Measurement of Technological Change

“Patterns of Technological Activity: their Measurement and Interpretation”


in Paul Stoneman (ed.), Handbook of the Economics of Innovation and Technological Change. Blackwell, 14-51
Introduction

- Two sources of funds: business and government
- Business funding is larger than government and is spent in-house mainly on applied research and development activities
- Government funding is divided amongst basic research performed mainly in university-type institutions and technical support for the provision of other public goods
Introduction

- Improvement in the empirical understanding of sources and patterns of technical change
- More resources devoted to measurement of technological activities due to (1) growing demand from government and firms and (2) developments in information technology
- The article reviews
  - The nature of technology
  - The strengths and weaknesses of the major measures of technological activities- R&D and patenting
  - Other measures
  - The variations in technological activities across time, sector, firm and country
The Nature of Technology

- Complexity and cumulative learning
- Indigenous R&D
- The complexity means that codified knowledge is always an insufficient guide to practice
- Firms spend more on development activities than on research activities
- The best path to further improvements depends on tacit knowledge accumulated through experience and on-the-job training
- The accumulation of tacit knowledge is just as important in processes of imitation and innovation
- This is why imitation costs are on average as much as 70% of innovation costs
The Nature of Technology

- These characteristics have major implications for the measurement of technological activities
- R&D activities are a necessary complement to the absorption of outside technology
- Technology can not be described as easily transferable information, since it consists of embodied tacit knowledge
- There is feedback loops from diffusion to innovation and invention
- The consequence of the complexity of technology is its variety
- Four technological families: mechanical, chemical, electrical-electronic and software
The Major Measures of Technological Activity

Research and Development (R&D)

- Better at measuring science-based classes of technology (chemical and electrical-electronic) than in the production-based and information-based classes (mechanical and software)

- The limitations of R&D as a measure of inputs to technological activities:
  - It underestimates (mechanical) technological activities related to production
  - They capture only very imperfectly the development of technology in small firms where technology-producing activities often do not have a separate functional identity
  - It underestimate the development of (software) technology related to information processing because a proportion of such technology is developed outside R&D departments
  - It measures input and not output
The Major Measures of Technological Activity

Patenting activity

- An intermediate output of R&D activities
- Timing important - if it takes place early in the innovation process, it will be a poor measure of the output of development activities
- Variations across both sectors and countries in R&D ‘productivity’ as measured by patents granted per unit of R&D spent
- Three factors to explain:
  - The intersectoral differences in the imperfections of R&D measurement
  - The intersectoral differences in the relative importance of patenting in achieving its prime objective - acting as a barrier to imitation
  - Major differences amongst countries in procedures and criteria for granting patents
The Major Measures of Technological Activity

Patenting activity

- Other criticisms of patenting as an indicator of technological activities:
  - Patents differ greatly in their economic value
  - It is not a drawback that technical patent classes do not always fit tidily into one product or industry class—‘economies of scope’
  - Patents do measure satisfactorily advances in software technology
Other Measures of Technological Activity

- The “technological balance of payments”
- Data on national receipts and payments for technology
- Limitations:
  - Not very accurate
  - Financial flows result from licensing agreements extending back as far as 10 years are poor indicator of shifts in contemporary performance
  - It does not measure the main channels through which technology is transferred across international boundaries
    - The main channels for the transfer of disembodied technology are the imitation of product innovations through independent R&D and reverse engineering
Other Measures of Technological Activity

- **Exports of “high” and “medium” technology products**

- **Limitations:**
  - The distinction between high and medium technology products is based on their measured R&D intensity
    - This means that the technological importance of production-intensive (mechanical) and information-intensive (software) products are underestimated
  - The share of a country’s exports in high technology products is often taken as a positive performance measure
    - Any measure of the relative technology intensity of a country’s exports should consist of a weighted measure covering all exports
Other Measures of Technological Activity

- The direct measurement of innovations and their diffusion
  - The total costs of innovation, including R&D, design, testing, production engineering, start-up investment and marketing
  - The output of innovations by the identification of significant innovations and their sources
  - The diffusion of innovations

- However, these are labor-intensive and therefore costly and time-consuming

- How to classify the varying degrees of innovation from the incremental through the significant?
Other Measures of Technological Activity

- **Surveys of technical experts**
- **Technometrics**
  - It consists of measuring and comparing the various dimensions of technical performance of a product or production process
- **Patent citations**
  - “invisible colleges” & “spillovers” to be geographically localized
- **Scientific papers and citations**
  - Lagging indicators of real activity than R&D expenditures and the granting of patents
Trends in Technological Activities Over Time

- Long waves?
- Diminishing returns?
  - Rather a changing composition of technological activities
  - R&D laboratory versus large firms and science-based technologies
- Epoch-making innovations
  - Increase in technical performance in electronic computing coexisting with declining rates of increase in productivity
  - The development and diffusion of epoch-making innovations
  - Technological paradigms pervading all sectors of the economy
Sectors

- Sectors differ greatly in the sources, rates and directions of their technological activities
- Results so far:
  - In most industrially advanced countries, more than 75% of the production of new technology is concentrated in the same “core” sectors: machinery and instruments, electrical and electronic, chemicals and transport
  - In all “core” sectors, the main focus is on product innovations that get adopted in a wide range of user sectors
  - The main user sectors within manufacturing are textiles, food and paper and printing
  - There has been an increasing trend in the use of innovations in sector outside manufacturing: agriculture, mining, construction, utilities and services
  - Intersectoral differences in productivity growth are best explained by the use of technology as compared to its production
Firms

- The nature and determinants of firm’s technological activity vary according to their size, principal sector of activity and country of origin

- **Size**
  - R&D statistics overestimate contributions of large firms to the production of new technology, since R&D is itself a function of specialization and size
  - The proportion of technological activities based on R&D falls progressively as firms get smaller
  - There is a statistically significant increase in technological diversity with size but still inconclusive
  - Large firms predominate in R&D intensive sectors (chemical, electrical-electronic, transport equipment)
  - Small firms predominate in capital goods (machinery, process, instruments and metal products)
Firms

- **Multinational firms**
  - Globalization of large firms?
  - The world’s largest firms performed only 11% of their innovative activities outside their home country.
  - The degree of globalization of a company’s technological activities turns out not to be in direct proportion to the technological sophistication of its products.
  - The firms with the highest proportion of their technological activities outside their home countries are making more traditional products where local R&D is more likely to be necessary either to adapt products or to exploit local natural resources: food, drink, petroleum and mining, building materials.
  - Only firms in drugs perform an above-average share of their technological activities outside their home country.
Firms

- **Multi-technology large firms**
  - Large firms are invariably “multi-technology”- they are active in a variety of technological fields
  - Non-electrical machinery technologies are most widely developed by firms in different product groups
  - The firms’ patterns of technological specialization are both highly stable over time and highly differentiated according to their principal products
Countries

- When measured through US patenting or business-funded R&D in OECD countries, more than 95% of the world’s technological activities are concentrated in 11 countries: Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Sweden, Switzerland, UK, USA.
- The recent explosive growth of US patenting by Taiwan and South Korea suggests they will do so in the next years.
- The volume of investment in technology has emerged as a statistically significant variable in explaining differences in growth and trade performance amongst the OECD countries.
- Amongst these countries, the development of technological activities has been very uneven over the past 25 years.
Countries

- Behind these aggregate trends are important differences amongst countries in sectors of relative strength and weakness
- Most countries differ in their fields of technological specialization
- Over time, patterns of specialization are stable and there is some evidence that they are becoming even more marked
- These country and sector differences are often reflected in the technological performance of nationally-based large firms
Countries

- There are major differences amongst countries in defense R&D expenditures as a proportion of GDP, the highest being that in the US, UK and France and the lowest in Japan.
- The overall trend since the 1960s has been downward in most countries.
- Most of these expenditures are concentrated in firms in the aerospace and electronic sectors.
Conclusions

- Three important challenges
  - The measurement of the development of software technology is inadequate
  - The measurement of technological accumulation in developing countries is unsatisfactory
  - There is still too much “theory without numbers” and “numbers without theory”