Firm-level Innovation Models: Perspectives on Research in Developed and Developing Countries

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ABSTRACT This paper provides a critical review of firm-level innovation models based on research in the industrially advanced countries (IACs) and draws implications for firms in industrialising countries such as Korea and Taiwan. The paper summarises different categories of innovation model and identifies their achievements and weaknesses, showing how a few researchers have successfully linked IAC models to innovation processes found within the more advanced developing nations such as Korea. One of the chief contributions of IAC models is that many of them go substantially into the management of innovation and the decision-making processes within the firm. However, in general, there is a lack of empirical evidence to verify existing models, weak theoretical underpinnings and, in some cases, a failure to sufficiently recognise the diversity and unpredictability of innovation processes. The paper suggests how best to use innovation models and how to overcome some of the difficulties in future research.

1 Introduction

In the past 30 years or so, firm-level models of innovation have proliferated and become ever more sophisticated. One of the chief contributions of industrially advanced country (IAC) models is that many of them go substantially into the management of innovation and the decision-making processes within the firm. In doing so, they go ‘beneath’ higher level general models of innovation and delve deeply into the nature of innovation itself. At the same time, ‘latecomer’ firms from the developing countries have increasingly built a competitive presence on the international stage. However, the relevance of IAC innovation models to such firms is, as yet, unclear. The purpose of this paper is therefore, first, to provide a critical review of firm level innovation models in the advanced countries and second, to draw implications for firms in industrialising countries as they approach the technology frontier. Using examples, the paper provides what is hopefully a useful summary of the different categories of innovation model, identifying achievements and remaining weaknesses.
Strictly speaking the definition of an innovation is the successful introduction of a new or improved product, process or service to the marketplace. However, this definition fails to capture the incremental innovations that can lead to large gains in productivity and product quality, and are often the source of structural change, economic growth and catching up. In the developing countries (and sometimes in the IACs) innovation tends to occur from ‘behind the technology frontier’ defined by leaders in the advanced countries. Therefore, in this paper innovation is defined as a product, process or service new to the firm, not only new to the world or marketplace. This broader definition also encompasses the stream of minor innovations that follow on from radical new products and processes. Innovation is also interpreted as a process that involves the application of new knowledge and skills, rather than easily identifiable once-and-for-all events.

The paper proceeds as follows. Following this introduction the next section examines the evolution of IAC innovation models using Rothwell’s notion of ‘five generations’ of innovation processes. Section 3 provides a critical assessment of each generation of models, highlighting both strengths and weaknesses. Section 4 shows how some researchers have successfully linked high-level IAC models to innovation processes found within advanced developing nations such as Korea. Section 5 provides an overall assessment of the innovation modelling field, raising concerns over the lack of empirical evidence and the failure to sufficiently recognise the diversity of innovation processes. It argues that innovation models often embody implicit theoretical assumptions that are not necessarily correct. Section 5 also draws implications for further innovation research in general and latecomer firms in particular. The conclusion provides a summary of the main findings and implications for the field.

2 Five Generations of Innovation Models

Since the 1950s, there has been a proliferation of innovation models, each purporting to explain and/or guide the process of innovation within industrial firms. In a seminal contribution to the field, Rothwell argued that the post-war era was characterised by successive waves of technological innovation associated with a corresponding evolution in corporate strategy. Table 1 summarises Rothwell’s view of the evolution of innovation models from the 1950s to the 1990s in five successive generations.

Before examining individual models, it is useful to emphasise five caveats stressed by Rothwell in his introduction to the five generations:

1. The evolution from one generation to another does not imply any automatic substitution of one model for another; many models exist side-by-side and, in some cases, elements of one model are mixed with elements of another at any particular time;
2. Each model is always a highly simplified representation of a complex process that will rarely exist in a pure form;
3. Often the progress from one generation to another reflects shifts in dominant perception of what constitutes best practice, rather than actual progress;
4. The most appropriate model will vary from sector to sector, and between different categories of innovation (e.g. radical or incremental);
5. The processes that occur within firms are to an extent contingent on exogenous factors such as the pace of technological change.
<table>
<thead>
<tr>
<th>Generation</th>
<th>Time Period</th>
<th>Model Description</th>
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<tbody>
<tr>
<td>1st Gen</td>
<td>1950s to mid-60s</td>
<td>Simple linear sequential process. Emphasis on R&amp;D push. The market ‘receives’ the results of the R&amp;D.</td>
</tr>
<tr>
<td>2nd Gen</td>
<td>Mid-1960s–1970s</td>
<td>Market (or need) pull; again a simple, linear sequential process. Emphasis is on marketing. The market is the source of ideas and provides direction to R&amp;D. R&amp;D has a reactive role.</td>
</tr>
<tr>
<td>3rd Gen</td>
<td>Mid 1970s–1980s</td>
<td>Sequential model, but with feedback loops from later to earlier stages. Involves push or pull-push combinations. R&amp;D and marketing more in balance. Emphasis is on integration at the R&amp;D–marketing interface.</td>
</tr>
<tr>
<td>4th Gen</td>
<td>Early 1980s–1990</td>
<td>Parallel development with integrated development teams. Strong upstream supplier linkages and partnerships. Close coupling with leading edge customers. Emphasis on integration between R&amp;D and manufacturing (e.g. design for manufacturability). Horizontal collaboration including joint ventures and strategic partnerships.</td>
</tr>
<tr>
<td>5th Gen</td>
<td>Post-1990</td>
<td>Fully integrated parallel development supported by advanced information technology. Use of expert systems and simulation modelling in R&amp;D. Strong linkages with leading edge customers (customer focus at the forefront of strategy). Strategic integration with primary suppliers including co-development of new products and linked CAD systems. Horizontal linkages including: joint ventures, collaborative research groupings, collaborative marketing arrangements etc. Emphasis on corporate flexibility and speed of development (time-based strategy). Increased focus on quality and other non price factors.</td>
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2.1 First Generation Models: Technology Push (1950s–Mid 1960s)

The first generation models of innovation, so called technology push models, were simple linear models developed in the 1950s (see Figure 1), which treated innovation as a sequential process that took place in discrete stages. The models assumed that scientific discovery preceded and ‘pushed’ technological innovation via applied research, engineering, manufacturing and marketing. As Rothwell argues, the model was often used to justify additional R&D spending by firms and governments as, it was held, this would lead to greater innovation and, in turn, faster economic growth. Public policies towards innovation stressed supply side interventions (e.g. R&D subsidies and credits) in support of innovation.

![Figure 1. First generation technology push models (1950s to mid 1960s). Source: Rothwell (1991, Ref. 9, p. 33; amended)](image)

2.2 Second Generation: Demand Pull Models (Mid 1960s–1970s)

Rothwell argues that in the latter half of the 1960s empirical studies of innovation processes began to emphasise market led (or need pull) theories of innovation. These were again linear in nature, stressing the role of the marketplace and market research in identifying and responding to customer needs, as well as directing R&D investments towards these needs. In these models, the marketplace was the chief source of ideas for R&D and the role of R&D was to meet market demands.

2.3 Third Generation: Coupling or Interactive Models (1970s)

Detailed empirical studies during the 1970s showed that both the above linear models (technology push and market pull) were extreme and atypical examples of industrial innovation. In particular, Mowery and Rosenberg argued that innovation was characterised by a coupling of (and interaction between) science and technology (S&T) and the marketplace. The coupling model presented in Figure 3 was described by Rothwell as ‘a highly simplified, but nevertheless more representative model of the innovation process’. Rothwell also noted that the process of interaction was not necessarily continuous but could be understood in terms of functionally interacting and interdependent stages, involving complex communication paths and intra- and inter-organisational linkages. Unlike the two previous models, the interactive model explicitly links the decision making of firms to the S&T community and to the marketplace.

![Figure 2. Second generation demand pull models. Source: Rothwell (1991, Ref. 9, p. 33)](image)
2.4 Fourth Generation: Integrated Models (1980s)

Although third generation models were non-linear with feedback loops, Rothwell\textsuperscript{18} nevertheless criticised them as being essentially sequential in nature. During the 1980s, following observations of innovation in Japanese automobile companies, integrated or parallel models began to be developed that involved significant functional overlaps between departments and/or activities. These models attempted to capture the high degree of cross functional integration within firms, as well as their external integration with activities in other companies including suppliers, customers and, in some cases, universities and government agencies.

![Image of the coupling or interactive model of innovation](image)

*Figure 3.* The coupling or interactive model of innovation. *Source:* Rothwell (1993, Ref. 7, p. 21)

2.5 Fifth Generation Systems Integration and Networking Models (Post 1990)

Fifth generation systems integration and networking models emphasised the learning that goes on within and between firms, suggesting that innovation was generally and fundamentally a distributed networking process. These models were based on observations during the 1980s and 1990s of an increase in corporate alliances, partnerships, R&D consortia and joint ventures of various kinds. These interpretations were extensions of fourth generation integrated models, further emphasising vertical relationships (e.g. strategic alliances with suppliers and customers) and with collaborating competitors. According to Rothwell\textsuperscript{19} the fifth generation approach was brought about by time pressures on leading edge innovators. Rothwell’s fifth generation process also relied on the use of
sophisticated electronic tools in order to increase the speed and efficiency of new product development across the entire network of innovation, including in-house functions, suppliers, customers and external collaborators. As Rothwell put it: ‘5G essentially is a development of 4G in which the technology of technological change it itself changing’ and ‘5G represents the electronification of innovation’.21

Figure 5 presents a recent version of a fifth generation model. This model, like its predecessors, is both a descriptive and normative model, put forward to suggest the processes a firm company should put in place if it wished to become a leading edge innovator.22 The main difference between fourth and fifth generation models according to Rothwell was the use of an electronic toolkit operating in real time to speed up and automate the process of innovation within the firm. More recently, some versions of business process re-engineering also emphasised the application of information technology systems in corporate strategy and innovation.23 Rothwell was clearly ahead of his time in pre-empting this trend in thinking. Rothwell24 also argued that despite the difficulties and costs of moving in the direction of 5G, the benefits to be gained were considerable in areas such as speed of innovation, cost reduction and attaining market leadership.

3. Assessment of Specific Innovation Models

3.1 Strengths and Benefits of Innovation Models

On the positive side, each generation of model captured the academic knowledge of the time and summarised perceptions of best practice. Each generation served as a foundation

![Figure 5]("image.png")

*Figure 5. An example of a systems integration and networking model. Source: Trott (1998), cited in Mahdi (2002, Ref. 61, p. 45)*
for more sophisticated models allowing the incorporation of additional factors relevant to
the innovation process. Also, each model generated useful insights and hypotheses into the
nature of innovation and decision making requirements at the level of the firm, pointing to
important links between innovation and other key processes within the firm (e.g. manage-
ment, marketing and manufacturing) and external to the firm (e.g. the S&T environment,
universities and government policies).

In addition to serving as a foundation for understanding, the various models have been
widely used by companies within the IACs to guide the innovation process. Major consult-
ty firms frequently adopt one or other of the innovation models, and further develop
them for guiding businesses wishing to improve their innovation processes. For example,
Cooper\textsuperscript{25} introduced the well-known, stage-gate model of innovation with
advice on each decision phase, linking innovation with market assessment at every
stage of the process and identifying key milestones at which to assess performance.
This model has a second generation character (market pull) with some aspects of third
generation (push–pull combinations and integration of R&D with the market place).

Another well-known decision model is the development funnel model of Wheelright
and Clark\textsuperscript{26} that is widely used by industrialists. The funnel model shows how innovation
ideas are gradually narrowed down and selected and how project portfolios could be
managed. It allows for feedback between stages of the innovation process, moving from
idea generation to the overall design of a project, on to rapid focused development.
This model can be seen as an example of a third generation model because it incorporates
feedback loops from one stage to another. Similar software development models (e.g. the
waterfall and spiral models) are also widely used in industry\textsuperscript{27} and provide guidance on
how to manage the software process through its life cycle. The spiral model can be see
as a fourth generation model because of the intensity of iteration involved.

3.2 Criticisms and Weaknesses of Innovation Models

3.2.1 First and second generation models

Turning to first and second generation innovation models, as Forrest notes,\textsuperscript{28} these have
been widely criticised by many observers for their linear, sequential nature and for oversimplifying the innovation process. These criticisms also apply to well-known higher level
linear stages models\textsuperscript{29} where firms (and/or entire industries) are viewed as moving from
one stage to another (e.g. from research to engineering to production, or from early to
late stage product cycles). Other models criticised for linearity include various firm
level ‘pipeline’ or departmental models where innovations move from one department
to another in sequence.\textsuperscript{30}

Table 2 presents six well-known criticisms of naïve stages models.\textsuperscript{31} The sequential,
pipeline nature of stages models tends to view innovation as one discrete activity followed
by another, with each activity or stage isolated from each other. In practice, the evidence
shows that the sequential nature is seldom valid, and there is much feedback from one
stage to another, as well as inter-dependencies between the stages.\textsuperscript{32} Innovation activities
are often concurrent, with overlaps between activities and/or departments. At the industry
level there is occasional ‘de-maturity’, when whole industries begin new cycles of develop-
ment as a result new technologies. At the firm level, there is reversal as, for example,
prototypes are returned to design departments for re-design.
There is little evidence to verify general claims regarding stages and, often, important inputs from the wider environment are ignored. Stages models underestimate the often chaotic nature of the innovation process, especially in the early stages when a new concept is being generated and tested. Second generation models make marketing and market research integral to the innovation process, for example, by pointing to the importance of interaction between marketing and R&D. However, like the pure technology push models they tend to ignore other important aspects of the innovation process including working relationships with customers, feedback loops from later to early stages, and interactions with the S&T environment.

3.2.2 Third generation models

Third generation coupling models are a major improvement on earlier models, and explicitly and/or implicitly attempt to address some of the weaknesses outlined in Table 2. For example, the Schmidt-Tiedemann concomitance model divides innovation into three spheres: exploration, innovation and diffusion. Unlike earlier models, feedback from the post-innovation diffusion stage is recognised and with it the need for firms to adapt new products to competition by improving quality and product features and reducing costs. The term concomitance is used to show how the various business functions (e.g. research, technical evaluation, engineering development, market research, sales and distribution) accompany and interact with each other during the innovation process. The main criticism of this, and other third generation models, is that they do not deal sufficiently with environmental factors (e.g. the S&T environment and government regulations).

Another well-known model with some coupling features is that of Utterback and Abernathy. This highlights the changing character of the relationship between process and product innovation as firms grow, volumes increase, industrial structure evolves, and markets mature. This model introduces the concept of a dominant design (or industry standard) that paves the way for a shift from product innovation in the early (or fluid) stage, to process-centred innovation as volumes grow. As markets mature, large firms dominate and an industrial shakeout occurs. However, as Forrest notes, when this model was tested empirically by de Bresson and Townsend, and Martin, it was found that it did not apply to all industries as initially suggested (and subsequently proposed more recently by Klepper). As Woodward and Kim point out, there are major differences in the relationship between product and process innovation, according to the product and technology in question. The distinction between unit (or project based) production, large batch/mass production, and continuous process technologies is especially important. For example, in high value complex products made in projects, the process-intensive

<table>
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<tr>
<th>Table 2. Criticisms of first and second generation models of innovation</th>
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<tr>
<td>1. Sequential nature not valid in practice; non linearity often observed</td>
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<tr>
<td>2. Many activities concurrent; feedback loops from later to earlier stages common</td>
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<td>3. Little systematic evidence to verify the claims of models</td>
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<td>4. Other inputs from the ‘environment’ not considered (e.g. S&amp;T knowledge, customers, users, suppliers, competitors, policy agencies and universities)</td>
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<tr>
<td>5. Little to say about what goes on within each stage</td>
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<tr>
<td>6. An overly orderly ‘rational’ process implied; no recognition of alternative pathways; human decisions and choices underplayed</td>
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Source: Derived from Forrest (Ref. 28).
innovation phase is never reached and product design remains at the early stage of the innovation ‘life cycle’.  

3.2.3 Fourth and fifth generation models

With respect to fourth and fifth generation models, there is little evidence to demonstrate that firms have adopted these models of innovation or that, in the case of fifth generation models, that the adoption of information technology (IT) leads to the benefits proposed. Indeed, some studies have questioned the value of IT, pointing to major disappointments in the adoption of IT systems at the firm level.  

These studies stress the negative aspects of IT (high costs, difficult and lengthy learning curves and unrealistic claims) and the need for strong internal capabilities as a pre-requisite for the successful use of IT in complex tasks such as innovation. These studies show that without accompanying organisational changes, the implementation of sophisticated IT systems can be a costly and inefficient exercise that can lead to worsening rather than improving performance.

In some cases, IT appears to improve efficiency. In others it does not. The ability of IT to improve innovation efficiency probably depends on the nature of the product and technology in question and the depth of IT knowledge within the firm. Also, if a task requires a great deal of tacit knowledge and informal communications then it is unlikely that IT alone will be able to improve efficiency. For simpler tasks, IT systems may well be able to automate and speed up operations. While IT may be able to support lower level, routine tasks it is unlikely to be a substitute for human interactions, team building, group work and the leadership required in successful product and process innovation.

4. Linking Innovation Models to Developing Countries

4.1 The Catch Up Dimension

None of the five generations of models above attempt to deal with the issue of latecomer catch up from behind the technology frontier. Most models implicitly assume firms with leadership status (or ambitions) and most are oriented towards large firms (e.g. with R&D departments and elaborate organisational divisions of labour), rather than medium or small firms that might operate with more informal processes (with perhaps no official R&D or engineering department). Most of the models deal with R&D-centred activities, where innovation is defined in the strict sense as a product or process new to the world or marketplace (see Introduction). Therefore, these models are not appropriate, at least in their current form, for dealing with catch up innovation. In catch up cases, the evidence shows that substantial innovation occurs based on minor improvements to existing processes and product designs via the absorption of foreign technology from abroad.

Although it is outside of the scope of this paper to review developing country catch up innovation models, it is clear that the building of firm-level innovation models for understanding how catch innovation occurs, and how it can be improved, is important for firms in developing countries. This work is needed not only for understanding past patterns of innovation but also for guiding and improving current and future processes of innovation as latecomer firms increasingly reach the frontier, perform R&D and compete as leaders.

4.2 IAC Models and Developing Countries

There have been few attempts to explicitly link IAC innovation models with innovation paths in developing countries. However, one important exception is Kim who connects
the well-known model proposed by Utterback and Abernathy with innovation processes in developing economies. Kim argues that the process of innovation in catching up countries is fundamentally different from that of developed countries. Initially, Kim proposed a three stage model, with developing countries moving from acquisition of foreign technology, to assimilation and eventually to improvement. During the early phase of industrial development, firms acquire mature, foreign technologies from IACs, including packaged assembly processes that only require some limited local production engineering. In the second phase, process development and product design technologies are acquired. In the third phase R&D is applied to produce new product lines. As Kim notes, the sequence of IAC innovation events is thus ‘reversed’ with developing countries moving from mature to early stages of the innovation process.

Building on Kim’s model, Lee et al. link the reversed sequence with that of Utterback and Abernathy as shown in Figure 6. The upper half of the figure presents the Utterback and Abernathy model in which the rate of product innovation is high in the early fluid stage while the rate of process innovation is low. In the transition stage, a dominant design is selected by buyers in the market place and suppliers begin to fix on a specific process technology. In the third phase, competition is largely based on incremental process improvements as product design matures.

Lee et al. counterpoise Kim’s catch up model onto the Utterback and Abernathy model as shown in Figure 6. In this version of the model, developing countries catch up not only in mature technologies but also during the transition and fluid stages as they progress in their capabilities. Later, Lee and Lim extended this model by postulating the possibility of ‘stage skipping’ opportunities. What these models show is that at the advanced stage, firms in developing countries are increasingly able to challenge leading firms in the advanced countries. Hobday confirms this general reversal process for the case of electronics in four countries: Korea, Singapore, Hong Kong and Taiwan, noting that the process can occur both within locally owned firms and foreign owned firms.

Unusually, Kim and Lee and Kim explicitly recognise that specific patterns of catching up are contingent on the nature of the production technology. Using Woodward’s now classic differentiation between: (a) unit/small batch; (b) large batch/mass production; and (c) continuous process technologies, Kim and Lee, and Kim chart the innovation progress of firms in Korea, showing that product innovation is most important for catching up in unit and small batch production (e.g. large shipbuilding producers and machinery makers), whereas in large batch and mass production (e.g. electronics and car production) a mix of process innovation and product development capabilities are important. By contrast, continuous process technologies (e.g. cement, chemicals, pulp and paper and steel) are usually the least differentiated in terms of product but the most capital and process intensive. Therefore, the primary emphasis is on production process capability and acquiring the detailed proprietary know-how embodied in foreign production processes.

These ‘high level’ studies provide a useful approach to understanding catch up innovation in the developing countries and can provide the basis for further detailed research on firm-level innovation management. For example, they show that contingency factors such as the nature of product technology, the impact of government policy and the importance of the socio-economic environment are central to innovation. Further ‘lower level’ intra-firm research on the lines of Choi for the case of semiconductors, would help elaborate key processes, milestones and decision making priorities in catching up across
different categories of firm under different technology transfer conditions and alternative contingency situations.

Further analysis would also be useful for incorporating fourth and fifth generation model insights into the catch up process (e.g. the role of networking and information technology). Future work could be useful to guide firms in their innovation management strategies and for enabling government policy makers to differentiate policies according to the capabilities of firms. Intra-firm case research could show how the management of catch up innovation changes as firms approach and reach the technology frontier in areas such as DRAMs and TFT-LCDs, when conventional technology transfer opportunities become increasingly difficult as latecomers become a threat to incumbent leaders and followers in the IACs. However, as Section 5 shows, it is important to resist overly rational and deterministic interpretations of catch up innovation.

**Figure 6.** A simple life cycle model of catch up innovation. **Source:** Kim (1997, Ref. 5, p. 89). As Kim notes, this figure borrows ideas from James M. Utterback, *Mastering the Dynamics of Innovation* (Boston, Harvard Business School Press, 1994) and Lee et al., Ref. 47
5. Problems and Opportunities in the Innovation Field

5.1 Innovation Models in the Light of Empirical Evidence

This section identifies generic weaknesses and gaps in the innovation modelling field, based upon selected evidence of actual innovation processes, discussing, in turn, problems in the treatment of innovation variety, the nature of decision making and the lack of underpinning theory. Based on the difficulties identified, it is possible to outline some of the future work needed to improve innovation models for both developed and catching up countries, bearing in mind the need for relevance and realism. The argument put forward that existing models tend to lack realism in the light of existing evidence is not necessarily a criticism of the models themselves, but more a comment on how models (especially stages models) should be used. A section on the use and misuse of innovation models is also presented and finally implications for future research are discussed.

5.2 Importance of Variety Across Industrial Sectors

In a recent review of the empirical literature Mahdi61 shows that most of the five generations of innovation models are deterministic. Usually ‘one best way’ of innovating is proposed (across or within an industrial sector) and very rarely are alternative models and paths offered or explored. This applies especially to practitioner models frequently used in business,62 which tend to revert to simple stages models for decision making. Again, this is not necessarily a criticism. Although the models do not necessarily cover all possibilities, at least they provide ‘a guide to action’ and are widely used in business. As argued below, as long as firms accept their limitations and tailor the models to suit their own particularly circumstances, resources and purposes then they can be a valuable input into innovation management and decision making.

Mahdi63 also argues that the evidence directly contradicts the ‘one best way’ assumption in most innovation models. Instead, the evidence demonstrates that: (a) there are major differences in innovation processes across and within different industrial sectors; (b) there are significant differences among firms in the same industrial sector; and (c) that these differences persist over time and are not a ‘deviation’ from a norm or best practice. Put another way, the evidence shows there can be no one single model of innovation for firms to follow, and the notion of a generalised, average or best practice approach is misleading. By contrast, there are many innovation approaches, contingent on historical and external circumstances, each with a distinct set of rules and activities, advantages and disadvantages, only partly governed by the technology in question. Mahdi cites three empirical cases to emphasise his point that innovation practices differ across industrial sectors:

1. Pharmaceuticals—here, a process of search generates many options for a new drug; these are later screened against multiple clinical test criteria;
2. Software—typically, software development proceeds iteratively; first a rough specification of the programme’s requirements is made, then a prototype is developed that is then tested and modified;64
3. Passenger aircraft—a new aircraft project typically begins with an intensive, costly and careful up front planning exercise; only much later is a prototype built; the prototype is a major physical investment and is designed to resemble, as far as possible, the final aircraft.
As Mahdi points out, most surveys of innovation in practice confirm this view of persistent variety. Cooper, for example identifies seven distinct industrial innovation patterns with marked differences in paths and procedures. Innovation differences matter and they persist through time. Therefore, innovation models that fail to differentiate between industrial sectors and purport to be ‘best practice’ are inherently misleading both as tools for understanding and as guidance to firms on strategy or as an input to government policy.

5.3 Variety Within Industrial Sectors and Among Firms

Mahdi goes on to show that there are major persisting differences in innovation processes within particular industrial sectors and among firms in the same industrial sector. For example, in a study of plant breeders in Sweden and Britain in the early 20th century, Roll-Hansen reveals two different strategies, one conforming to a ‘rational’ design and test model, another to a step-by-step incremental approach. More generally, Miller and Blais show significant and persistent differences in innovation strategies among firms within six industrial sectors (pharmaceuticals, finance, software, metallic products, pulp and paper, and apparel and clothing). This also challenges the so-called contingency view that the product market, industry or technology determines innovation processes.

A study of the development of synthetic analogues of naturally occurring fungicides in agrochemical firms by Den Hond shows that despite similarities in research and technological trajectories, major suppliers adopted three different approaches to the same innovation problem: (a) the classic ‘generate many options, screen and test’; (b) the ‘rational’ approach, emphasising early stage design; and (c) recursive search, with prototyping and modifying functional categories, until promising results emerge. Similarly, in the electronics sector, a study of innovation in fax machines in Japan showed that one major supplier (Ricoh) approached the development with a ‘crash’ programme approach (involving multiple prototypes, multiple errors and frequent modifications), while another (Matsushita) followed a careful, rational planning process that structured the project into different groups, dealing with problems largely at the functional level. Both were successful.

In short, the evidence suggests that there is no ‘one best strategy’ and no single or ‘unitarian’ model as Mahdi puts it. Instead, if the evidence is correct there can be no possible generalisable approach or one best ‘best practice’ model of innovation. Different firms appear to generate alternatives paths, based on their resources, size, past experiences, culture, history and particular capabilities. This criticism applies to almost all of the five generations of innovation models, especially those that recommend paths for firms to follow.

5.4 Nature of Decision Making and ‘Rationality’

Most of the five generations of models assume firms are ‘hyper-rational’ in that they are able to hypothesise a solution to an innovation problem (e.g. a new product) and then proceed systematically to resolve the problem via a process such as concept design, prototype development and finished product. However, as Mahdi argues, this assumption of rationality is highly questionable for many firms. He cites the case of aircraft airfoil design to illustrate the nature of rationality in decision making and how this can change over time,
as experience is gained. Initially, airfoils (which determine the lift and drag performance of an aircraft) were developed by rudimentary trial-and-error experimentation. Later, they tended to be designed from knowledge gained from gliders. In the 1930s, wind tunnels began to be used to test and develop airfoils. By the 1940s, US firms were able to choose from a catalogue of around 2000 airfoils, similar to a ‘generate and screen’ strategy now followed in pharmaceuticals. Today, sophisticated computer modelling is widely used to generate a hypothetical design that is then developed and tested. Similarly, in the case of drug development, in the 1940s ‘serendipity’ was the primary method of searching, but today rational planning has been adopted by many firms, using sophisticated IT systems.

Mahdi interprets these examples, as evidence of the ‘bounded rationality’. Firms can only behave rationally if they have sufficient experience and capability to resolve the innovation problem confronting them (and the technology exists for a rational approach to be taken). If not, innovators resort to ‘non-rational’ trial-and-error experimentation. Therefore, any general purpose, rational (or prescriptive) model cannot apply to firms that lack the deep knowledge and experience required. Instead, most firms behave in a boundedly rational manner, according to their own specific histories and experiences.

Mahdi goes on to argue the case not only for pluralism (which recognises wide diversity of innovation models between and within sectors and across firms) but also for an approach that recognises that choices and paths taken are determined by the innovator’s own history, experiences and resources. He shows that product innovation approaches range from: (1) serendipity (i.e. luck or unexpected events); to (2) generate and screen; to (3) iterative design; to (4) precision planning. Each of these approaches is evident in the empirical literature. However, most of the models, tend to assume a hyper rational, but often unrealistic, decision-making capability.

A key empirical research question for developing countries arising from the above discussion then becomes: ‘Are the actual practices of innovation any more deterministic or rational than models of frontier innovation processes in IACs?’ Alternatively, do we witness similar variety across and within industrial sectors, and among competing firms? If so, how do we explain such variety and can models incorporate the factors that do tend to shape innovation processes in developing nations? To help answer the questions, it is useful to turn to the issue of theory in innovation models.

5.5 The Need for Underpinning Theory in Innovation Models

The lack of a coherent and explicit theoretical base is evident in most innovation models and may well underpin the problems of (usually implicit) rationalism and determinism frequently encountered. An explicit theoretical base is important because it exposes the users’ or researchers’ underlying assumptions about how innovation processes occur and the purpose and orientation of the innovation model itself. Theory can help guide research and embed innovation within the wider organisational and strategic context in which it probably belongs.

In the five generations of models, innovation is often treated as an isolated or separate process or, at best, a process that links to other factors. However, innovation is more than likely to be embedded within other major business processes and guided by the strategic management of the firm. Innovation is also likely to be heavily influenced
by the culture of the firm (e.g. outward-looking vs inward-looking; learning organisation vs static organisation). The evidence also suggests that innovation is strongly influenced by the resources available to the firm and the capabilities already developed within the company.

5.6 A Resource-based Theory of Innovation?

Although it is outside of the scope of this paper to integrate innovation studies within an appropriate school of thought (indeed, there may be more than one), it is possible to point to some useful approaches that deal explicitly with the needs of innovation theory. If we assume that innovation is a dynamic and contingent process, embedded within the firm, and if we wish to develop a realistic model of innovation, then modern resource-based theories of the firm are probably a good place to start as these deliberately deal with the internal dynamics of the firm and provide frameworks for analysing internal competence and strategic variety.

Resource-based theories of the firm assume that companies have access to specific internal resources and competencies that interact with the environment in which they compete. For example, building on the original resource-based approach of Penrose, authors such as Teece et al. have proposed a dynamic capabilities view of the firm. The Teece and Pisano formulation of ‘positions, paths and processes’ of individual firms is especially relevant.

Positions refer to the actual market relations and resources of a firm at any point in time, dividing resources (or assets) into two main categories: technological and complementary, showing how the position of a firm is shaped by its historical internal learning processes, corporate history, key strategic decisions, and past market successes and failures (i.e. its paths). Paths refer to the past and future possible business directions of the firm. Paths include actual patterns of technological innovation, organisational learning, product market achievements and financial investments. Future paths are ‘path dependent’ on historical choices, previous capital investments and the firms’ repertoire of routines. Processes (or business processes) refer to patterns of organisational, managerial, technological and operational practices—the ‘way things are done’—within the firm. Processes take place within and across the various functions of the firm (e.g. marketing, production, finance, engineering, R&D and personnel) and occur both formally and informally, shaping the efficiency and effectiveness of a firm.

The fact that innovation practices are often specific, ‘sticky’ and shaped by history (and therefore frequently very hard to change) is recognised by modern resource theory. The resource approach also rejects the somewhat determinist/rationalist view of strategy arguing that strategic options are both constrained and shaped by internal resources. Resource-based theory could therefore be a useful theoretical location for innovation models. Indeed, Hamel makes the important observation that innovation needs to occur at the strategic level, reflected in the business model of the firm. Otherwise, there is little to differentiate it from competitors. Rule breaking is therefore at the heart of strategic innovation.

Other related literatures may also be useful for developing a resource-based view of innovation. For example, the issue of how managerial learning relates to technological innovation is dealt with by learning organisation scholars such as Garvin, Stata and Senge. If organisational learning can become myopic, confused and misdirected and
lead to competence traps, then so too can innovation processes. Misdirected processes can lead to innovation back alleys and unnecessary re-invention and perhaps result in core rigidities within the firm. The important fact of divergences between a firm’s official strategy and its actual behaviour is analysed by Seeley Brown and Daguid, a pattern that may well apply to innovation in firms.

The need for organisations to reflect upon, control and reshape learning processes to prevent core rigidities (e.g. via ‘double -loop’ learning) is addressed by Argyris and Schon. As firms learn to innovate, such reflection may also be equally important. It is also highly probable that innovation performance is heavily influenced by the culture of the firm a subject covered by scholars of organisational psychology. These and other contributions could well help build up a realistic resource-based view of innovation.

5.7 Resource-based Theory and Developing Countries

Usually, resource-based theory assumes a developed country context, with a modern and sophisticated national system of innovation. In the IACs, firms draw upon this system and demanding markets guide decision making and influence firms’ visions of the future. Resource-based theory may therefore provide a useful ‘home’ for mainstream innovation studies. However, in developing (or latecomer) economies, this dynamic Schumpeterian environment rarely exists. Firms frequently operate within small, underdeveloped markets and the innovation infrastructure (including educational institutions and human resources) may well be lacking. In addition, technology has to be transferred and absorbed from foreign sources for catch up innovation to take place. Therefore, existing resource-based theory may not be adequate for dealing with latecomer innovation positions, paths and processes.

Indeed, the experience of successful East and South East Asian countries shows that a latecomer resource-based theory would need to deal with various categories of firm (local and foreign), which compete from behind the technology frontier. Most modern theories assume the firm in question is leader or a follower, rather than a latecomer (and usually a large firm), both in terms of intra-company resources and the external environment. These resources and complementary assets cannot be taken for granted in developing countries.

Therefore, a latecomer innovation theory needs to account for the major disadvantages faced by firms that (at the start at least) are dislocated from advanced markets and technologies. It should also account for latecomer advantages, including low cost manual, technical and engineering labour. These may enable latecomer firms to conduct innovative activities, such as the improvement of products and processes at a fraction of the cost facing firms in developed economies.

The empirical evidence on latecomer innovation contrasts markedly with traditional ‘Western’ models of innovation and place advanced R&D at the centre of innovation. As Kim shows for the case of Korea, the path to catching up was one of step-by-step assimilation of foreign technology, leading to more creative activities. At the national level, Gerschenkron provides a theory of latecomer advantages and disadvantages, but, barring a few exceptions, this has yet to be done at the firm level. An elaboration of latecomer firm ‘positions, paths and processes’ would be useful in understanding why innovation occurs in some developing countries but not in others and for identifying the barriers and enablers of innovation at the company level.
5.8 The Need for Innovation in Innovation Models

In addition to resource-based arguments for variety in innovation patterns, there is a further fundamental reason why one should expect to see major differences in innovation models and strategies, not identified in the literature. Put simply, if all firms followed established models or best practices, then virtually all firms would be imitators. This clearly cannot be the case. For example, first movers, by definition, establish new innovation models and strategies that can often change the competitive rules of the game (e.g., IBM’s resurgence with e-commerce, Dell in personal computers). As noted earlier, this is sometimes called strategic innovation, which encompasses not just technology, but marketing, corporate strategy, distribution and other business processes. However, it is also the case that to be successful, followers must also create new strategies and improve on existing technologies and develop novel business models to counter the advantages of first movers. In other words, followers do not (and cannot) merely pass through the stages of the first movers.

Equally, latecomer firms in developing countries must create new strategies to overcome their sometimes acute technological and market disadvantages in order to gain entry into international markets. They too must engage in innovation at the strategic and technological levels in order to create new market channels and benefits for customers. For example, Korean electronics producers such as Samsung did not merely imitate other competitors in the 1960s and 1970s when they began to compete in electronics. Instead, they created new strategies, shaped by their latecomer advantages and disadvantages, which involved rapid technological learning, new distribution channels and novel subcontracting relations with leaders in the advanced countries. The original equipment manufacture (OEM) system is a case in point. This system was brought into existence, developed and expanded by East Asian firms and their international buyers. It is an example of a new institutional innovation, vital for technological catching up and the successful export-led growth of Korean latecomer firms.

To the extent that latecomer firms do not simply follow existing models or past behaviours when competing, then catching up is essentially an innovative activity, at the level of strategy, marketing and technology. In many circumstances latecomer firms cannot merely imitate the leaders. The advance of leaders often changes the market and technology circumstances facing latecomers by moving the technology frontier in new directions. In addition, the latecomer will have its own distinctive resources, capabilities and stage of backwardness. Therefore, it is highly likely that instead of following prescribed catch up models or stages, a latecomer firm must develop its own distinctive strategies based on its own particular resources. At the early stages of catching up technological innovation may well be less important than cost advantages. However, through time as the firm begins to compete with international leaders, technological innovation is likely to become central to the overall business model followed by the firm in question.

To the extent that latecomer firm strategies differ from what has gone before, and stages are not merely passed through then innovation exists in the process and strategy of innovation, and models of innovation should accept and reflect this. Empirical studies should attempt to identify the innovative dimensions of catch up at the levels of strategy, technology, organisation, management, human resources, marketing and other key areas. Studies should also analyse how technological innovation is embedded within the firm and reveal the extent to which imitation and innovation are combined in processes of catch up.
5.9 Use and Misuse of Innovation Models

The need for variety and innovation in innovation models implies that models (especially stages models) cannot be used either as prescriptions or lessons for contemporary latecomer firms, or for explaining previous paths of firm level innovation (except perhaps at a very general level). Latecomer innovation paths are likely to vary according to the distinctive resources of a particular firm and its specific stage of backwardness. Therefore, it is likely that empirical research will find that many firms did not follow particular paths specified in models and that significant differences exist and persist among firms, even within the same sector.

However, innovation models can be quite useful both for understanding and for practical purposes if used appropriately. One important use of innovation models is to use them to ‘benchmark’ new patterns and thereby make sense out of them. Indeed, without such a benchmark it would be very difficult to analyse the different patterns of firms and therefore very difficult to build new, more sophisticated and accurate models.

To summarise, on the one hand, innovation models should not be used:

- to assume a particular historical behaviour on the part of a firm or group of firms;
- to recommend any specific form of innovation behaviour on the part of existing firms;
- to inform policies to support particular forms of innovation, except perhaps at a very general level (e.g. to support creative experimentation);
- as a decision making tool within firms, unless it is made clear that each firm will need to tailor and adapt the model to its own resources and circumstances.

On the other hand, innovation models can be very important as benchmarking tools for understanding the actual pattern followed by firms. They can also be useful for practice and strategy, as long as managers use them as a method for identifying actual practices and tailor them to suit their own particular market circumstances, resources and capabilities.

5.10 Implications for Empirical Research

The above arguments and evidence have interesting implications for empirical research on innovation. For example, more attention should be given to the extent of variety in models of innovation within and across sectors and among firms in the same sector. Empirical research might be able to show, in practice, how firms arrive at their particular innovation process or model, showing what a resource-based model ‘looks like’ in practice. Evidence could be gathered on contrasting types of innovation models that firms in different sectors tend to follow and how firms chose among them. This could help us understand the key factors that determine the evolution of innovation processes, including variables such as management strategy, technology/product, sector requirements, leadership and so on. It would be interesting to know how much room for manoeuvre a firm has in choosing an approach, given the lock in affect of history, resources and capabilities. Research could show how much room for manoeuvre there is in contrasting sectors, distinguishing between incremental and radical innovations. All this would be useful for academic understanding, teaching, company strategy formulation and practitioner training.

Equally, it is important to situate and analyse innovation within the wider context of business strategy and other aspects of business behaviour, culture and decision-making.
Empirical research could reveal the extent to which innovation processes are embedded within, and subject to, wider business processes and sector circumstances. Again, this would help reveal the space for strategic manoeuvring in innovation practice. Research could also try and show the sources of creativity in innovation models: does it arise from company leadership, market necessity, ‘bottom up’ employee contributions, or a mixture of these and other factors? Evidence on a representative selection of firms could show the extent to which innovation models differ in reality and how they were arrived at, helping us to understand more deeply the sources and causes of innovation.

5.11 Innovation Benchmarking in Industrialising Countries

For advanced developing countries empirical research could help reveal the scope for innovation variety in different sector catch up situations. Is there less, more or the same amount of variety as appears to be the case among leading firms in the advanced countries? Research could help show the differences across and within sectors, and among similar firms in the same sector, explaining the strategic choices made by particular firms. How important is imitation vs innovation in strategies followed? If strategic variety is necessary and desirable for promoting innovation and new ways of competing from behind the frontier, then what are the sources of experimentation and learning and how can these be stimulated through policy (if at all)?

Section 5.7 suggests that in order to approach these types of questions, it is useful to identify an approximate high level catch up innovation model and compare it with the empirical reality of what actually occurred, identifying both similarities and differences (and reasons for them) at the firm level. This form of innovation benchmarking could produce new, more realistic innovation catch up models relevant to different sectors, small firms and companies with contrasting sets of resources and capabilities. This might help identify the key factors that shape innovation behaviour and lead to success and failure in catch up innovation. In turn, this would help us build more robust and realistic models that could then be used for further data gathering and benchmarking in different developing countries, in the continuous search for a deeper understanding of the nature of catch up innovation.

Future research could build new innovation benchmarking frameworks for groups of firms in countries such as Korea, Taiwan and China. While it is true that no one innovation model fits all sectors, there are broad patterns according to industry type as shown by Cooper. Therefore, it would be useful to compare the innovation paths followed by firms facing different technology and market contingencies. It may well be useful to differentiate firms according to the extent and depth of their capabilities (advanced/world leadership, fast follower, latecomer/imitator etc). There will also be significant differences between large, small and medium sized firms, as well as local and foreign owned companies.

Benchmarking firms against models and cross industry comparisons could reveal how and why individual latecomer firms arrive at particular innovation processes. This would help researchers to understand the key factors that determine innovation choices and establish how much room for manoeuvre a firm has in adopting an innovation strategy, given the lock in affect of history and internal capabilities. Research should distinguish clearly between high level general process models and more detailed lower level decision making models for understanding and guiding firm behaviour. It is also important to distinguish between incremental, significant and radical innovations in future research.
It is wise to analyse innovation within the wider context of business strategy and other aspects of business behaviour and culture, showing the extent to which innovation processes are embedded within, or independent from, other business processes. Research could try and show the sources of creativity in innovation, comparing the role of leadership with other factors such as market necessity, imitation, and bottom up employee contributions to innovation. Such benchmarking research could help reveal the scope for innovation variety in different industrial catch up contexts, showing whether there is the same, more or less variety compared with frontier competitors in the advanced countries. At the current stage of development of a particular country, how important is creative innovation, compared with the ‘imitate and improve’ strategies? If innovation variety is desirable for promoting competitiveness, then how can the sources of experimentation be expanded and what role, if any, does government policy have in this area?

6. Conclusions

Each of the five generations of IAC innovation model reflects a growing body of academic knowledge and deeper analytical insights into the innovation process. Although first and second generation models tend to exclude vital elements of the innovation process, the later more sophisticated models incorporate feedback loops from later to early stages of innovation, and from the S&T environment and government policies to the firm and vice versa. Fourth and fifth generation models also account for the pre-innovation idea generation stage. The fifth generation network model attempts to show the benefits to be gained from automating the innovation process through the use of sophisticated information technology systems.

However, the individual models and the way innovation modelling has proceeded are subject to at least three significant criticisms. First, there is very little evidence to support the idea that actual innovation processes have evolved in the way suggested. Indeed, the interpretation of five successive generations appears to have as much to do with evolving academic perceptions of innovation processes, rather than empirically observed changes. Second, most innovation models lack an explicit theoretical basis, the emphasis being on empirical description. Third, innovation is often treated as an isolated process rather than as a part of the strategic management of the firm or as a process embedded in other important organisational activities.

More fundamentally, many of the models tend to imply there is one ‘best practice’ model to follow. This is a highly dubious implication. The evidence shows that there can be no standard textbook for innovation. Innovation not only depends on firm culture and context, but also leadership, ingenuity and vision. While the search for underlying structures and patterns is useful as a benchmark to understand progress, problems and patterns, the essential feature of innovation is rule-breaking rather than identifying and pursuing rules or patterns. This ‘anti routine’ view of innovation is supported by the evidence that points to a wide variety of innovation models between sectors, within sectors, and even among firms in the same industry approaching the same innovation problem. The appropriate model will not only depend on the sector and the particular innovation challenge, but also on the history, experience and capability of the firm in question.

This is not to say that innovation research and innovation models have no practical or analytical use. Firm-level models can be very useful for firm strategy and implementation processes, as long as managers tailor them to suit their own particular circumstances,
resources, needs and experiences. By using models in this way, firms can help clarify key innovation variables and processes, and develop a distinctive innovation strategy. From an analytical perspective, innovation models would be more convincing if they were located within an appropriate body of theory that could deal with external contingencies, strategic choices and the distinctive competencies of the firm in question. For firm level innovation management purposes, modern resource-based theories of the firm provide one possible body of theory, making explicit the assumptions and purposes of the models, and helping to ‘embed’ innovation within the broader context of firm activities and decision making.99

With respect to developing countries, as more latecomer firms reach the technology frontier, innovation models and processes based on leading firms in the IACs will become increasingly relevant. No doubt, as greater numbers of latecomer firms begin to threaten the position of IAC leaders, access to foreign technologies will become increasingly constrained and new mechanisms for acquiring and generating technology will be required, similar to those in the IACs. Future innovation research could fill a gap in the field by developing new catch up and ‘forge ahead’ models, relevant to different sectors and to the small and medium sized firms that have tended to be neglected in the past. Research could also show how catching up firms make the full transition to leader and the difficulties, risks and rewards involved. The paper suggested some ways of carrying out this work in advanced industrialising countries, some of which has begun in Korea,100 taking into account differences between industries, technologies and the firms themselves. Such research might also prove useful to other developing countries in their own search for innovation strategies to promote competitiveness, as long as any resulting models are tailored to their own resources, challenges and opportunities.

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Notes and References

1. So far, most of these firms have been from a small number of Asian economies, principally South Korea and Taiwan (M. Hobday, Innovation in East Asia: the Challenge to Japan (Aldershot, Edward Elgar, 1995)). Hopefully, other advanced developing nations, such as China and India, may find the issue of firm innovation models of interest as they seek to compete internationally. Because of the substantial differences between the levels of development of different developing countries and firms, the paper is mainly concerned with those firms approaching the innovation frontier.

2. The technology frontier is defined as the point at which R&D becomes central to overall competitive strategy and advantage of the firm. For an assessment of Korean firm ‘leadership’ innovation in important electronic components such as semiconductor dynamic random access memories (DRAMs), see Y. Choi, Dynamic techno-management capability: the case of Samsung semiconductor sector in Korea, PhD Thesis, Department of Economics and Planning, Roskilde University, 1994, and in thin film transistor/liquid crystal displays (TFT/LCDs), see T. S. Oh, Catching-up and forging ahead of latecomer firms: the catch up of the thin film transistor liquid crystal display industry in Korea, Unpublished MSc Thesis, SPRU, University of Sussex, UK, 2002.


6. The paper focuses mainly on technological innovation. However, organisational innovation, which is closely linked to technological innovation (R. Stata, Organisational learning—the key to management innovation, *Sloan Management Review*, Spring 1989, pp. 63–74; D. A. Garvin, Building a learning organization, *Harvard Business Review*, July–August 1993, pp. 78–92), is also touched upon.


8. The Appendix provides definitions of terms such as technology, research and development (R&D) and innovation.


10. Most post-Rothwell models fall into the category of fourth or fifth generation.


14. Ibid.


17. Rothwell, *op. cit.*, Ref. 7, p. 3.

18. Ibid., p. 4.

19. Ibid., p. 6.

20. Ibid.

21. Ibid., p. 11; emphasis from original text.

22. Ibid.


34. Utterback and Abernathy, *op. cit.*, Ref. 29.


40. The notion of a latecomer firm, as distinct from a leader or follower, is introduced by Hobday, *op. cit.*, Ref. 1, ch. 3.

41. Kim, *op. cit.*, Ref. 5

42. Utterback and Abernathy, *op. cit.*, Ref. 29.


44. Kim (1980), *op. cit.*, Ref. 43.

45. Kim, *op. cit.*, Ref. 5.

46. Kim (1980), *op. cit.*, Ref. 43.


49. Lee et al., *op. cit.*, Ref. 47.


52. This is also shown for the case of electronics in Malaysia and Thailand (M. Hobday, Innovation in South-East Asia: lessons for Europe? *Management Decision*, 34(9), 1996, pp. 71–81).


56. Kim and Lee, *op. cit.*, Ref. 54.

57. Kim, *op. cit.*, Ref. 5.

58. Ibid.

59. Choi, *op. cit.*, Ref. 2.
60. Ibid.; Oh, op. cit., Ref. 2.
63. Mahdi, op. cit., Ref. 61.
64. Even within the software field there are a number of competing approaches, depending on the nature and complexity of the software. Most complex software projects involve a high degree of iteration from concept to detailed design, final testing, installation and rework (M. Hobday and T. Brady, Rational vs soft management in software: lessons from flight simulation, International Journal of Innovation Management, 2(1), 1998, pp. 1–43).
67. As noted in Section 5.9, such models can be useful if they are used as devices for data gathering and benchmarking but not for explanation or prescription. A similar point was made by Gerschenkron in his critique of the ‘stages of development model’ put forward by Rostow in the 1960s (A. Gerschenkron, Economic Backwardness in Historical Perspective (Cambridge, MA, Harvard University Press, 1962).
71. Cited in Mahdi, op. cit., Ref. 61.
72. Mahdi, op. cit., Ref. 61.
73. Ibid.
79. E.g. Teece et al., op. cit., Ref. 76.
83. Garvin, op. cit., Ref. 6; Stata, op. cit., Ref. 6; P. M. Senge, The leader’s new work: building learning organizations, Sloan Management Review, No. 9, Fall 1990, pp. 7–23. Also see L. Kim, Crisis construction and organisational learning: capability building and catching-up at Hyundai Motors, Paper presented at the Hitotsubashi Organization Science Conference, 19–22 October 1995, for the case of Korea.
92. Kim, *op. cit.*, Ref. 5.
94. Hamel, *op. cit.*, Ref. 82.
96. This argument is derived from the work of Gerschenkron (1968) and elaborated upon in M. Hobday, Innovation in Asian industrialisation: a Gerschenkronian perspective, *Oxford Development Studies*, 31(3), September 2003, pp. 293–314, which argues the case for innovation at the policy and national levels for development to occur.
97. E.g. Lee et al., *op. cit.*, Ref. 47.
98. Cooper, *op. cit.*, Ref. 66.
99. This is a major subject for future research. Also, depending on the purpose of the research, alternative theories might also be appropriate (e.g. political, sociological or strictly economic approaches). Again, there can be no one ‘correct’ or best approach to understanding or modelling innovation.
100. Ho et al., 2003; Oh, *op. cit.*, Ref. 2.
103. P. Brimble, Technological innovation of industrial enterprises in Thailand, in Regional Workshop on Innovation in the Manufacturing Sector, National Science and Technology Development Agency (NSTDA), Bangkok, Thailand, 18 July 2001, p. 3.

Appendix: Definitions of Technology, R&D and Innovation

**Definition of Technology**

Beginning with Schmookler’s102 broad definition of technology as the ‘social pool of the industrial arts’, technology can be seen as a resource embodied not only in physical capital but also, more importantly, in human skills, institutions and social structures. In contrast with the static concept of production capacity, technology represents the capability to create and extend the existing pool of technological knowledge.
In developing countries technology transfer has occurred when some or all of the skills and knowledge related to a particular production process or product have been acquired. Transfer and acquisition are therefore two sides of the same coin. Without the capability to acquire technology, technology cannot be transferred. Effort, investment and purpose are required to acquire, assimilate and adapt technology and build up the stock of technological capabilities.

**Definition of R&D**

According to authoritative Frascati Manual of the OECD R&D is defined as creative work carried out on a systematic basis in order to create new or improved products, services or other applications. R&D always includes a substantial element of novelty and the use of science and technology techniques for resolving problems and uncertainties. There are three main classes of R&D:

1. Basic research (i.e. experimental or theoretical work with no application in mind);
2. Applied research (which is original research required to acquire and/or develop new technology with a possible application in mind);
3. Experimental development (which is directed at producing new materials, products, processes and services).

**Definition of Innovation**

As noted in the introduction, innovation is defined in this paper as a product, process or service new to the firm, as well as one new to the world or marketplace. Innovation is a process, involving the application of new knowledge and skills, rather than easily measurable once-and-for-all events. In the Asian newly industrialising economies, as in many other developing countries, most innovation occurs from ‘behind the technology frontier’ defined by the leaders in the advanced countries.

For developing countries to catch up, rather than merely ‘keep up’ with developed countries learning and innovation are required. Building technological capability through learning is a necessary but insufficient condition for narrowing the technology gap with developed countries. This is because the technology frontier itself is a moving target and can be shifting away from the developing countries fairly rapidly in areas such as information technology, the internet, new materials, telecommunications and bio-technology. Therefore, the pace and pattern of innovation in developing countries strongly influences their ability to catch up.

**Uncited References**
