex post than ex ante.

Business R&D spending: Important, but not the full story

- Until recently, most empirical studies of innovation have focused on business R&D spending.
- Cross-sectional studies: robust results, strong link between R&D and productivity.
- Time-series studies: R&D-productivity link weakens (and in some cases disappears altogether).
- Policymakers should worry about the inconclusive time-series results.

“New growth theory” and innovation

- Recognizes that innovation is the result of deliberate economic activity.
  - “Eureka moments” or serendipity cannot create innovation without accompanying innovation infrastructure.
- Offers little practical guidance on what such infrastructure consists of.
  - Recent “new growth” innovation papers focus on business R&D spending.

Importance of academic science

- Industrial innovation benefits from (and in some cases depends upon) basic discoveries made in academic or university settings.
- Recent economic studies demonstrate that transmission of such knowledge takes many forms:
  - Citations of academic journals in patents.
  - Migration of academics to industrial employment.
  - Business-university basic research partnerships.

Importance of academic science (2)

- Branstetter and Ogura (2005): from mid-80s to late-90s, citations to basic science in patents increased 13-fold, compared to doubling of patents and 40 percent increase in real business R&D spending.
  - Supports notion that knowledge spillovers from university research are a central complement to industrial R&D and, ultimately, innovation.

- Empirical evidence indicates academic-industrial links are strongest in hi-tech industries (e.g. biotech, semiconductors)

A multivariate model of innovation

- Gu and Tang (2003): Innovation as unobserved "latent variable" determined by four observable indicators.
  - Business R&D spending, patent approvals, equipment investment, skill level of the labor force.
- Patents and skilled labor are more important and reliable indicators of innovation than R&D spending.
- NONE of the four observable indicators on its own has a statistically significant link to productivity growth.

Expanding on Gu and Tang’s Approach

- Innovation is more than just new products
  - Traditional R&D-centric concept of innovation tends to equate innovation with new products and improvements to existing products.
  - Supply chain optimization, lean, 6-sigma are all examples of “process innovation” which need to be included in a full innovation model.
- Process innovation is often only marginally related to business R&D spending.
  - Manufacturing productivity growth has accelerated since 2001 despite a drop in R&D spending.

A multivariate model of product and process innovation

Product innovation	Process innovation
▪ Average U.S. private-sector R&D intensity (R&D as a percent of sales) ▪ Growth of R&D funds originating from the public sector. ▪ University-performed basic research or federally-funded university research. ▪ Industry employment of either science PhDs or former university research personnel. ▪ Degree of U.S. trade openness with the rest of the world.	▪ Investment In information technology. ▪ A measure of workforce quality, such as the percent of employees with a B.A. or higher. ▪ A measure of the relative cost of production between the United States and key trading partners. ▪ University-performed basic research or federally-funded university research. ▪ Industry employment of either science PhDs or former university research personnel.

Analytical Strategy

- To validate these indicators we first need a statistical "representative" of product and process innovation
- For process innovation the obvious candidate is multi-factor productivity (MFP) in manufacturing, which is the growth in output per combined unit of inputs that include capital, labor, energy, raw materials, and business services.
- Since MFP measures the growth in output that can not be accounted for by growth in inputs, one of its primary drivers must be process improvements that come in the form of a more efficient use of inputs.

Analytical Strategy (2)

- With regard to product innovation, utility patent approvals serve as a reasonable benchmark.
- The risk of reverse engineering creates incentives for manufacturers to protect many new products (as well as improvements to existing products) with patents.
- These data are very volatile and thus we chose a 4-year moving average to reveal underlying trends.

But Neither is Without Flaws

- Multi-factor productivity encompasses more than process innovation in that it is partially related to the business cycle.
- For various reasons, companies may chose to protect their product designs via trade secrets. Therefore, some product improvements will not be revealed by trends in utility patent approvals.
- But these appear to be the best variables for using ordinary least squares regression analysis to test the statistical relationship of our postulated indicators to product and process innovation.

The Results for Product Innovation

- Due to statistical problems, we had to remove two variables that have high correlations with others-public sector R&D and trade openness
- We found that the size of the science and engineering workforce, basic university R&D lagged six years, and manufacturing R&D as a percent of manufacturing sales comprise a statistically solid model of product innovation. These variables collectively account for 70 percent of the variation in trend patent growth.
- Given long-standing arguments on the importance of R&D, we removed the manufacturing R&D intensity variable from the equation and found that the statistical properties of the model deteriorated significantly.
- The results illustrate the return to university frontier science. The equation roughly suggests that a 10-percent increase in nominal dollar expenditures on basic university R&D generates a nearly 4.2 percent increase in a 4-year moving average of utility patents.

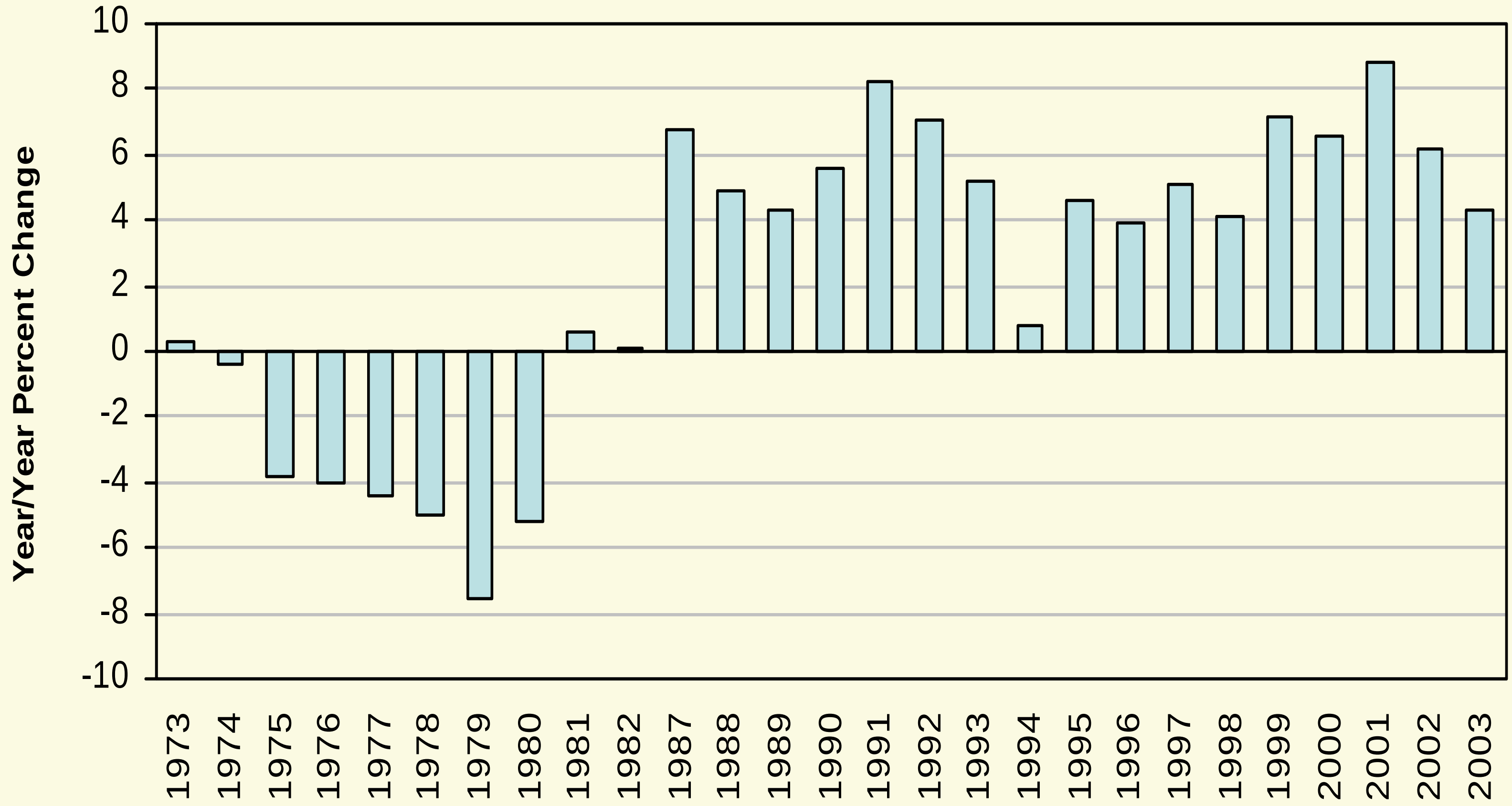
The Results for Process Innovation

- Our statistical work shows that basic university R&D and the science workforce also matter to process innovation.
- But two other variables tested quite positive in our process equation. Total economy-wide capital spending, both current and lagged 3 years, is of great importance to process innovation. This squares with other studies which show that lags of several years strengthen the relationship between capital spending and business productivity.
- Secondly, unit labor costs in manufacturing, lagged two years, is significant in our process equation. This cost variable, while not a complete measure of costs, appears to nicely proxy the competitive pressures that force organizational changes which stimulate productivity gains.
- Our model illustrates the return to key investments. A 10 percent increase in equipment and software investment is, at least over the short term, associated with a 2.4 percent increase in multi-factor productivity in manufacturing with a further increase of nearly 0.8 percent after 3 years. A 10 percent increase in university R&D would increase MFP by 1.9 percent five years hence.

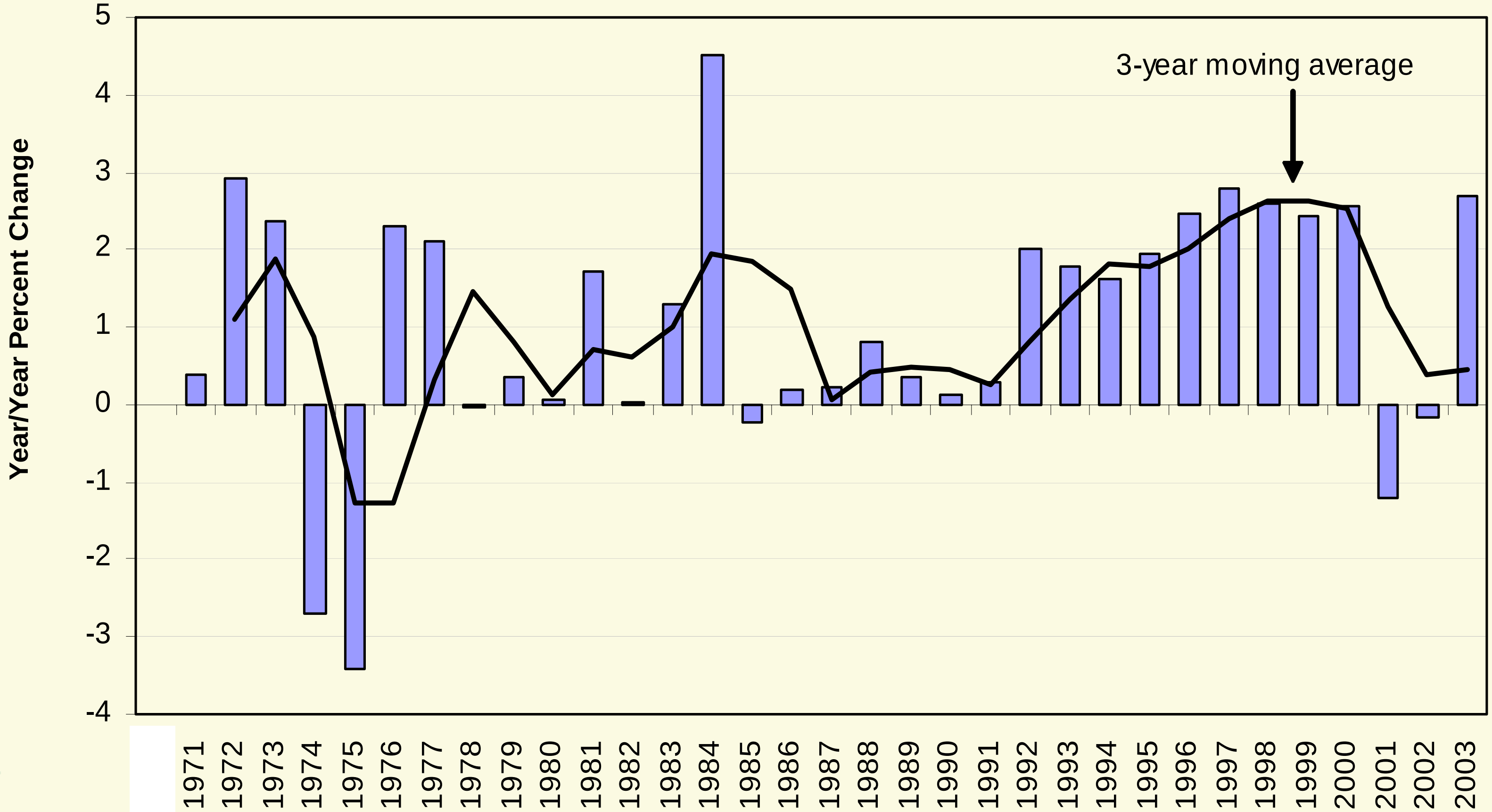
Creating Innovation Indicators

- We used our model results to create composite indicators of product and process innovation to help policy makers and corporate innovation strategists track these trends through time.
- Further, we used a simple statistical procedure (beta coefficients) to assess the relative importance of the explanatory variables for explaining the movement of these composite indicators.
- The strongest driver of the composite product innovation indicator is the science workforce variable but manufacturing R&D intensity is a close second. There is a somewhat smaller but significant contribution from basic university science.
- Current investment growth and basic university R&D are the key drivers of the process innovation indicator

The Product Innovation Indicator



The Process Innovation Indicator



Conclusions

- We believe that our empirical work provides a benchmark of the innovative performance of the U.S. manufacturing sector. This will help policy makers and corporate strategists to better understand the determinants of innovation.
- The drivers of innovation go far beyond business R&D spending. Capital investment, university basic research, science employment, and cost pressures all matter.
- So beyond stimulating R&D investment, policies that stimulate capital investment and open new foreign markets spur companies to improve business efficiency.
- And product innovation in addition to being catalyzed by R&D is a product of the science workforce in tandem with university basic research.
- Our research provides clear evidence of the importance of university R&D to both product and process innovation. We conclude that efforts to boost funding of university R&D as well as build and encourage university-industry linkages will pay off in tangible innovation benefits.
- Governments must look beyond the short term in developing innovation policy.

Future Research

- To the extent that data permit, our model structure and the resulting innovation indices could be used for cross-country or inter-industry comparisons of innovative capacity and performance.
- For the purposes of developing an innovation strategy, it will be useful to investigate the *types* of investment and university R&D that have the most impact on process innovation and to dig more deeply into *which* scientific and engineering disciplines contribute most to product innovation.
- We could-in a number of ways-advance our model structure. For example, we should consider the relationship between product and process innovation, a question that is ripe for serious consideration.

Questions/comments?

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