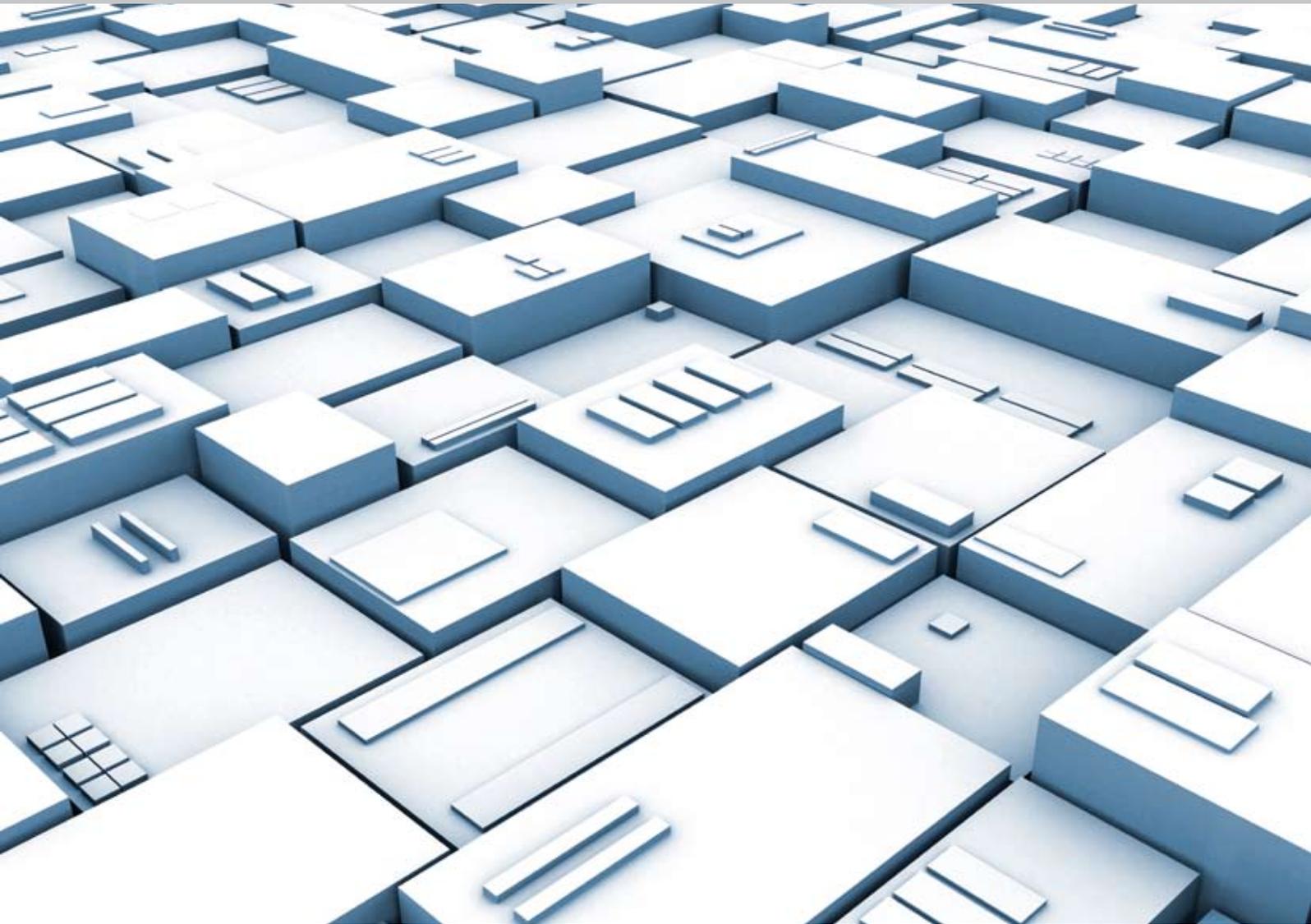


Innovation Models



Paper 1

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1

A Review of Innovation Models

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Abstract

Innovation is central to the policy debate on how to maintain strong economic growth in an era that is increasingly being defined by the globalization of competition, as well as major fiscal and demographic challenges. However, attempts to systematically draw on the concepts, theories and empirical evidence accumulated over three decades of innovation studies to inform this policy debate have been limited.

In this paper we review models of the innovation process and the empirical evidence for them. We discuss the early linear, push-pull models, which still influence much practice and debate, and identify their many limitations. We track the evolution of more realistic dynamic models of innovation, which involve complex systems of disruptive and discontinuous events that involve networks of actors and sources. This latter perspective reveals some of the bottlenecks and unintentional dysfunctional implications that accompany partial views of the innovation process. In particular, we propose that preoccupation with the science base and novel inventions is insufficient, because commercial success is highly dependent on the later stages of the innovation process, namely, development and diffusion.

Next, we consider appropriation, or sharing of the benefits created by innovation, as well as the incentives and constraints that influence this process at the level of the firm and of society. We consider a range of factors that influence this process and the implications for the rate, type and direction of future innovation. In particular, we discuss the concepts of radical and incremental innovation and their interpretation in the biopharmaceuticals sector. We suggest a number of ways to improve the dialogue between stakeholders to achieve a more balanced view of the whole innovation process, which includes the mechanisms for the development, diffusion and appropriation of the benefits of innovations in the biopharmaceutical field.

Introduction

Technological and commercial innovation is central to the policy debate on the future of Europe in an era of globalization and fiscal and demographic constraints. Little attempt has been made in the business and policy communities to systematically draw on the concepts, theories and empirical evidence that have been developed over the past three decades of innovation studies in order to improve the overall climate for innovation.

In this paper we review the different models of the innovation process. We draw heavily upon recent reviews of technological innovation (Tidd, 2006), organizational innovation (Isaksen and Tidd, 2006), and attempts to synthesize technological, organizational and commercial aspects of the innovation process (Tidd, Bessant and Pavitt, 2005). We begin with an assessment of the limitations of the more conventional linear technology-push models, and track the evolution to the more recent and realistic dynamic models of innovation that feature a network of actors, sources and constraints. This latter perspective more readily reveals some of the negative implications of a partial, disaggregated view of the innovation process. In particular, it suggests that a focus on improving the science base and novel technological innovation is insufficient, because many problems occur during the later stages of the innovation process, in terms of development and diffusion.

Next we consider ways to apportion the costs and benefits of innovation, and the incentives and constraints that exist at the level of the firm and the economy. We consider the balance between incremental and more radical forms of innovation, and the different stakeholders they might serve.

Evolving Models of the Innovation Process

The importance of an understanding of innovation as a process is that it shapes the way in which we try and manage it. This understanding has changed a great deal over time. Early models (both explicit and, more importantly, the implicit mental models whereby people managed the process) saw innovation as a linear sequence of functional activities. Either new opportunities arising out of research gave rise to applications and refinements which eventually found their way to the marketplace ('technology push'), or else the market signaled needs for something new which then drew out new solutions to the problem ('need pull', where necessity becomes the mother of invention). The limitations of such an approach are clear; in practice innovation is a coupling and matching process, where interaction is the critical element. Sometimes the 'push' will dominate, sometimes the 'pull', but successful innovation requires an interaction between the two.

One of the key problems in managing innovation is to make sense of a complex, uncertain and highly risky set of phenomena. Much recent work recognizes the limits of linear models, and tries to build more complexity and interaction

into the frameworks. Most innovation is messy, involving false starts, recycling between stages, dead ends, and jumps out of sequence. In an important programme of case study-based research looking at widely different innovation types, van de Ven and colleagues (2000) explored the limitations of simple models of the process. They drew attention to the complex ways in which innovations actually evolve over time, and derived some important modifiers to the basic model:

- Shocks trigger innovations – change happens when people or organizations reach a threshold of opportunity or dissatisfaction
- Ideas proliferate – after starting out in a single direction, the process proliferates into multiple, divergent progressions
- Setbacks frequently arise, plans are overoptimistic, commitments escalate, mistakes accumulate and vicious cycles can develop
- Restructuring of the innovating unit often occurs through external intervention, personnel changes or other unexpected events
- Top management plays a key role in sponsoring – but also in criticizing and shaping – innovation
- Criteria for success shift over time, differ between groups, and make innovation a political process
- Innovation involves learning, but much of the outcome is due to other events which occur as the innovation develops – often making learning 'superstitious' in nature

Roy Rothwell was for many years a key researcher in the field of innovation management, working at SPRU at the University of Sussex. In one of his later papers, he provided a useful historical perspective on innovation management, suggesting that our appreciation of the nature of the innovation process has evolved from simple linear models (characteristic of the 1960s) to increasingly complex interactive models (Table 1). His 'fifth-generation innovation' concept sees innovation as a multi-actor process, which requires high levels of integration at both intra- and inter-firm levels, and which is increasingly facilitated by IT-based networking.

Table 1: Progress in conceptualizing innovation: Rothwell's five generations of innovation models

Generation	Key features
First and second	The linear models – need pull and technology push
Third	Interaction between different elements and feedback loops between them – the coupling model
Fourth	The parallel lines model, integration within the firm, upstream with key suppliers and downstream with demanding and active customers, emphasis on linkages and alliances
Fifth	Systems integration and extensive networking, flexible and customized response, continuous innovation

Source: Adapted from Tidd, Bessant and Pavitt, 2005.

Consequences of Partial Understanding of the Innovation Process

Mental models are important because they help us frame the issues which need managing, but therein also lies the risk. If our mental models are limited, then our approach to managing innovation is also likely to be limited. Examples of such ‘partial thinking’ include:

- Seeing innovation as a linear ‘technology push’ process (in which case all the attention goes into funding R&D with little input from users) or one in which only the market is relied upon to pull through innovation
- Seeing innovation simply in terms of major ‘breakthroughs’—and ignoring the significant potential of incremental innovation. In the case of electric light bulbs, the original Edison design remained almost unchanged in concept, but incremental product and process improvement over the 16 years from 1880 to 1896 led to a fall in price of the light bulb of around 80%, thus ensuring its widespread use
- Seeing innovation as a single isolated change rather than as part of a wider system
- Seeing innovation as product or process only, without recognizing the interrelationship between the two.

Table 2 provides an overview of the difficulties that arise if we take a partial view of innovation (Tidd *et al*, 2005).

Table 2: Problems of partial views of innovation

If innovation is only seen as...	... the result can be
Strong R&D capability	Technology which fails to meet user needs and may not be accepted
The province of specialists	Lack of involvement by others, and a lack of key knowledge and experience input from other perspectives in the R&D
Understanding and meeting customer needs	Lack of technical progression, leading to inability to gain competitive edge
Advances along the technology frontier	Producing products or services which the market does not want or designing processes which do not meet the needs of the user and whose implementation is resisted
The province only of large firms	Weak small firms with too high a dependence on large customers. Disruptive innovation as apparently insignificant small players seize new technical or market opportunities

If innovation is only seen as...	... the result can be
Only about ‘breakthrough’ changes	Neglect of the potential of incremental innovation: with an inability to secure and reinforce the gains from radical change because the incremental performance ratchet is not working well
Only about strategically targeted projects	May miss out on lucky ‘accidents’ which open up new possibilities
Only associated with key individuals	Failure to utilize the creativity of the remainder of employees, and to secure their inputs and perspectives to improve innovation
Only internally generated	The ‘not invented here’ effect, where good ideas from outside are resisted or rejected
Only externally generated	Innovation becomes simply a matter of filling a shopping list of needs from outside and there is little internal learning or development of technological competence
Only concerning single firms	Excludes the possibility of various forms of inter-organizational networking to create new products, streamline shared processes, etc.

Source: Adapted from Tidd, Bessant and Pavitt, 2005.

The Challenge of Discontinuous Innovation

Most of the time, innovation takes place within a set of rules which are clearly understood, and involves players who try to innovate by doing what they do (product, process, position, etc.), but better. Some manage this more effectively than others, but the ‘rules of the game’ are widely accepted and do not change. But occasionally something happens which dislocates this framework and changes the rules of the game. By definition, these are not everyday events. Thus they have the capacity to redefine the space and conditions in which innovative activity takes place. They open up new opportunities, but also challenge existing players to reframe what they are doing in light of new conditions. This is a central theme in Schumpeter’s original theory of innovation. He saw it as involving a process of ‘creative destruction’. Certain ‘steady state’ innovation conditions are punctuated by occasional discontinuities which can cause one or more of the basic conditions (technology, markets, social, regulatory, etc.) to shift dramatically. In the process, the underlying ‘rules of the game’ change, and new opportunities for innovation open up. Table 3 gives some examples of such triggers for discontinuity.

Table 3: Sources of discontinuity

Triggers/ sources of discontinuity	Explanation	Problems posed
New markets	Most markets evolve through a process of growth, or segmentation. But at certain times completely new markets emerge which cannot be analysed or predicted in advance or explored through conventional market research/ analytical techniques.	Established players don't see it because they are focused on their existing markets. Players may discount it as being too small or not representing their preferred target market. Originators of new product may not see potential in new markets and may ignore them.
New technologies	Step change takes place in product or process technology – it may result from convergence and maturing of several streams (e.g. industrial automation, mobile phones) or as the result of a single breakthrough (e.g. LED as white light source).	Established players don't see it because it is beyond the periphery of technology search environment. Tipping point may not be a single breakthrough, but convergence and maturing of established technological streams, whose combined effect is underestimated “Not invented here” effect – new technology represents a different basis for delivering value – e.g. telephone vs. telegraphy
New political rules	Political conditions which shape the economic and social rules may shift dramatically—for example, the collapse of communism meant an alternative model, and many ex-state firms couldn't modify their ways of thinking	Old mindset about how business is done is challenged, and established firms fail to understand or learn new rules
Market Exhaustion	Firms in mature industries may need to escape the constraints of diminishing space for product and process innovation and the increasing competition of industry structures by either exit or by radical reorientation of their business	Current system is built around a particular trajectory and embedded in a steady-state set of innovation routines which militate against widespread search or risk taking experiments
Sea change in market sentiment or behaviour	Public opinion or behaviour shifts slowly and then tips over into a new model – for example, the music industry is in the midst of a (technology-enabled) revolution in delivery systems.	Established players don't pick up on it or persist in alternative explanations – cognitive dissonance – until it may be too late
Deregulation/ shifts in regulatory regime	Political and market pressures lead to shifts in the regulatory framework and enable the emergence of a new set of rules – e.g. liberalization, privatization or deregulation	New rules of the game but old mindsets persist, and existing player is unable to move fast enough or to see new opportunities opening up
Fractures along 'fault lines'	Long-standing issues of concern to a minority accumulate momentum (sometimes through the action of pressure groups) and suddenly the system switches/ tips over – for example, social attitudes to smoking or health concerns about obesity levels and fast-foods	Rules of the game suddenly shift and then new pattern gathers rapid momentum, wrong-footing existing players working with old assumptions. Other players who have been working in the background developing parallel alternatives may suddenly come into the limelight as new conditions favour them
Unthinkable events	Unimagined and therefore not prepared for events which – sometimes literally – change the world and set up new rules of the game	New rules may disempower existing players or render competencies unnecessary
Business model innovation	Established business models are challenged by a reframing, usually by a new entrant who redefines/reframes the problem and the consequent 'rules of the game'	New entrants see opportunity to deliver product/ service via new business model and rewrite rules – existing players have at best to be fast followers
Shifts in 'techno-economic paradigm' – systemic changes which impact whole sectors or even whole societies	Change takes place at system level, involving technology and market shifts. This involves the convergence of a number of trends, which results in a 'paradigm shift' where the old order is replaced.	Hard to see where new paradigm begins until rules become established. Existing players tend to reinforce their commitment to old model, reinforced by 'sailing ship' effects
Architectural innovation	Changes at the level of the system architecture rewrite the rules of the game for those involved at component level	Established players develop particular ways of seeing and frame their interactions – for example, who they talk to in acquiring and using knowledge to drive innovation – according to this set of views. Architectural shifts may involve reframing but at the component level it is difficult to pick up the need for doing so –and thus new entrants better able to work with new architecture can emerge.

Source: Adapted from Tidd, Bessant and Pavitt, 2005.

The models of innovation we have been reviewing so far are very much about the world of repeated, continuous innovation where there is the underlying assumption that we are ‘doing what we do, but better’. This is not necessarily only about incremental innovation – it is possible to have significant step changes in product/service offering, process, etc. – but these innovations still take place within an established framework. The ‘rules of the game’ in terms of technological possibilities, market demands, competitor behaviour, political context, etc. are fairly clear. Although there is scope for pushing the limits, the space within which innovation happens is well defined. But we also need to take into account that innovation is sometimes *discontinuous* in nature. Things happen which lie outside the ‘normal’ frame, and result in changes to the ‘rules of the game.’ Table 1 lists potential sources for such disruptions. Under these conditions, doing more of the same ‘good practice’ routines may not be enough, and may even be inappropriate, to deal with the new challenges. Rather, we need a different set of routines – not to use instead of, but in addition to, those that we have developed for ‘steady state’ conditions.

In their pioneering work on this theme, Abernathy and Clark (1985) developed a model describing the pattern in terms of three distinct phases. Initially, under discontinuous conditions, there is what they term a ‘fluid phase’ during which there is high uncertainty along two dimensions:

- The target – what will the new configuration be and who will want it?
- The technical – how will we harness new technological knowledge to create and deliver this?

No one knows what the ‘right’ configuration of technological means and market needs will be, so there is extensive experimentation (accompanied by many failures) and fast learning by a range of players, including many new entrepreneurial businesses. Gradually these experiments begin to converge around what they call a ‘dominant design’ – something which begins to set up the new rules of the game. This represents a convergence around the most popular (not

necessarily the most technologically sophisticated or elegant) solution. At this point, a ‘bandwagon’ begins to roll and innovation options become increasingly channelled around a core set of possibilities – what Dosi (1982) calls a ‘technological trajectory’. It becomes increasingly difficult to explore outside this space, because entrepreneurial interest and the resources that it brings increasingly focus on possibilities within the dominant design corridor. This can apply to products or processes; in both cases the key characteristics become stabilized. Experimentation moves to getting the bugs out and refining the dominant design. Table 4 sets out the main elements of this model.

Importantly, the ‘fluid’ or ‘ferment’ phase is characterised by *co-existence* of old and new technologies, and by rapid improvements to both. It is here that the so-called ‘sailing ship’ effect can often be observed, in which a mature technology accelerates its rate of improvement as a response to competition with new alternatives –as was the case with the development of sailing ships in competition with newly emerging steamship technology.

While some research suggests existing incumbents do badly, this is not always the case. Many are able to build on the new trajectory and leverage their accumulated knowledge, networks, skills and financial assets to enhance their competence by building on the new opportunity (Tushman and Anderson). Equally, while it is true that new entrants – often small entrepreneurial firms – play a strong role in this early phase, we should not forget that we see only the successful players. We need to remember that there is a strong “ecological” pressure on new entrants, which means only the fittest or luckiest survive.

It is more helpful to suggest that there is something about the ways in which innovation is *managed* under these conditions, which poses problems. Good practice of the ‘steady state’ kind described above, is helpful in the mature phase, but it can actively militate against entry and success in exploiting the fluid phase of a new technology. How do

Table 4: Stages in the innovation life cycle

Innovation characteristic	Fluid pattern	Transitional phase	Specific phase
Competitive emphasis placed on ...	Functional product performance	Product variation	Cost reduction
Innovation stimulated by ...	Information on user needs, technical inputs	Opportunities created by expanding internal technical capability	Pressure to reduce cost, improve quality, etc.
Predominant type of innovation	Frequent major changes in products	Major process innovations required by rising volume	Incremental product and process innovation
Product line	Diverse, often including custom designs	Includes at least one stable or dominant design	Mostly undifferentiated standard products
Production processes	Flexible and inefficient – aim is to experiment and make frequent changes	Becoming more rigid and defined	Efficient, often capital intensive and relatively rigid.

Source: Adapted from Tidd, Bessant and Pavitt, 2005.

enterprises pick up signals about changes if they take place in areas where they don't normally do research? How do they understand the needs of a market that doesn't exist yet? If they talk to their existing customers, it is likely that those customers will tend to ask for more of the same. Which new users should they talk to – and how do they find them?

Although major advances or breakthroughs along the *technological* frontier can disrupt the rules of the game, they are not the only mechanism. The influential work of Clayton Christensen (1997) drew attention to cases where the *market* was the effective trigger point. His distinctive observation was that with each generation, almost all of the previously successful players involved in what was a multi-million dollar market failed to make the transition effectively and were often squeezed out of the market or into bankruptcy, even though these players were textbook examples of good practice: ploughing a high percentage of sales back into R&D, working closely with lead users to understand their needs and develop product innovations alongside them, delivering a steady stream of continuous product and process innovations and systematically exploring the full extent of the innovation space defined by their market.

The problem Christensen exposed is not a failure to cope with a breakthrough in the technological frontier, but the emergence of new *markets* with very different needs and expectations. In essence, the existing players were too good at working with their mainstream users. They failed to see the longer-term potential in the newly emerging market. Their systems for picking up signals about user needs and feeding them into the product development process, were all geared around a market for machines designed to run sophisticated engineering and financial applications software. Their success in meeting these needs helped their businesses to grow, by keeping up with that industry.

It is here that market *disruption* emerges. What began as a fringe business has moved into the mainstream and eventually changes the rules under which the mainstream business operates. Importantly, the new players who rewrote the 'rule book' for one generation found their markets disrupted in turn by a later generation of players doing the same to them. This underlines the point that it is not stupid firms who suffer this kind of disruption. The recipe for success in following a new dominant design becomes one which shapes the signals about future opportunities that firms perceive, and the ways in which they allocate resources to them. Riding along on one particular bandwagon makes the enterprise vulnerable in its ability to jump on to the next one, when the bandwagon starts to roll.

In more recent work Christensen and Raynor (2003) have extended this powerful market-linked analysis to deal with two dimensions of discontinuity, one where disruption occurs because of a new bundle of performance measures competing against existing markets, and one where it competes against non-consumption. Effectively, the latter case is about creating completely new markets. Disruptive products and services can begin in high-technology niches

that feature pioneering innovations (Utterback and Acee, 2005), or in lower-technology niches that feature new configurations of existing technologies (Schmidt, 2004). This makes the conventional distinction between incremental and radical innovation misleading; there is a need to differentiate between the nature of technology inputs and market impact.

The problem market disruption brings to a firm is further compounded by the networks of relationships the firm has with other organizations. Typically, much of the basis of innovation lies at a system level involving networks of suppliers and partners who configure knowledge and other resources to create a new offering. Discontinuous innovation is often problematic because it may involve building and working with a significantly different set of partners than those the firm is accustomed to working with. Whereas 'strong ties' – close and consistent relationships with regular partners in a network – may be important in enabling a steady stream of continuous improvement innovations. Evidence suggests that where firms are seeking to do something different, they need to exploit much weaker ties across a very different population in order to gain access to new ideas and different sources of knowledge and expertise.

Networks and Systems of Innovation

In the 1990s, only about 12% of the innovative activities of the world's largest 500 technologically-active firms were located outside their home countries, compared to about 25% of their production and much larger shares of sales (Cantwell, 1992; Patel, 1995). As a consequence, we find that the technological strengths and weaknesses of countries are reflected in their major firms. This is because even global firms draw on mainly one – or perhaps two – countries for their strategic skills and expertise in formulating and executing their innovation strategies. Analysts like Porter (1990) have shown that business firms – and even the largest ones competing in global markets – are strongly influenced in their choice of technological strategies by the conditions existing in their home countries. The strategic importance to corporations of home countries' technological competencies would matter little, if they were all more or less the same. But countries differ greatly in both the level and the rate of increase in the resources devoted by business firms to innovative activities, and sectoral specialization. Thus, the national systems of innovation in which a firm is embedded matter greatly, since they strongly influence both the direction and the vigour of their own innovative activities.

Several approaches have been taken on the nature and impact of such national systems (Nelson, 1992). Our own task here is to identify the main national factors that influence the rate and direction of technological innovation: more specifically, the market *incentives and pressures* to which firms have to respond, and their *competencies in production and research*.

Incentives and Pressures: National Demand and Competitive Rivalry

Patterns of national demands

Those concerned to explain international patterns of innovative activities have long recognized the important influence of local demand and price conditions on patterns of innovation in local firms. Strong local 'demand pull' for certain types of product, generates innovation opportunities for local firms, especially when demand depends on face-to-face interactions with customers. In addition to the obvious examples of local buyers' tastes, we identify:

- Local (private and public) investment activities, which create innovative opportunities for local suppliers of machinery and production inputs, where competence is accumulated mainly through experience in designing, building and operating machinery
- Local production input prices, where international differences can help generate very different pressures for innovation (e.g. the effects of different petrol prices on the design and related competencies in automobiles in the USA and Europe).
- Local natural resources, which create opportunities for innovation in both upstream extraction and downstream processing

A subtle but significant influence is social concerns and pressure on the environment, public safety and corporate governance. For example, nuclear power as a technological innovation has evolved in very different ways in the US, UK, France and Japan. Similarly, innovation in genetically modified crops and foods has taken radically different paths in the US and Europe, mainly due to public concerns and pressure. Beyond these new opportunities lies a second powerful driver for innovation around sustainability in business practices – for example, ethical investment services, or environmentally responsible management of resource inputs. Trends such as those outlined above can build for some time and suddenly flip as social attitudes harden or new information emerges. The shift in perception of smoking from leisure activity to health hazard, and the recent concerns about fast foods as a major contributor to obesity levels, are examples of shifts which have had marked impacts on the rate and pattern of innovation in their industries. Sustainability issues are often linked to regulation, and such legislation can add additional force, changing the rules of the game – for example, the continuing effects of clean air and related environmental pollution legislation have had enormous and cumulative effects on industries involved in chemicals, materials processing, mining and transportation, both in terms of products and processes. Innovation linked to issues of sustainability often has major systems-level implications and emphasises the need to manage innovation in an integrated fashion. Such innovations arise from concerns in, and need to be compatible with, complex social, political and cultural contexts. There is a high risk of failure if these demand side elements are neglected.

Frans Berkhout and Ken Green (2003) argue for a systems approach to innovation. They suggest potential ways to link innovation, sustainable research, policy and management. They also identify a number of limitations in the way innovation is currently conceptualised:

- (i) A focus on managers, the firm, or the supply chain is too narrow. Innovation is a distributed process across many actors, firms and other organizations, and is influenced by regulation, policy and social pressure.
- (ii) A focus on a specific technology or product is inappropriate. Instead, the unit of analysis must be technological systems or regimes, and their evolution rather than management.
- (iii) The assumption that innovation is the consequence of coupling technological opportunity and market demand is too limited and needs to include the less obvious social concerns, expectations and pressures. These may appear to contradict stronger, but misleading market signals.

They present empirical studies of industrial production, air transportation and energy to illustrate their arguments, and conclude that, "greater awareness and interaction between research and management of innovation, environmental management, corporate social responsibility and innovation and the environment will prove fruitful." Similar arguments can be applied to the development of pharmaceutical and biotechnology based innovations.

Competitive rivalry

Innovation is always difficult and often upsetting to established interests and habits, so that local demands alone do not create the necessary conditions for innovation. Both case studies and statistical analysis show that competitive rivalry stimulates firms to invest in innovation and change, because their very existence will be threatened if they do not. A comparison by Lacey Glenn Thomas (1994) of public policies towards the pharmaceutical industries in Britain and France has shown that the former was more successful in creating a local competitive environment conducive to the emergence of British firms amongst the world leaders. German strength in chemicals was based on three large and technologically dynamic firms, BASF, Bayer and Hoechst, rather than on one super-large firm. Thus although corporate policy-makers might be tempted in the short term to seize the cost saving advantages by merging with their competitors, the long-term costs could be considerable. Public policy-makers should be persuaded by the evidence that creating gigantic firms does not automatically increase innovation –on the contrary, lack of competitive rivalry can make firms less fit to compete on global markets through innovation.

Competencies in Production and Research

Local demand opportunities and competitive pressures will not result in innovation unless firms have the competencies that enable them to respond. Corporate and national competencies in *production* and in *research* are essential. National competencies in *research* are also an important input

into firms' technological capabilities. Especially in large firms, R&D laboratories actively seek support, knowledge and skills from national basic research activities like those in universities. The knowledge they seek is mainly tacit and person-embodied, which explains why language and distance are real barriers to cooperation, and why the firms generally prefer to deal with domestic universities. These differences in national endowments of research and production competencies influence managers in their search to identify technological fields and related product markets where specific national systems of innovation are likely to be most supportive to corporate innovative activities. For example, firms in the UK and US are particularly strong in software and pharmaceuticals, both of which require strong basic research and graduate skills, but few production skills; they are therefore particularly well matched to local skill structures.

In many countries, national advantages in natural resources and traditional industries have been fused with related competencies in broad technological fields that then become the basis for technological advantage in new product fields. Firm-specific investments in technology and related basic research and training in universities led to the mastery of broad technological fields with multiple potential applications: metallurgy and materials in Sweden, machinery in Switzerland and Sweden, and chemistry and (more recently) biology in Switzerland and Denmark (Laursen, 1997).

Innovation involves attempts to deal with an extended and rapidly advancing scientific frontier, fragmenting markets flung right across the globe, political uncertainties, regulatory instabilities, and a set of competitors who are increasingly coming from unexpected directions. Thus, spreading the net wide and trying to pick up and make use of a wide set of knowledge signals is what is needed for effective management of innovation – in other words, learning to manage innovation at the *network* level. This is something which Roy Rothwell foresaw in his pioneering work on models of innovation, with a gradual move away from thinking about (and organising) a linear science/technology-push or demand-pull process, to one which saw increasing *inter-activity* – first across the firm with cross-functional teams and other boundary-spanning activities, and then outside the firm and its links with others.

There is now a recognition that networks may not simply be one end of the traditional spectrum between doing everything in-house (vertical integration) and of outsourcing everything to suppliers (with the consequent transaction costs of managing them). It is possible to argue for a 'third way,' which builds on the theory of systems and the theory that networks have emergent properties – the whole is greater than the sum of its parts. This does not mean that the benefits flow without effort – on the contrary, unless participants in a network can solve the problems of co-ordination and management, they risk being suboptimal. But there is growing evidence of the benefits of networking as a mode of operation in innovation. Even the biggest and most established innovators are recognising this shift. Procter and Gamble spend around 2

billion US dollars each year on what used to be termed R&D – but these days, they use the phrase 'Connect and Develop' instead, and have set themselves the ambitious goal of sourcing much of their ideas from outside the company. As Nabil Sakkab, Senior Vice President of Research & Development commented recently, "*The future of R&D is C&D – collaborative networks that are in touch with the 99% of research that we don't do ourselves. P&G plans to keep leading innovation and this strategy is crucial for our future growth*". Similar stories can be told for firms like IBM, Cisco, Intel – examples of what Henry Chesbrough (2003) calls the move towards 'open innovation' where links and connections become as important as the actual production and ownership of knowledge.

The importance of such networking is not simply firm to firm – it is also about building rich linkages within the national system of innovation. Government policy to support innovation is increasingly concerned with enabling better connections between elements – for example, between the many small firms with technological needs, and the major research and technology institutes, universities, etc. which might be able to meet these needs. There is an increasing trend towards trying to build innovation networks in a purpose-built fashion into what some researchers call "engineered" networks (Conway and Stewart, 2006). The purpose might be to create a completely new product or process by bringing together radically different combinations of knowledge, or it could be a network whose members are simply geared toward adopting and embedding innovative ideas. Players could be linked together by some geographical focus – as in a cluster – or as part of a supply chain trying to develop new ideas along the whole system. What they share is the recognition that they can get traction on some aspects of the innovation problem through networking. Table 5 provides an outline typology of this process.

Whatever the purpose for setting it up, actually operating an innovation network is not easy – it needs a new set of management skills, and it depends heavily on the type of network and the purposes it is set up to achieve. For example, there is a big difference between the demands for an innovation network working at the frontier, where issues of intellectual property management and risk are critical, and one where there is an established innovation agenda, as might be the case in using supply chains to enhance product and process innovation. We can map some of these different types of innovation network on to a simple diagram which positions them in terms of (i) how radical the innovation target is with respect to current innovative activity, and (ii) the similarity of the participating companies (Figure 1).

Different types of networks have different issues to resolve. For example, in zone 1 we have firms with a broadly similar orientation working on tactical innovation issues. Typically, this might be a cluster or sector forum concerned with adopting and configuring 'good practice' in manufacturing. Issues here would involve enabling networks to share

experiences, disclose information, develop trust and transparency and build a system level sense of shared purpose around innovation.

Zone 2 activities might involve players from a sector working to explore and create new product or process concepts – for example, biotechnology/pharmaceutical networking around frontier developments in genomics, and the need to look for interesting connections and synthesis between these adjacent sectors. Here, the concern is exploratory and challenges existing boundaries. But it will rely on a degree of information sharing and shared risk-taking, often in the form of formal joint ventures and strategic alliances.

In Zones 3 and 4, the players are highly differentiated and bring different key pieces of knowledge to the party. Their risks in disclosing can be high, so ensuring careful IP management and establishing ground rules will be crucial. At the same time, this kind of innovation is likely to involve considerable risk, so putting in place risk and benefit sharing arrangements will also be critical. For example, in a review of ‘high value innovation networks’ in the UK, researchers from the Advanced Institute of Management Research (AIM, 2004) found the following characteristics were important success factors:

- Highly diverse: network partners from a wide range of disciplines and backgrounds who encourage exchanges about ideas across systems.
- Third-party gatekeepers: science partners such as universities but also consultants and trade

associations, who provide access to expertise and act as neutral knowledge brokers across the network.

- Financial leverage: access to investors via business angels, venture capitalists firms and corporate venturing which spreads the risk of innovation and provides market intelligence.

Proactive management: participants regard the network as a valuable asset and actively manage it to reap the innovation benefits.

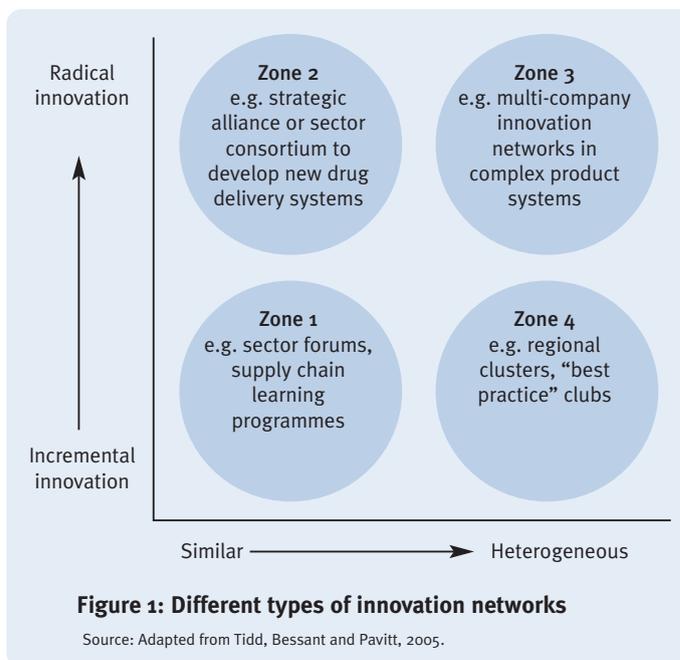


Table 5: Typology of innovation networks

Type of innovation network	Primary purpose / innovation target
New product or process development consortium	Sharing knowledge and perspectives to create and market new product or process concept – for example, the Symbian consortium (Sony, Ericsson, Motorola and others) working towards developing a new operating system for mobile phones and PDAs.
Sectoral forum	Shared concern to adopt and develop innovative good practice across a sector or product market grouping – for example, in the UK the SMMT Industry Forum or the Logic (Leading Oil and Gas Industry Competitiveness), a gas and oil industry forum.
New technology development consortium	Sharing and learning around newly emerging technologies – for example, the pioneering semiconductor research programmes in the US and Japan.
Emerging standards	Exploring and establishing standards around innovative technologies – for example, the Motion Picture Experts Group (MPEG) working on audio and video compression standards.
Supply chain learning	Developing and sharing innovative good practice and possibly shared product development across a value chain – for example, the SCRIA initiative in aerospace.
Cluster	Regional grouping of companies to gain economic growth through exploiting innovation synergies.
Topic network	Mix of firms companies to gain traction on key new technology.

Source: Adapted from Tidd, Bessant and Pavitt, 2005.

Appropriating the Benefits from Innovation

Technological leadership in firms does not necessarily result in economic benefits. David Teece (1998) argues that the capacity of the firm to appropriate the benefits of its investment in technology depends on two factors: (i) the firm's capacity to translate its technological advantage into commercially viable products or processes; and (ii) the firm's capacity to defend its advantage against imitators. Some of the factors that enable a firm to benefit commercially from its own technological lead can be strongly shaped by its management: for example, the provision of complementary assets to exploit the lead. Other factors can be influenced only slightly by the firm's management, and depend much more on the general nature of the technology, the product market and the regime of intellectual property rights: for example, the strength of patent protection. We identify below nine factors that influence the firm's capacity to benefit commercially from its technology:

- (i) Secrecy.
- (ii) Accumulated tacit knowledge.
- (iii) Lead times and after-sales service.
- (iv) The learning curve.
- (v) Complementary assets.
- (vi) Product complexity.
- (vii) Standards.
- (viii) Pioneering radical new products.
- (ix) Strength of patent protection.

We begin with those over which management has some degree of discretion for action, and move on to those where the range of choices is more limited.

- (i) *Secrecy* is considered by industrial managers to be an effective form of protection, especially for process innovations. However, it is unlikely to provide absolute protection, because some process characteristics can be identified from an analysis of the final product, and because process engineers are a professional community. They talk to each other and move from one firm to another, so information and knowledge inevitably leaks out. Moreover, there is evidence that in some sectors, firms that share their knowledge outperform those that do not, and that those that interact most with innovators in a global network of contacts have the highest innovative performance. Specifically, firms that regularly have their research (publications and patents) cited by foreign competitors are rated more innovative than others, after controlling for the level of R&D. In some cases, this is because sharing knowledge with global innovators may influence standards and dominant designs (see below), and can help attract and maintain research staff, alliance partners, and other critical resources.

- (ii) *Accumulated tacit knowledge* can be long and difficult to imitate, especially when it is closely integrated in specific firms and regions. Examples include product design skills, ranging from those of Benetton and similar Italian firms in clothing design, to those of Rolls-Royce in aircraft engines.
- (iii) *Lead times and after-sales service* are considered by practitioners to be major sources of protection against imitation, especially for product innovations. Taken together with a strong commitment to product development, they can establish brand loyalty and credibility, accelerate the feedback from customer use to product improvement, generate learning curve cost advantages (see below) and therefore increase the costs of entry for imitators.
- (iv) *The learning curve* in production generates both lower costs, and a particular and powerful form of accumulated and largely tacit knowledge that is well recognized by practitioners. In certain industries and technologies (e.g. semiconductors, continuous processes), the first-comer advantages are potentially large, given the major possibilities for reducing unit costs with increasing cumulative production. However, such 'experience curves' are not automatic, and require continuous investment in training, and learning.
- (v) *Complementary assets*. The effective commercialization of an innovation very often depends on assets (or competencies) in production, marketing and after-sales to complement those in technology.
- (vi) *Product complexity*. However, Teece was writing in the mid-1980s, and IBM's performance in personal computers has been less than impressive since then. Previously, IBM could rely on the size and complexity of their mainframe computers as an effective barrier against imitation, given the long lead times required to design and build copy products. With the advent of the microprocessor and standard software, these technological barriers to imitation disappeared and IBM was faced in the late 1980s with strong competition from IBM 'clones', made in the USA and in East Asia. Boeing and Airbus have faced no such threat to their positions in large civilian aircraft, since the costs and lead times for imitation remain very high. Managers recognize that product complexity is an effective barrier to imitation.
- (vii) *Standards*. The widespread acceptance of a company's product standard widens its own market, and raises barriers against competitors. Standards compatibility is an essential feature of market growth, and 'standards wars' an essential feature of the competitive process. Among other things, the market leader normally has the advantage in a standards war, but this can be overturned through radical technological change, or a superior response to customers' needs. Competing firms can adopt either 'evolutionary' strategies, minimizing switching costs for customers (e.g. backward compatibility with

earlier generations of the product), or 'revolutionary' strategies based on greatly superior performance – price characteristics, such that customers are willing to accept higher switching costs. Standards wars are made less bitter and dramatic when the costs to the losers of adapting to the winning standard are relatively small.

- (viii) *Pioneering radical new products.* It is not necessarily a great advantage to be a technological leader in the early stages of the development of radically new products, when the product performance characteristics, and features valued by users, are not always clear, either to the producers or to the users themselves. Especially for consumer products, valued features emerge only gradually through a process of dynamic competition that involves a considerable amount of trial, error and learning by both producers and users. New features valued by users in one product can easily be recognized by competitors and incorporated in subsequent products. Success goes to so-called 'early entrants' with the vision, patience and flexibility to establish a mass consumer market. Studies suggest that the success of product pioneers ranges between 25% (for consumer products) and 53% (for higher technology products), depending on the technological and market conditions.
- (ix) *Strength of patent protection* can be a strong determinant of the relative commercial benefits to innovators and imitators. Patents are judged to be more effective than process innovations in protecting product innovations in all sectors except petroleum refining, probably reflecting the importance of improvements in chemical catalysts for increasing process efficiency. It also shows that patent protection is rated more highly in chemical-related sectors (especially drugs) than in other sectors. This is because it is generally more difficult to 'invent around' a clearly specified chemical formula than around other forms of invention.

Finally, we should note that firms can use more than one of the above nine factors to defend their innovative lead. For example, in the pharmaceutical industry, secrecy is paramount during the early phases of research, but in the later stages, research patents – where much basic information is disclosed – become critical. Complementary assets, such as global sales and distribution, become more important at the commercialisation stage.

Diffusion and Adoption of Innovations

A great deal of research has been conducted to try to identify what factors affect the rate and extent of adoption of an innovation by the markets. A number of characteristics of an innovation have been found to affect diffusion (Rogers, 2003):

- Relative advantage
- Compatibility
- Complexity
- Trialability
- Observability

Relative advantage is the degree to which an innovation is perceived to be better than the product it supersedes, or competing products. Relative advantage is typically measured in narrow economic terms, for example cost or financial payback, but non-economic factors such as convenience, satisfaction and social prestige may be equally important. In theory, the greater the perceived advantage, the faster the rate of adoption. It is useful to distinguish between the primary and secondary attributes of an innovation. Primary attributes, such as size and cost, are invariant and inherent to a specific innovation irrespective of the adopter. Secondary attributes, such as relative advantage and compatibility, may vary from adopter to adopter, being contingent upon the perceptions and context of adopters. Incentives may be used to promote the adoption of an innovation, by increasing the perceived relative advantage of the innovation, subsidizing trials or reducing the cost of incompatibilities.

Compatibility is the degree to which an innovation is perceived to be consistent with the existing values, experience and needs of potential adopters. There are two distinct aspects of compatibility: existing skills and practices, and values and norms. The extent to which the innovation fits the existing skills, equipment, procedures and performance criteria of the potential adopter is important, and relatively easy to assess. So-called 'network externalities' can affect the adoption process. For example, the cost of adoption and use, as distinct from the cost of purchase, may be influenced by the availability of information about the technology from other users, as well as the availability of trained skilled users, technical assistance and maintenance, and complementary innovations, both technical and organizational. However, compatibility with existing practices may be less important than how they fit with existing values and norms. Significant misalignments between an innovation and an adopting organization will require changes in the innovation or organization, or both. In the most successful cases of implementation, mutual adaptation of the innovation and organization occurs.

Complexity is the degree to which an innovation is perceived to be difficult to understand or use. In general, innovations that are simpler for potential users to understand will be adopted more rapidly than those which require the adopter to develop new skills and knowledge.

Trialability is the degree to which an innovation can be experimented with on a limited basis. An innovation that is trialable represents less uncertainty to potential adopters, and allows for learning by doing. Innovations that can be trialed will generally be adopted more quickly than those which cannot. The exception is where the undesirable consequences of an innovation appear to outweigh the desirable characteristics. In general, adopters wish to benefit from the functional effects of an innovation, but avoid any dysfunctional effects. However, where it is difficult or impossible to separate the desirable from the undesirable consequences, trialability may reduce the rate of adoption.

Observability is the degree to which the results of an innovation are visible to others. The easier it is for others to see the benefits of an innovation, the more likely it will be adopted. The simple epidemic model of diffusion assumes that innovations spread as potential adopters come into contact with existing users of an innovation.

Processes of Diffusion

Research on diffusion attempts to identify what influences the rate of adoption of an innovation. The diffusion of an innovation is typically described by an S-shaped (logistic) curve. Initially, the rate of adoption is low, and adoption is confined to so-called 'innovators'. Next to adopt are the 'early adopters', then the 'late majority', and finally the curve tails off as only the 'laggards' remain. Such taxonomies are fine with the benefit of hindsight, but provide little guidance for future patterns of adoption. Hundreds of marketing studies have attempted to fit the adoption of specific products to the S-curve, ranging from television sets to new drugs. In most cases, mathematical techniques can provide a relatively good fit with historical data, but research has so far failed to identify robust generic models of adoption. In practice, the precise pattern of adoption of an innovation will depend on the interaction of demand-side and supply-side factors:

- (i) Demand-side models, mainly statistical:
 - (a) Epidemic, based on direct contact with or imitation of prior adopters;
 - (b) Bass, based on adopters consisting of innovators and imitators;
 - (c) Probit, based on adopters with different benefit thresholds;
 - (d) Bayesian, based on adopters with different perceptions of benefits and risk.

- (ii) Supply-side models, mainly sociological:
 - (a) Appropriability, which emphasizes relative advantage of an innovation;
 - (b) Dissemination, which emphasizes the availability of information;
 - (c) Utilization, which emphasizes the reduction of barriers to use;
 - (d) Communication, which emphasizes feedback between developers and users.

The epidemic model was the earliest, and is still the model most commonly used. It assumes a homogeneous population of potential adopters, and that innovations spread by information transmitted by personal contact and the geographical proximity of existing and potential adopters. This model suggests that the emphasis should be on communication, and the provision of clear technical and economic information. However, the epidemic model has been criticized because it assumes that all potential adopters are similar and have the same needs.

As a result, the Bass model of diffusion is modified to include two different groups of potential adopters: innovators, who are not subject to social emulation; and imitators, for whom the diffusion process takes the epidemic form. This produces a skewed S-curve because of the early adoption by innovators, and suggests that different marketing processes are needed for the innovators and subsequent imitators. The Bass model is highly influential in economics and marketing research.

The Probit model takes a more sophisticated approach to the population of potential adopters. It assumes that potential adopters have different threshold values for costs or benefits, and will only adopt beyond some critical or threshold value. In this case differences in threshold values are used to explain different rates of adoption. This suggests that the more similar potential adopters are, the faster the diffusion.

In the Probit model, potential adopters know the value of adoption, but delay adoption until the benefits are sufficient. However, it is unrealistic to assume that adopters will have perfect knowledge of the value of an innovation. Therefore, Bayesian models of diffusion introduce lack of information as a constraint to diffusion. Potential adopters are allowed to hold different beliefs regarding the value of the innovation, which they may revise according to the results of trials to test the innovation. Because these trials are private, imitation cannot take place and other potential adopters cannot learn from the trials. This suggests better-informed potential adopters may not necessarily adopt an innovation earlier than the less well informed, which was an assumption of earlier models.

The choice between the four models will depend on the characteristics of the innovation and nature of potential adopters. The simple epidemic model appears to provide a good fit to the diffusion of new processes, techniques and

procedures, whereas the Bass model appears to best fit the diffusion of consumer products. However, the mathematical structure of the epidemic and Bass models tends to overstate the importance of differences in adopter characteristics, but tends to underestimate the effect of macroeconomic and supply-side factors. In general, both these models of diffusion work best where the total potential market is known, that is, for derivatives of existing products and services, rather than for totally new innovations.

All demand-side models have limitations:

- Adopters are assumed to be relatively homogeneous, apart from some difference in progressiveness or threshold values. They do not consider the possibility that the rationality and the profitability of adopting a particular innovation might be different for different adopters. For example, local 'network externalities' such as the availability of trained skilled users, technical assistance and maintenance, or complementary technical or organizational innovations are likely to affect the cost of adoption and use, as distinct from the cost of purchase
- The population of potential adopters and the innovation are assumed to be the same at the beginning and at the end of the diffusion period. However, research confirms that many innovations change over the course of diffusion, and that this change affects the potential population of adopters, who in turn may lead to subsequent modifications of the innovation
- They focus almost exclusively on the adopters' or demand side of the diffusion process, and ignore supply-side factors. In reality, both demand- and supply-side factors must be taken into account.

Sociological models place greater emphasis on the relationship between demand- and supply-side factors. The early appropriability models focus almost exclusively on the supply side, and assume that innovations of sufficient value will be adopted. This suggests that the most important issues are the relative advantage of an innovation. The subsequent dissemination model assumes that the availability of information and communication channels is the most critical issue in diffusion. The utilization model incorporates demand-side issues, in particular problems of adoption and application, both structural and perceptual. Finally, there are recent communication models of diffusion, which are based on feedback between developers and potential adopters.

Conclusions

In this paper we have reviewed various models of the innovation process, and some of the empirical research that has contributed to them. Our central argument has been that the (common) partial understanding of this process can result in a narrow focus on radical technological inputs, rather than a more informed debate that considers a much wider range of factors which influence innovation, including a number of key stylised facts:

- (i) We need to identify more fruitful ways to begin a more constructive dialogue between pharmaceutical innovation research, policy and practice. There is scope for disruptive innovation from discontinuous technological (e.g. biotechnology), and market changes (funding and regulation of healthcare), but the current conceptualization of innovation in the sector and relationships between actors are likely to simply reinforce historical shortcomings.
- (ii) A shift away from an emphasis on inputs, such as the science base and radical technological advances, towards a more balanced support for the whole innovation process, which includes development and diffusion of all types of innovation – technological, commercial, and organizational.
- (iii) The assumption that innovation is the consequence of coupling technological opportunity and market demand is too limited. It needs to include the less obvious social concerns, expectations and pressures. These may appear to contradict stronger, but misleading market signals.
- (iv) Cumulative incremental improvements to platform technologies often create significant commercial and social benefits.
- (v) Long-term investments in and development of organizational processes and capabilities are necessary to translate scientific and technological opportunities into successful new products and services that are widely adopted and supported.
- (vi) An equal and sometimes greater emphasis is needed on the outputs of the innovation process, specifically the processes of diffusion and adoption of innovations. This includes non-zero-sum issues of commercial appropriability and social externalities.

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