What Can Policy-Makers Learn from Science Policy and Innovation Studies?

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Introduction

Structure

- Nature of field
- What have we learned in 50 years?
- 20 major advances in understanding
- Impact?
- Where next?
- Some concluding questions

Scope of field

“Economic, policy, management and organisational studies of science, technology and innovation (STI) with a view to providing useful inputs to decision-makers concerned with policies for and the management of STI.”

Primary focus = policy/mngt issues rather than theory

Research multi/inter-disciplinary – ‘Mode 2’

Grown from a dozen or so researchers in 1950s to several thousand today

Scope of field

Terminology changed over time

- Science/research policy, eng/R&D management
- S&T policy, technology & innovation management
- Neo-Schumpeterian/evol'y economics, innovation studies

'Science policy and innovation studies'

- Policy – science/research, technology, innovation
- Economics – science, technology, innovation
- Management – R&D, technology, innovation, knowledge
- Org'l studies – innovation, RBV of firm, org'l learning
- Sociology – e.g. diffusion of technology & innovation (but excluding 'science and technology studies'/STS)
- History of technology and innovation, econ/bus history
- Psychology – org psychology, psychology of creativity etc.

What have we learned?

Field now ~50 years old

What have we learned about the interaction between science, technology and innovation, and the nature of the innovation process?

What have been the key developments in our understanding?

How do these help us with improving policies for, and the management of, STI?

Previous reviews

Reviews of literature in books, review articles

But most based on

- subjective assessment
- limited aspect/perspective

Tried to adopt

- rigorous approach to identifying main contributions
- global perspective on entire field of sc policy & innovation studies

Identified 20 key advances in our knowledge

Methodology

Search for high-impact publications

- No obvious measure of impact on policy/practice
- Use HCPs as indicator of high academic impact, then subjectively assess impact on policy/practice
- Assumes most highly cited = most influential
- Also various problems and biases with *SSCI*

Starting point

- List of ~600 leading STI policy authors
- Surveyed ~80 journals
- Key word search

Identified ~200 publications with >250 citations

From these, synthesised 20 major advances

1. From individual entrepreneur to corporate innovators

Schumpeter (1934, 1939, 1942)

- One of few economists in early 20th C to recognise importance of innovation
- Innovation central in competition between firms
- Distinction between ‘invention’ and ‘innovation’
- ‘Schumpeter Mark I’
  - stressed central role of individual entrepreneur
- ‘Schumpeter Mark II’
  - gave increasing importance to collective innovative activities of large firms and in-house R&D
  - reflected changes in US industry in mid-20th C
- But still examples of Schumpeter Mark I (especially in IT)

2. From *laissez faire* to government intervention

Pre-WWII – limited involvement of govt in R&D & innovation, except in agriculture & medicine

WWII – Manhattan project, radar, cryptography, etc.

Post-WWII – major R&D programmes in defence, nuclear energy, space, health etc.

Based on belief in 'linear model' of innovation (Bush, 1945)

Basic res → Applied res → Tech devlpt → Innovation

Simple, clear (and convenient!) model

1950-60s – Govt emphasis on supply-side policies

- Public investment in R&D
- Training of QSEs

2. From *laissez faire* to government intervention

Economic justification for govt intervention in STI based on 'market failure'

Nelson (1959), Arrow (1962)

- Scientific knowledge a 'public good' – i.e.
  - 'non-rival'
  - 'non-excludable'
- Because they can't appropriate all the benefits from their investment, private firms tend to under-invest in R&D
- To achieve socially optimal level of investment in S&T, govt ∴ needs to fund R&D
- Public funding thus expands pool of economically useful knowledge

3. From 2 factors of prod'n to 3

Solow (1957)

- Econ growth not just ∵ changes in labour & capital
- A large 'residual' – attributed to tech change

Griliches (1957, 1958)

- High rates of return to R&D
- Social rate of return > private rate of return

Other important contributions by

- economists, e.g. Mansfield (1961, 1968), Schmookler (1966), Scherer (1965, 1970)
- economic historians, e.g. Gerschenkron (1962), David (1975), Rosenberg (1976)
- Freeman and SPRU colleagues
  - *The Economics of Industrial Innovation* (1974 + later editions)
  - 'Long waves' and economic development (1982)

4. From single division to multi-divisional efforts

Burns & Stalker (1961), *The Mngt of Innovation*

- Tech innovation influenced by different forms of org'n (e.g. mechanistic VS organic) with associated communication patterns
- Successful innovation requires integration of R&D with knowledge of market etc. – often hindered by internal divisions in the firm

Zaltman et al. (1973), *Innovations and Organisation*

Allen (1977), *Managing the Flow of Technology*

- Importance of communication flows
- Certain organisational structures enhance innovation

5. From technology adoption to innovation diffusion

Adoption of technology not just a single point event but a gradual process of diffusion

Coleman et al. (1957, 1966)

- individ's/org'ns respond to innov'n opportunities in different ways
  ➔ 'social contagion' model of diffusion

Rogers (1962 + later editions), *Diffusion of Innovations*

- diffusion of tech'y & innovation often follows logistic 'S-curve'
  - slow diffusion, rapid growth, growing saturation, then slow-down
- different categories of innovators
  - early adopters, early majority, late majority, laggards

Vernon (1966)

- four-stage model of the product cycle
  - new goods (i.e. innovations) generally developed 1st in industrialised countries, then diffused to LDCs as product matures

Model later formalised by Krugman (1979)

6. From sc push to demand pull

Science-push model – Bush (1945)

- Provided rationale for govt funding
- Favoured by scientists

Demand-pull model – changed market demand 'calls forth' innovation

Mkt demand ➔ App res ➔ Tech devlpt ➔ Innovation

- Often attributed to Schmookler (1966)
- Model picked up by e.g. Myers and Marquis (1969)
  - Study of >550 innovations in 5 industries
  - "Recognition of demand is a more frequent factor in innovation than recognition of technical potential"

2 models have very different policy implications, so various empirical studies to investigate

Science push VS demand pull

- Project Hindsight (1967) – DoD funded
  - Study of 20 military innovations
  - Critical research events primarily ‘technology’ rather than ‘science'
  - 95% of critical research events directed towards a DoD need

    ➔ Demand pull more important
  - BUT arbitrary cut-off point of 20 years
- TRACES (1968) – NSF funded
  - Study of 5 civilian innovations
  - Much longer time-period (100+ years)
  - 70% of critical research events ‘non-mission-oriented’

    ➔ Science push more important
- Battelle (1973) – NSF funded
  - Study of ~10 civilian innovations
  - ‘Recognition of technical opportunity’ important in 89% of decisive events, cf. 69% for ‘recognition of need’

Science push VS demand pull

- Comroe & Dripps (1976) – NIH funded
  - Key research underpinning advances in cardiovascular medicine
  - 62% of the research ‘basic’ – pays off “twice as handsomely”
- Langrish et al., *Wealth from Knowledge* (1972*)*
  - Study of 84 innovations
  - Innovation “must involve synthesis of some kind of need with some kind of technical possibility”
  - Rejected simple linear models – “the sources of innovation are multiple”
- Mowery & Rosenberg (1979) review
  - Innovation an “iterative process, in which *both* demand and supply forces are responded to”
  - i.e. both demand and supply side influences crucial to understanding the innovation process

7. From single factor to multifactor explanations of innovation

Early studies – focus on ***successful*** innovations

Project SAPPHO (Rothwell et al., 1974)

- 43 matched pairs of successful & unsuccessful innovations
- Most important factor = 'user needs understood'
- Other significant factors include
  - attention to marketing
  - support of senior 'product champion'
  - size of project team
  - coordination of R&D, production & marketing
  - good communication with ext sc'ic community
- Success not greatly affected by
  - R&D organisation, incentives, academic qualifications of staff, size of firm, no. of QSEs, project planning, growth rate of firm

Subsequent work on how best to manage & exploit innovation

- e.g. Hayes & Wheelwright (1984), Abernathy & Clark (1985), Teece (1986), Womack et al. (1990), Clark & Fujimoto (1991), Utterback (1994), Christensen (1997)

8. From a static to a dynamic model of innovation

Abernathy & Utterback (1975 & 1978) – dynamic model of product & process innovation

- Initial period dominated by radical product innovation
- Attracts new entrants ➔ several competing designs
- Process innovations then become more important
- Emergence of a dominant design (e.g. QWERTY typewriter, Model T Ford, Hoover, Boeing 747, IBM PC)

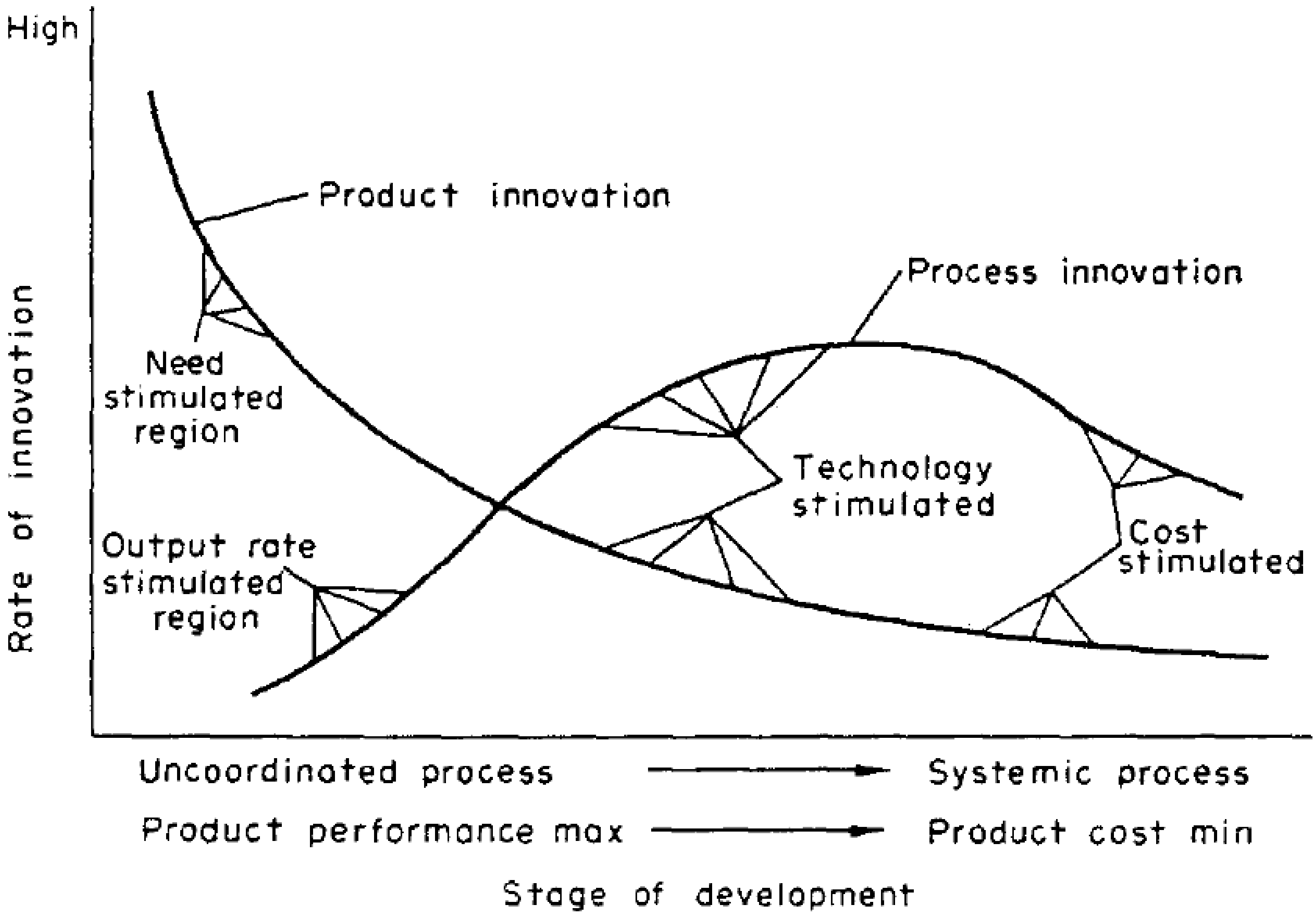


FIG. 1. *Innovation and stage of development.*

8. From a static to a dynamic model of innovation

Barras (1986 & 1990) – innovation in services follows ‘reverse product cycle’?

- Cycle starts with process improvements to increase efficiency of delivery of existing services – larger firms likely to dominate
- Moves on to process innovations which improve service quality
- Leads to product innovations through generation of new types of services – scope for small entrepreneurial firms to generate radical innovations

9. From the linear model to the interactive ‘chain-link’ model

Kline and Rosenberg (1986)

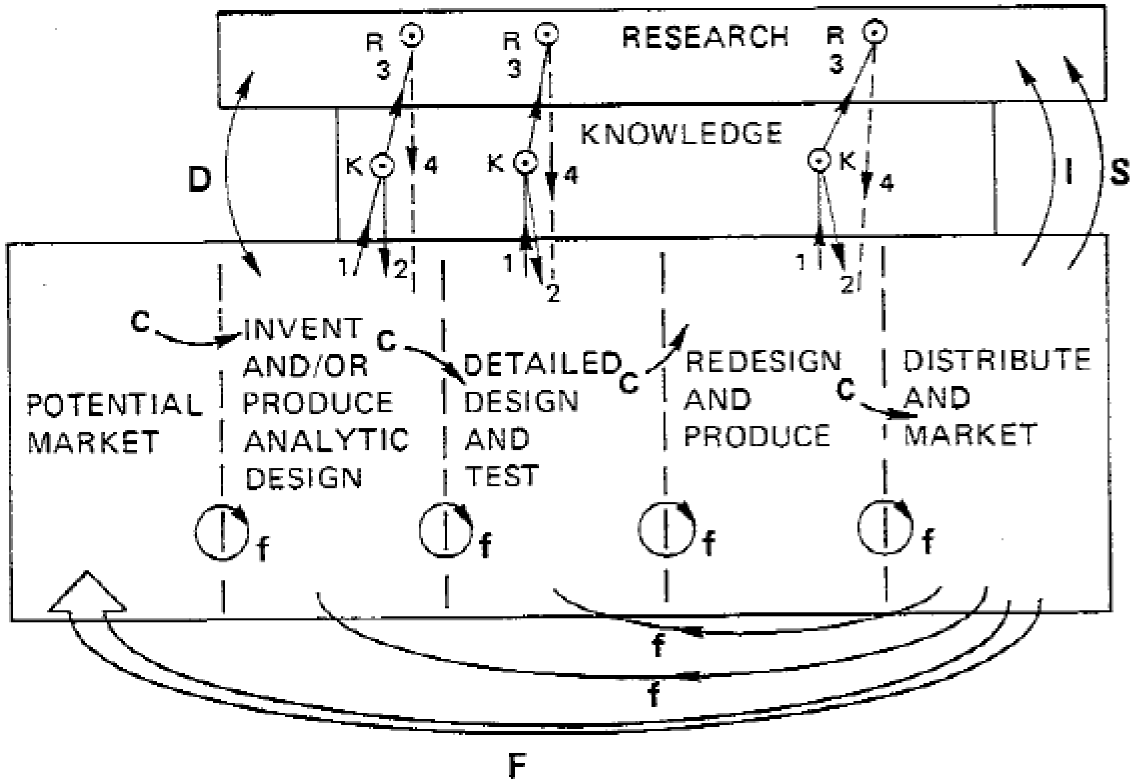


FIGURE 3 Chain-linked model showing flow paths of information and cooperation. Symbols on arrows: **C** = central-chain-of-innovation; **f** = feedback loops; **F** = particularly important feedback.

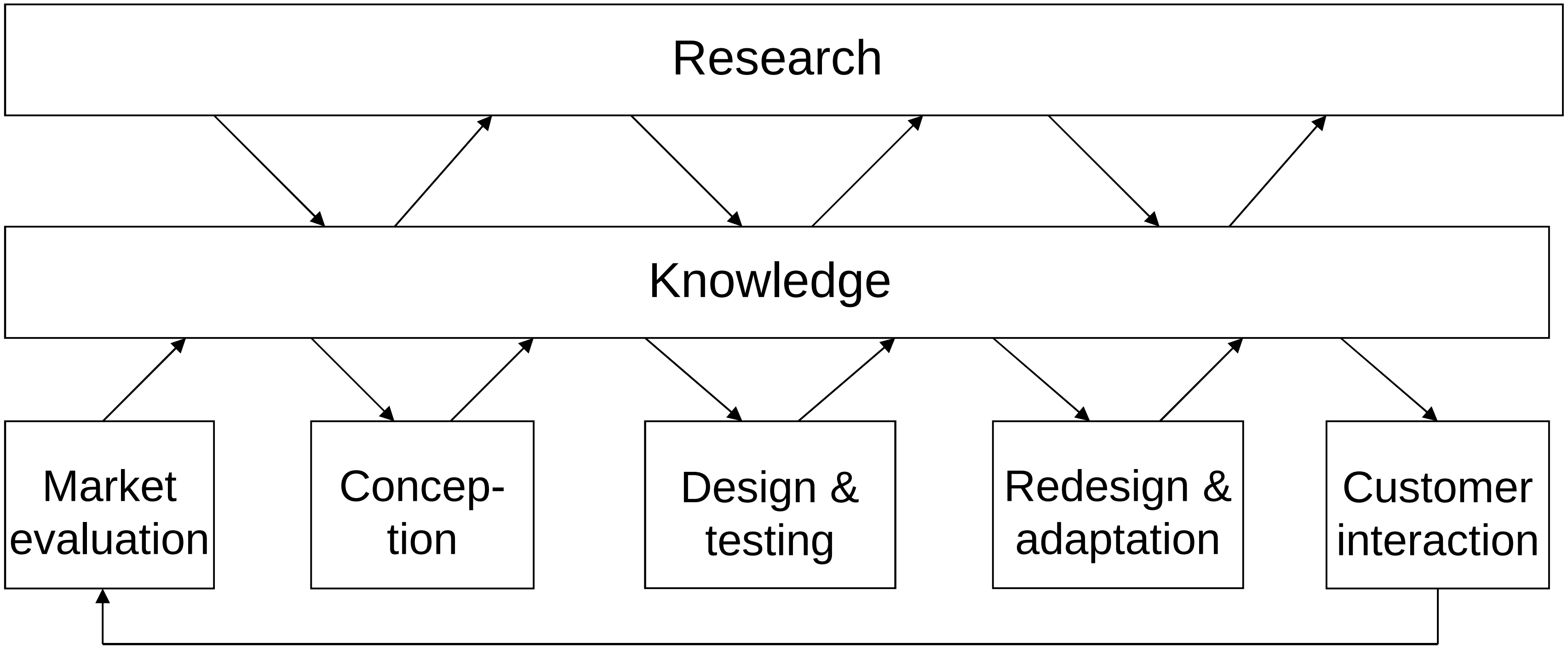
K–R: Links through knowledge to research and return paths. If problem solved at node K, link 3 to R not activated. Return from research (link 4) is problematic—therefore dashed line.

D: Direct link to and from research from problems in invention and design.

I: Support of scientific research by instruments, machines, tools, and procedures of technology.

S: Support of research in sciences underlying product area to gain information directly and by monitoring outside work. The information obtained may apply anywhere along the chain.

9. From the linear model to the interactive 'chain-link' model



Adapted from Kline & Rosenberg (1986)

A better representation of (complex) reality

But harder to use for policy/mngt purposes

STI researchers keep 'slaying' ***the*** linear model

But what happened to the other linear model?

10. From one innovation process to several sector-specific types

From earlier empirical studies, clear that sources & nature of innovation process vary with sector

Pavitt (1984) – analysed sectoral patterns

- SPRU database of ~2000 innovations
- Taxonomy of sectors
  - supplier-dominated
  - scale-intensive
  - specialised equipment suppliers
  - science-based
- Taxonomy resolves some earlier differences in empirical findings re
  - S&T push VS demand pull
  - product VS process innovation
  - relationship between firm size and innovation

Recent work shows this sectoral approach too static

11. From neo-classical to evolutionary economics

Nelson & Winter (1977)

- ‘In search of a useful theory of innovation’
- Existing economic literature fundamentally flawed

Nelson & Winter (1982), *An Evolutionary Theory of Economic Change*

- Tech change and innovation central – generate ‘variation’ in form of new products, services etc.
- Firms compete with these products/services – market provides ‘selection’ mechanism
- Products/services strongly influenced by ‘routines’ within firms – provide ‘self-replication’ mechanism
- Analogy with biological evolution and ‘survival of the fittest’
- Single most cited publication in field (Rogers – several eds)
- Cited by most social scientists apart from economists!

12. From old to new growth theory

Solow (1956) – neo-classical economic growth theory

- Technology treated as exogenous

David (1985), Katz and Shapiro (1986)

- Technology adoption ➔ network externalities

Romer (1986, 1990) – ‘New/endogenous growth theory’

- Neo-classical econ’s – can’t explain rate of growth – depends on exogenous factors e.g. rate of savings, rate of tech change
- Human capital and new technologies crucial – latter can generate ‘increasing returns’ (Arthur, 1989)
- R&D can create important ‘spillovers’ (Jaffe, 1986)
- Investment in education & R&D can boost growth, as can other incentives to innovate (e.g. patents)

  ➔ investment in ‘intangibles’ cf. previous emphasis on investment in ‘tangibles’ (e.g. capital goods)

Further developed by Grossman & Helpman (1991) and Aghion & Howitt (1992, 1998)

13. From the optimising firm to resource-based view of the firm

Neo-classical economists

- Firm = an optimising organisation, with perfect information & rationality

Resource-based view of firm

- e.g. Wernerfelt (1984), Grant (1991, 1996)
- Firm = a collection of resources (human, physical, etc.)
  - e.g. brand names, tech knowledge, equipment, skilled personnel, trade contacts, efficient procedures, capital
- Built on earlier work by Coase (1937) and Penrose (1959)

13. From the optimising firm to the resource-based view of the firm

Subsequent work on e.g.

- knowledge & competence as strategic assets (Winter, 1987)
- absorptive capacity (Cohen & Levinthal, 1990) (see below)
- core competences (Prahalad & Hamel, 1990)
- the learning organisation (Senge, 1990)
- organisational learning & ‘communities of practice’ (Brown & Duguid, 1991)
- learning ‘myopia’ (Levinthal & March, 1993)
- core capabilities & rigidities (Leonard-Barton, 1992)
- dynamic capabilities (Teece et al., 1997; Eisenhardt & Martin, 2000; Zollo & Winter, 2002))
- social & intellectual capital (Nahapiet & Ghoshal, 1998)

14. From individual actors to systems of innovation

Freeman (1987) – success of Japan heavily dependent on wider national system of innovation (NSI)

Lundvall (1988, 1992), Nelson (1993) – extended to other countries

NSI definition

> "that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of inter-connected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies." (Metcalfe, 1995)

How effectively a NSI operates depends not just on the strength of the individual actors (companies, gov't labs, universities etc.) but more particularly on ***the strength of the links*** between them

15. From market failure to system failure

Nelson (1959) & Winter (1962)

- Private firms tend to under-invest in R&D
- To overcome this 'market failure', government needs to fund R&D

cf. new rationale – govt needs to overcome system failures & develop/strengthen links in NSI (e.g. Smith, 2000)

- From 'picking winners' to building/strengthening links
- e.g. via networks, collaboration, strategic alliances etc.
- Technology Foresight as a means of 'wiring up the national system of innovation'

16. From one to ‘two faces’ of R&D

Cohen & Levinthal (1989 & 1990) – two roles (or ‘faces’) of in-house company R&D

- to develop new knowledge internally
- to identify potentially useful external knowledge, access and quickly exploit it

Concept of ‘absorptive capacity’ – crucial for

- combining technologies (see below)
- successful open innovation (see below)

Jaffe et al. (1993) – R&D generates ‘spillovers’

- firms need to be in position to exploit effectively spillovers generated by others

17. From Mode 1 to Mode 2?

Gibbons et al. (1994), *The New Production of Knowledge*

- Mode 1 – discipline-based, largely in academic institutions, primarily concerned with furthering knowledge, subject to internal scrutiny
- Mode 2 – transdisciplinary, in variety of institutions, pursuing knowledge 'in the context of application', subject to ext accountability
- Shift over time from Mode 1 to Mode 2?

'Pasteur's Quadrant' – Stokes (1997)

- Research that is **both** aimed at increasing knowledge **and** at generating useful results – cf.
- Bohr's Quadrant – aimed solely at increasing knowledge
- Edison's Quadrant – aimed solely at generating useful results

'Triple Helix' (Etzkowitz & Leydesdorff, 1997)

- Growing 3-sided interaction of universities, industry and government
- 'The second academic revolution' – adoption of '3rd Mission'
  ➔ emergence of 'the entrepreneurial university'

18. From single-technology to multi-technology firms

Many major innovations involve bringing together previously separate streams of technology

- ‘confluence’ or ‘technology fusion’ (Kodama)

Granstrand, Patel & Pavitt (1997)

- Technological diversity of growing importance to innovation
- In some sectors, firms need to combine several technologies

  ➔ Need for strategic alliances, links with universities etc.

19. From national to multi-level systems of innovation

NSI concept extended to other dimensions

- ***Regional system of innovation*** – e.g. Saxenian (1994), Jaffe et al. (1993), Audretsch & Feldman (1996), Morgan (1997), Cooke & Morgan (2000)
- ***Sectoral system of innovation*** – e.g. Malerba, Breschi, Orsenigo, McKelvey
- ***Technological systems*** – e.g. Bijker & Hughes, Carlsson

Regional system of innovation also influenced by e.g. cultural factors

- R Florida (2002) – cities/regions with more cultural diversity & 'bohemian' lifestyles more creative/ innovative?

Firms need to have effective links with all these different levels of systems if to benefit fully

20. From closed to open innovation

Knowledge required for innovating becoming more organisationally dispersed (?)

Locus of innovation shifting from within the firm to networks, alliances, collaborations etc. – i.e. innovation increasingly co-produced with partners (suppliers, users, universities etc.)

Variously characterised (e.g. by Powell et al., 1996; Chesborough, 2003; von Hippel, 2005) as

- open innovation
- networked innovation
- distributed innovation
- interactive innovation
- democratic innovation

Firms need good links with external knowledge sources + ability to exploit these promptly & effectively

20 developments in science policy

From individual entrepreneur to corporate innovator

From *laissez faire* to government intervention

From 2 factors of production to 3

From single division to multi-divisional efforts

From technology adoption to innovation diffusion

From science push to demand pull?

From single factor to multi-factor explanations of innovation

From static to dynamic model of innovation

From linear model to interactive 'chain-link' model

From one innovation process to several sector-specific types

From neo-classical to evolutionary economics

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Impact on T&I management

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Impact on STI policy

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Where next?

Have we kept up with our changing world?

Or are we

- like generals, still ‘fighting the last war’?
- like politicians, “in the thrall of the ideas of some long-dead economist”?

Focus of many innovation studies still reflects central issues of previous decades – e.g.

- innovation in manufacturing (especially hi-tech) rather than services & other sectors
- innovation for productivity rather than sustainability
- innovation for wealth creation rather than wellbeing or quality of life

Concluding questions

After 50 years of advances in science policy and innovation studies,

- Is STI policy now more effective?
- Do we have evidence that evidence-based policy is better?
- Are the benefits from using inputs from science policy & innovation studies greater than the costs and unintended adverse consequences?
- Are science and technology now ‘better’?
- Is the world a better place?