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Managing R&D in Technology-followers

by

Naushad Forbes (Stanford University, USA)
and David Wield (Open University, UK)

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Abstract

The R&D effort, even of the largest, most technologically advanced developing countries, and their most sophisticated firms, cannot match that of the major industrial nations or the largest corporations. Our objective in this paper is to analyse innovation, technical change and R&D management in technology-leaders to build a framework for R&D in technology-followers outside of those major nations. This framework emphasises the importance of specific learning mechanisms and puts forward an argument that in-house R&D is indeed required in technology-followers, but a profoundly different type of R&D. R&D units, based in the firm, can become the location for organised learning, the problem-solver of last resort in production, the in-house knowledge store and gatekeeper, and the focus for independent design and product development capacity.

(Forthcoming in *Research Policy*)

1 Introduction

Innovation and technology management *do* take place outside large, globally famous, high tech corporations though those activities receive much less attention. Much work on technology management focuses on innovation in leader-firms. We are concerned with technology management for 'the rest', in particular for the rest of the world outside the USA, Europe, and Japan. R&D is just one issue important for the study of innovation. It is, however, *the* issue that is most closely associated with innovation. But what is the role of R&D in a technology-follower?[1] Why is R&D necessary in technology-followers? How is R&D best organised to meet the special needs of technology-followers? What opportunity does the distinction between technology and design provide for technology-followers?

Although there is a range of excellent studies of technological capability building in technology-follower countries,[2] theoretical and empirical work has focused less on R&D content in technology-follower firms. There are good firm-level case studies and some excellent national studies but as yet few attempts to synthesise the evidence both for theory and practitioners. Kim (1997a) and Lall (1987) are very much exceptions. Kim extends valuable case studies to the more general framework we propose in this paper. Korea is, nevertheless, an exceptional case with the world's highest growth in R&D expenditures by far. Business R&D, mainly by the giant chaebols, grew at 32% a year in the 1980s. Korea, as Kim convincingly argues, did *everything* - deepening industrial structure went with huge efforts by individual firms to learn from developed countries, with increased state R&D, and with drastically increasing private R&D, all accomplished with strong government support in the form of finance, protection, and, in the 1970s, active direction. Lall provides valuable case studies of the technological activities of Indian firms, conducted in the mid-80s, that can be used together with a relevant framework for R&D in follower firms today.

Our analysis of R&D in contemporary technology-follower firms provides a framework relevant beyond the state-supported huge-firm environment that characterises Korea. In particular, our analysis leads to conclusions as much of what need *not* be done as what must be done, since we argue that, in most firms and nations, not all can be done at the same time, and sequencing is necessary.

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[1] By "technology follower" we mean something quite specific, as detailed in the next section. Simply it means firms from newly-industrialising countries who do not define the state-of-the-art in technology.

[2] See, for example, Lall, Kim, 1997a,b, 1998, Katz, 1987, Lall, 1987, 1996, Hobday, 1995.

To develop our argument that a different type of R&D is needed in technology followers first, we clarify the key concepts of innovation, technology-follower, and the innovation tasks in technology-followers (section 2). Second, in section 3, we examine the critique that R&D is a waste of money and scarce expertise in a developing country and go on, in the following sections, to develop an argument that R&D is required in technology-followers. We use empirical evidence from a range of sources to detail the specific role for R&D in a technology-follower, emphasising the importance of in-house R&D units, intangible in-house assets and benefits for the firm, the specific role of R, and the key role of independent design capability and 'soft' quality in moving up the value-chain of global production.

The paper focuses on technology-followers in newly-industrialising countries, although many of our arguments apply more generally to all followers. Rather than pushing out the technology frontier, we argue instead that the innovation task in followers should aim to approach and follow the frontier as efficiently as possible, with the objective to move the firm up the value-chain of global production by increasing productivity and making higher value products. That the future technology frontier is known to followers reduces the uncertainty involved in innovation, but makes the innovative task different rather than trivial.

At one level this argument seems uncontroversial, especially to those who have accompanied the rise of innovation studies, including the study of individual innovations and push-pull theories; innovation in industrial sectors and firms; the rise of national innovation systems research; growth of studies of industrial clusters; and associated attempts to synthesise new knowledge systems differently.[3] However, there is still a need to synthesise the evidence and lessons, merge the available knowledge on innovation in developing countries, for micro-use by innovative and aspiring-to-be-innovative firms. As with many seemingly uncontroversial approaches,[4] traditional practices are well-ingrained and new practices harder to be accepted.

A new conceptualisation of R&D and its role in NICs[5] is required, the focus of this paper. First, one obvious lesson from the understanding of technological change in

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[3] For example, Faulkner, 1994, Coombs and Richards, 1991, Pavitt, 1984, Nelson, 1993, Edquist, 1997, Gibbons et al, 1994.

[4] A similar example is the difficulty of establishing alternatives to the linear innovation model.

[5] We use the term NIC more broadly than others, to include not only so-called first and second tier NICs, but also historically relatively strongly developing countries like Mexico, Brazil and India. Our observations are also relevant to firms in a wide range of developing countries, and the countries of eastern and central Europe. A recent special edition of *Technovation* (Chataway, Webster and Wield, 1999) entitled Technologies in Transition looks at a number of issues addressed in this paper, with articles from 'north' and 'south'.

technology-leaders is that the bulk of R&D is *development*, not *research*. If R&D is overwhelmingly *d* in technology-leading countries, then it should certainly be so in technology-followers. The figures, however, clearly indicate otherwise, with countries like India, Mexico and Brazil spending upwards of 50% of national R&D on research. The consensus of studies of R&D in these countries is not only that R&D spending is much lower than in technology-leaders, but the bulk of industrial research never appears in the productive sector (Forbes, 1991). Second, the balance of industrial research is heavily fragmented - in India, for example, around $600 m of total private-sector R&D is spread over 1,300-plus separate firms (General Motors, IBM, HP, Glaxo Wellcome, Philips and Merck spend a multiple of that *each*). Technology-followers cannot hope to compare with technology-leaders in R&D spending. They do not have to because the role of R&D in a follower is quite different.

Our analysis thus contrasts significantly from the generally prevailing view that it is only a matter of time before followers have to match the R&D spending of those at the leading edge. It is our thesis that increased focus on R&D in NICs can pay rich dividends. This is hardly new: politicians and academics in these countries have been arguing the virtues of increased R&D for at least five decades. What is new is the insight that the type of R&D and its focus is far more critical to the success of industrial innovation than the level of R&D spending, until firms become concerned with pushing forward the leading edge. First, industrial R&D must be done in firms, not autonomous labs. Second, it is not research that is needed but development. Third, the role of R&D activity in follower firms has to be fundamentally rethought, learning from recent work in technology-leaders. On the one hand, it is the role of R&D to effectively support the followers' quest for long-run competitiveness in manufacturing. This involves solving shop-floor problems and fostering learning across the firm. But the role of R&D is also to deliver an independent product development capacity to the firm. Doing so involves recognising the importance of design, and the distinction between design and technology. We argue that it is the role of R&D in followers to push out the design frontier while following the technology-frontier, and we advance an argument as to how this can be done. The role of R&D in NICs, then is not one of Research and Development, but of Development and Design. Focusing on the dual role of the R&D function in followers, of efficient frontier-following and effective design leadership, provides the potential for firms in NICs to move substantially up the value-chain of global manufacturing. Each element of this argument is well-known, the issue is how to break old and develop alternative practices.

2 *Innovation in Technology followers*

One such 'old' practice is based on the linear innovation model. For almost three decades, thinking about science and technology was dominated by a linear research-to-marketing model where the development, production and marketing of new technologies followed a well-developed time sequence that originated in research, involved a product-development phase that led to production and eventual commercialisation. This model had the advantage of being conceptually simple but the disadvantage of being misleading. Kline[6] provides a more complex, grounded and systemic model of the reality of innovation by emphasising the central role of design, the feedback effects between the downstream and upstream phases of the earlier linear model and the interactions between science, technology, and the process of innovation. Kline combines two different types of interaction: processes within a given firm, and the relationship between the individual firm and the wider science and technology system within which it operates.

What being a Technology-follower means

Technology-leader countries are those which collectively define the technological frontier at any point in time, *and move it forward*.[7] Successful innovation in technology-leader countries requires first, a commercially correct definition of the new frontier, and second, the activities involved in reaching it. There is uncertainty in both these tasks, and the challenges involved will depend on the specific innovation.[8] Contingency is important. For example, the technology-follower innovation required in producing laser printers in India for the first time is quite different both in its technological uncertainty and the technical effort required than producing, say, the next generation RAM chip. Technology-follower countries (and firms within them) may be far, near, or even at the technology frontier for particular industries, but are generally not involved in pushing it forward. For technology-follower countries *the future is already shaped*. Technology-follower countries and firms usually approach

[6] See Kline, 1989 and OECD, 1992.

[7] In practice, it is unlikely that any one country will be pushing forward the technology frontier in all sectors. The US might define and move forward the frontier in aerospace, while Japan does so in automobile manufacturing, and Switzerland does so in food processing. Indeed, it is often more correct to talk of sub-sectors – braking systems or avionics or micro-computers. It is also more correct to talk of technology-leader *firms* that operate in countries, within particular innovation systems. Since our concern is with technology followers outside of the USA, Europe and Japan we focus on particular regions of the world and on firms located there. There are countries outside of USA, Europe and Japan where some firms and sub-sectors have been on the frontier. Examples have been mining in South Africa, perhaps small aircraft in Brazil and some sub-sectors in the ex-Soviet Union.

[8] The concept national innovation system attempts to encapsulate the notion that leader-nations contain various types of institutions, including firms.

the frontier through the transfer of technology from a technology leader (avoiding reinventing the wheel).[9] Flexibility varies but there is, for the follower, an example, or examples to follow, perhaps slavishly at the beginning, what Dore (1989) calls Indigenous Technology Learning Capability. The innovative task in the above example is to *learn* how to make laser printers efficiently. The laser printer exists as a product; the future is specified. There is also less uncertainty - it is known that making a laser printer is possible and is commercially successful.

The Innovative task in Technology-follower countries

This does not mean that the innovative task for technology-follower countries is a minor one of adapting imported technology to local conditions. First, the technology-leader may not be willing to supply all the technology possessed. Second, technology has a large uncodified component. This tacit component means that even in the best case, where the supplier is willing to provide all the technology available, the receiver always winds up with less technology than the supplier has (Teece, 1981). The receiver is thus *by definition* behind the frontier to start with and has to make up for this difference locally. Third, as the technology frontier is always moving, and at an increasing pace in many industries, if a follower does not progress technologically at more than the speed of the leader, it will not catch up.[10] Fourth, even adaptation to local conditions is often much more than minor adaptation. Tackling problems thrown up by local materials, labour, market and environment requires a major development effort.[11] Finally, and one of our central arguments in this paper, the development of new products to move up the value chain of international manufacturing directly demands substantial technical effort.[12]

To summarise, a technology-follower is not concerned with the generation of new technology; the frontier is defined by the technology leader. Even if the technology-leader is willing to provide all the technology available, the tacit dimension and dynamic nature of technology requires considerable innovation on the part of the receiver to keep up with the technological frontier. The conclusion is that the

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[9] See Radosevic (1999) for an analysis of the change from contract bargaining to sourcing in recent technology transfer policy.

[10] Many developing countries made the mistake in formulating policies for technology transfer in the seventies and eighties of seeing technology as static and technical change as a one-time affair. On the contrary, constant, increasing technical change characterises the most attractive markets in the world today, even those (like automobile or even steel manufacturing) previously thought to be 'mature'.

[11] Lall, 1987, 1990, Kim, 1997a,b, and Katz, 1987 give a range of evidence of the technological effort of developing countries to adapt foreign technology to local conditions.

[12] The first four Innovative tasks would be a large part of the picture for followers, but – as we argue in this paper – missing the fifth would be to miss the increasingly important task for them.

innovative task in technology-follower firms (and countries) is not less difficult, but it is different.

What kind of innovation is key in technology-followers?

We suggest five linked propositions on the innovative task in technology-follower countries, together leading to new practices for R&D in followers:

(i) *Incremental innovation is key:* it is simplistic to think of innovation in *either* incremental *or* radical terms but as a continuum and a combination of incremental and radical, what Tushman and Nelson call 'the essential interplay between major and incremental innovation over the course of the product cycle' (1990, p.1). The analysis of innovation as a leap process followed by subsequent incremental steps applies in both technology-leaders and followers. Perhaps in leaders the leap can be a *new technological paradigm* but in followers the leap is *new to the firm.* As the technology-leader continues to improve the technology, keeping up requires incremental innovation, catching up requires incremental innovation at a faster pace than in the leader. Incremental innovation is thus the primary source of long-run competitiveness in technology-followers.

(ii) *Process innovation* will often be more important than product innovation, but both product *and* process innovation matter and are different at different stages in industrial development (Kline, 1991). Technology-follower industries will be more mature when the innovation drivers change to cost competition where process innovation matters more. Riggs argued that the Japanese industrial 'miracle' through the mid-seventies was built around process innovation and, to a lesser extent, incremental product innovation.[13] More subtly, it is simplistic to think of either product or Process - their unity is the essence of Design for Manufacturability. As an example, Hewlett Packard's subsidiary in Singapore reduced manufacturing cost of the HP 41C calculator by redesigning the product to use fewer components illustrating well that products may be changed to improve the manufacturing process, and vice versa.

(iii) *Shop-floor Innovation* arising in day to day operations, *thrown back from the work*, is the major source of cost-saving on the shop-floor.

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[13] See Riggs, 1984, 'Innovations: A United States-Japan perspective', an unpublished paper presented to the US-Japan project on high technology. An abridged version is reprinted in Okimoto and Rohlen, Eds., 1988.

(iv) *Organisational, cultural and managerial*: building an environment where innovation happens everywhere is crucial to firm technical capability. For incremental innovation to be powerful, it has to be widespread and continuous. Quality circles, suggestion schemes, and *kaizen* continuous improvement programmes are precisely systematic ways of capturing creativity across the organisation.

There are many variables that go into the crucial issue of building an innovation culture. An important barrier is a subtle combination of NIH + FIB that is quite lethal to technological effort (and quite pervasive in technology-followers). The *Not Invented Here* syndrome, where cast a supercilious eye on learning from outside the firm is often combined with a big exception in its gaze - *Foreign Is Better*.[14] The deadly result is an attitude and practices against fiddling with imported technology - a feeling that it cannot be improved on locally. Instead, the objective is to be as close to the foreign firm's quality as possible, and not attempt improvement. International competitiveness requires cultural confidence which permits a combination of openness to learning from outside and pride internally that takes nothing as given, regardless of nationality.[15] For example at one medium engineering firm in India 'Before 1991, Forbes Marshall had a sizeable R&D department but it was not developing new products ... When the R&D engineers were called together to discuss product development, they were quite mystified. They thought that the existing collaborations forbade conceptualising new products. A list of products within the company's technological capability was made, and it was shown that in most of them, their freedom was quite unconstrained. Still, the engineers had no idea how to go about conceptualising a new product and designing it.' (Desai, 1997, Forbes, 1999). Evidence suggests that innovative firms reward success, tolerate failure, and punish inactivity, directly contributing to the willingness of individuals in an organisation to experiment.

Kim (1997a) makes the case for crisis construction as a way of forcing much technological effort and innovation. The chaebol set unreasonable deadlines that required 7-day weeks by the engineering, thus establishing a pace of local innovation where rapid change and great effort became the innovation culture,

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[14] A favourite cartoon by the Indian cartoonist Laxman has a doctor looking into a patient's eye saying, 'You have some foreign matter in your eye. Would you like to keep it since it is foreign? See Tidd, Bessant and Pavitt, 1997 for a discussion of NIH as a barrier to learning in firms.

[15] See Dore, 1990, for an insightful discussion of this cultural requirement for being a good learner.

a culture suited to the rapid catch-up that has characterised Korean development over the last forty years.

(v) Finally, and the focus of this paper, *the role of R&D* in a technology-follower will be different. This different role in turn demands that R&D should be organised differently. The relationship between design and technology provides opportunities for technology-followers to move up the value-chain.

3 *Why do R&D in a technology-follower?*

R&D as the expensive option

The developed world accounts for around 95% of total global R&D spending. It is technological *uncertainty* which makes R&D expensive in a technology leader. In a technology-follower the degree of technological uncertainty involved is massively less. The key issue for R&D in followers, then, is not *how much* R&D, but *what* R&D. The rest of this section substantiates this argument.

Most studies of R&D in industrialising countries draw comparisons of R&D spending as a percent of GDP or as a percent of turnover (see Table 1), usually with the objective of arguing that R&D spending must be increased to build local technical capability.

Although some NICs spend, by developing country standards, large (and increasing) amounts on R&D, this is still relatively small in comparison to technology-leaders, whether at national or firm-level. In terms of scale, the highest spending NIC in 1987, South Korea, was reported to have spent $4.5 bn on corporate R&D, about what one firm, General Motors spent in the same year. Glaxo-Wellcome spends well over $1 bn on R&D each year, more than the *total* pharmaceutical sector in all six NICs (every firm and government lab) added together.[16] In 1989, India's total private-sector R&D spending in over 1000 industrial 'labs' came to $450m; Stanford University, meanwhile, had an R&D 'budget' of $286m in the same year.[17] But although technology-followers cannot compare with technology-leaders in R&D spending, they do not have to: 'Quite simply, the vast majority of attempts at innovation fail' (Rosenberg, 1996, p.334). Well over half of all R&D projects in technology-leading firms are simply cancelled.[18] Indeed, Nelson describes capitalism as simultaneously wasteful and powerful. It is powerful because it is capable of generating many alternative approaches to technical change and then has institutions in place (firms and markets) to select the best alternative. But this approach is 'wasteful' with duplication of effort, much that turns out fruitless, and areas where no work is done because the benefits are not appropriable enough to justify effort by any

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[16] In 1996, the recently merged Glaxo-Wellcome had 9000 employees in research and spent $1.8 billion on R&D. Merck spent $1.3 billion with plans to significantly increase R&D spending in the future. Glaxo and Merck, Annual Reports, 1996.

[17] The number for universities is hugely understated since the availability of cheap but highly skilled labour (graduate students) does not show up in the numbers. Stanford numbers from OECD, India from DST.

[18] A report from 1982 indicates that for every 100 projects that enter development, 63 are cancelled, 25 become commercial successes, and 12 are commercial failures. See Leonard-Barton and Doyle, 1996.

one firm. It is precisely this wasteful attribute of technical change that makes R&D expensive in a technology leader. In a technology-follower, the ex-post selection[19] has already taken place, the new technological paradigm selected and the uncertainty of a different magnitude.

The Role of Research in R&D

R&D is largely D even in technology-leaders. Over 80% of industrial R&D expenditures are devoted to improving products that already exist (a development activity) (Rosenberg, 1996). In technology-leaders, research 'expands the base of knowledge on which existing industries depend and generates new knowledge that leads to new technologies and the birth of new industries' (Rosenbloom and Spencer, 1996, p.1). Kline suggests that research as an activity aimed at generating new knowledge is neither central to innovation, nor essential to industrial competitiveness. Gordon Moore, one of the founders of Intel, a world-leading technology-based firm in *the* technology-leading country says:

> Intel operates on the Noyce principle of minimum information: one guesses what the answer to a problem is and goes as far as one can in a heuristic way....Thus, rather than mount research efforts aimed at truly understanding problems and producing publishable technological solutions, Intel tries to get by with as little information as possible ... (1996, p.168).
> While operating as it does may, at some point, cause Intel to miss a revolutionary idea that has the potential to wipe out established positions, having a large competent R&D organization has not been shown to be protection against change in a basic business paradigm ... (ibid, p.169).

Research is critical both to advancing the technological frontier in fields dependent on formal research, like biotechnology and semiconductors, and as one of technology's 'well-springs'. However, as Moore points out, research tends to be much less firm-specific than product development, and proprietary innovation within the firm may well depend on knowledge added to the pool through research elsewhere.[20] This

[19] Nelson argues that technical change is best seen as an evolutionary process for three reasons: there is a variation-generating mechanism (R&D in firms) which develops several alternatives based generally on where they have been in the past. Technical change is thus 'path dependent'. Having generated these alternatives, there is then a systematic mechanism – the market – which selects on these variations such that only one or a few survive. This selection takes place ex-post. The technical change process is thus evolutionary because of both the variation and the systematic ex-post selection. See Nelson, 1987, 1993, 1995.

[20] One of the main reasons that firms do research is to increase their absorptive capacity for research being done outside the firm. See the discussion on absorptive capacity, above, and also Rosenberg, 1990.

points to a limited role for research in technology-followers. There are some exceptions, where technology-followers should do research, but this is beyond the scope of this paper.[21]

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[21] Briefly, the four exceptions are: (i) research in Universities to improve science and technical education (ii) organised research in specialty areas of importance where research would not otherwise be done worldwide (iii) research where local appropriability is a problem – say where a particular industrial sector is hugely fragmented in structure with hundreds of small firms, and (iv) research as a ticket of admission to understanding and accessing work done elsewhere. See Forbes, 1991.

4 The role and organisation of R&D in technology-followers

One might conclude that technology-followers should not do R&D. There are, however, at least four reasons why followers should do R&D. First, formal R&D effort can usefully complement process thrown-back-from-the-work innovation. Second, R&D teams can play a crucial role as the firm's 'learners' of knowledge produced elsewhere. Third, doing R&D can have intangible spin-off benefits for the rest of the organisation. Fourth, and increasingly importantly, moving up the value chain to more attractive markets depends on a firm's ability to develop proprietary product-designs. Each of these is introduced below.

As a complement to shop-floor innovation

Most problems which arise on the shop-floor are best solved right there. But some need an organised and focused team effort, drawing on the skills embodied in an R&D department. Thus an obvious role for R&D in a technology-follower is to be the solver, though of last resort, of problems that arise on the shop-floor.

This argument draws from Nelson's analysis on why industrial R&D takes place primarily in specialised laboratories, and why these laboratories tend to be in-house. First, in many fields, bringing about significant technical change requires a concentration of people trained in science and engineering that is most easily found in a distinct institution - the R&D laboratory.

Second, even though one needs R&D to be distinct and separate, it needs to be *closely and permanently* connected to the firm:

> ...to be effective, industrial R&D generally needs good communication channels to the firm whose problems are being addressed, and who will in the end use the product of R&D.... Thus, while there are exceptions ... a firm is going to be forced to establish a long-term relationship with a research and development laboratory which, in turn, is committed to it....All this strongly pulls towards having an in-house laboratory (Nelson, 1992, p.173).

So too in technology-followers a specialised R&D laboratory can provide a concentration of skilled and qualified people, sufficiently removed from day-to-day routine, to solve bigger and longer-term shop-floor problems. The laboratory must be within the firm. Only then will it be primarily responsive to the problems of the firm and develop the long-term formal and informal communication channels needed for a close relationship.[22] Lall (1987) and Kim (1997a) provide several examples of the role of R&D in de-bottlenecking process plants and adapting imported technology to local raw materials to improve local manufacturing.

As the formal 'learning' unit of the firm

In technology-leaders, organised R&D is often the formal *innovating* unit of the firm. In a technology-follower, we argue, R&D might instead function as the firm's formal *learning* unit. In particular, R&D must build absorptive capacity to be able to access work done in other firms. This absorptive capacity is primarily a function of prior related knowledge which 'confers an ability to recognise the value of new information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990, p.128). R&D can thus perform the role of a gate-keeper to plug into external storehouses of knowledge. The knowledge a firm must access from the outside is usually highly specialised, requiring advanced training to understand it. Any R&D function grouping usually contains a high concentration of more qualified people, making them suited to carry out a gate-keeping role (particularly valuable in a technology-follower where the availability of experienced people is lower). Further, understanding of R&D being done elsewhere may require doing some R&D as a 'ticket of admission' to research done elsewhere (Rosenberg, 1990). This 'learning' role is of great importance in technology-leading firms.[23] In technology-following firms, it becomes R&D's *raison d'etre*. For several Korean firms the R&D department played the key role in transferring imported technology such that capability was built in-house for subsequent project execution (Posco, 1994, Kim, 1997a).

Building learning capacity in follower-firms includes 'the information-gathering network that can survey what is available in the world, detect new developments, judge what is worthwhile buying and learning in detail' what Dore (1984) called Independent World Technology Reconnaissance Capacity. Leading Japanese firms and South Korean chaebol have set up subsidiaries and bought firms to function as 'outposts' that, together with doing R&D, monitor research activities in advanced countries. Kim (1997a) documents several dozen such examples: in electronics alone, LG has laboratories in 'Tokyo, Sunnyvale, Chicago, Germany and Ireland ...

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[22] Although peripheral to this paper, this analysis explains why the autonomous government or non-government R&D lab, so beloved in NICs from India to Mexico, has contributed so little to technical change in local industry. See also Forbes, 1991.

[23] This argument is based on Cohen and Levinthal, 1990, and Nelson, 1992. Both papers talk of technology-leading environments. Indeed the learning and creating roles of R&D are closely related – an earlier paper by Cohen and Levinthal is titled 'Innovation and Learning: the two faces of R&D' (1989).

Samsung in San Jose, Maryland, Boston, Tokyo, Osaka, Sendai, London, Frankfurt and Moscow; Daewoo has two in France and one in Russia; Hyundai has laboratories in San Jose, Frankfurt, Singapore and Taipai' (p.143). In automobiles too, Hyundai has technical centres 'to monitor technological change' in Michigan and another in Frankfurt (p.120). In semi-conductors, Samsung, LG and Hyundai have bought firms in Silicon Valley as a way of monitoring advances.

Organising for learning requires that individual R&D engineers see themselves as technology-keepers. A technology-keeper has responsibility for tracking useful knowledge inside and outside the firm.[24] In a technology-follower, this useful knowledge will be overwhelmingly technological, not scientific. As Nelson points out, recruiting new scientists and engineers from university can keep a firm adequately up-to-date with scientific knowledge.[25] The technology keeper thus needs to be primarily concerned with what *other firms* are doing. The disadvantage of geographical distance between technology follower and leader can be compensated by regular access, formal and informal, to technical change at the technology leader that originally 'provided' the technology for the follower's current paradigm.

Effective technology keeping has at least three distinct roles: (i) boundary spanning and gate-keeping to track advances in the area wherever they may happen; (ii) codification, in that external knowledge needs to be 'captured' in some permanent form - collections of articles, reviews of new products of other firms, and so on, put together to represent the state of 'kept' technology. Codified knowledge provides a base for further since drawing on previously captured learning can dramatically shorten the learning curve; (iii) communication and utilisation, because unused knowledge is useless to an organisation. Knowledge from the keeper may be useful in very different work areas. Codification permits knowledge to be communicated more easily. But knowledge may also need to be translated into a form that is understandable to those needing it. Thus, the technology-keeper's role is not just to codify, but to translate and then communicate knowledge.

As a source of intangible spin-off benefits for the firm

R&D can also provide significant intangible benefits to the firm. First, R&D can set the tone for discourse on technology. Second, R&D can play a role as a change agent for a firm. As technology-followers start looking to international markets, the quality of such elements as product finish and packaging require a quantum leap. R&D can

[24] See Leonard-Barton, 1995, especially chapter 6, for recent appraisal of this concept, and boundary spanning.

[25] See Nelson, 1992 and Klevorick et al, 1995, for this argument for technology-leaders.

play a 'demonstrator' role of setting new standards that match the best internationally. Indeed, one of the most effective ways of building absorptive capacity is by bench-marking against competitive products. Bench-marking should extend across all key firm activities, but R&D is a natural place to begin the process, because it directly feeds into product development - a key activity for the firm's future. Third, doing R&D can help in attracting good technical people who are needed by the firm but who might not otherwise join.[26]

These intangible benefits are just that: vague and difficult to measure. But the role of a nucleus for new attitudes and new procedures, and attracting more technical people, is potentially important.

To build an Independent Product Design Capability

Finally, and perhaps most importantly, is the development of new products not based on new technology, but certainly new product conceptualisations: in short, new *designs*. Products range from homogenised low cost, usually mass-produced items, to high-value added items. Incremental innovation, process innovation, design for manufacturability, and optimising the supply-chain are all critical at the homogenised end. The high value-added end offers some of the most attractive opportunities, but at that end the firm must be able to define the design specifications. The development of products to meet *particular* local market needs also demands design capability. The firm thus needs design freedom - and R&D can deliver on this. In a later section, we will deal in more detail with the role of design and its relationship with technology, with examples of product development to meet local and global market needs.

---

[26] There are parallels: in Brazil, some universities simply do R&D as a way of attracting good teachers (see Forbes, 1991). Some technology leaders like HP, IBM and AT&T commit to some basic research to attract the best technical minds. Writing on the growth of US industrial research, David Hounshell says "throughout most of the twentieth century, research directors ... have had to find ways to give industrial researchers the semblance of academic research'. See Hounshell, 1996, p.27.

5 Learning Hierarchy in Technology-followers

Hobday (1995) cogently argues that several firms in Taiwan, Singapore, Korea and Hong Kong made a transition from being Original *Equipment* Manufacturers (OEM), to Original *Design* Manufacturers (ODM), to Original *Brand* Manufacturers (OBM). Firms such as Acer in computers and Samsung in microwaves began by making products to the specification of technology-leading firms in the US, Japan and Europe. Taiwanese firms continue to have over 80% of the world market for computer mice, most sold under US or Japanese brand-names. Samsung has been the world's largest microwave manufacturer since at least 1989.

The move from OEM to ODM to OBM has not been without pain or problems - Acer made a well-publicised retreat back to ODM from OBM in the early 1990s, and relaunched its own brand more cautiously in the mid 1990s. But this move demonstrates substantive learning and competence building by the firms involved, which leads us to speculate on a possible learning hierarchy for technology-following firms:

> *Learning to Produce* - the learning at this stage is Learning by Doing. Every firm learns by producing, whether in a protected import-substitution environment or in the face of international competition.
>
> *Learning to Produce Efficiently* - at internationally competitive levels. The source of competitiveness may simply be low labour cost, as it has been in the *maquiladora* industry in Mexico.
>
> *Learning to Improve Production* - such that as an economy develops and wages rise, the firm can improve the whole manufacturing process. This stage also includes design for manufacturability, to change the product to improve the manufacturing process.
>
> *Learning to Improve Products* - the performance and specification of the product itself.

The last technology-follower stage is *Learning to Develop* new products, requiring the ability independently to conceptualise and develop new product designs.

Following this, when the firm is no longer a technology-follower, is to develop new technology.

Hewlett Packard's (HP) subsidiary in Singapore illustrates this Learning hierarchy well - see Table 2.[27]

Key points from this chronology are the move from simple component assembly based on low labour cost, to more complex assembly, full product manufacture, production improvement, product redesign for production improvement, product improvement, to developing new products. Some of these stages nested with others - assembly of much more complex printers began after HP Singapore had successfully redesigned calculators, for example.

A statement from the engineering manager of HP Singapore in 1988 captures the ambition of this learning hierarchy: 'We wanted to move beyond advanced manufacturing to do world-class R&D. HP wanted to utilize [Singapore employees] in a better way than any other company, by integrating them closer and closer into the fundamental strategy. We also wanted to build products for as low cost as anybody' (Hewlett Packard, 1994a, p.7). HP Singapore is today equal with any technology-leading part of the company.

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[27] Taken from Hewlett Packard, 1994a,b,c. Although HP is hardly a technology-follower internationally, the case of *HP Singapore* illustrates how a firm in a NIC country can move up the value chain.

6 The key role of design

A key role for R&D in technology-followers is to build independent design capability for the firm. By design in technology-followers we mean the deliberate conceptualisation of a product to achieve certain desirable performance characteristics. These performance characteristics can apply at different levels including an aesthetic level (form) and a performance level (function). A new design, a new form and function, is concerned with 'matching techniques and markets' (Freeman, 1983, quoted in Walsh et al, 1992, p.23). Design tends to be market driven rather than technology driven, with technology providing the capability to meet new market needs. The Kline model of innovation, discussed earlier, identifies the 'central chain of innovation' as one which begins with a market finding and continues through various stages of design to marketing. Design plays a different role over time. Walsh indicates that 'a shift in emphasis may be observed in the life cycle of an industry or technology, from an early period primarily of designing for experimentation and technological innovation, to one where designing for technical improvement, lower cost and ease of manufacture becomes more important, and finally a mature phase where a multiplicity of design variations, fashions, styles and re-designs within product ranges aimed at different market segments predominates' (Walsh, 1996, p.516). Technology-followers will operate at the later stages.

We argue that technology-followers should be concerned with new design. This argument rests on the premise that the design and technology frontiers are distinct. It is quite feasible to push out the design frontier while being a technology follower; indeed by doing this a technology-follower can capture the higher value-added market segment.

Walsh et al identify the distinctiveness of Design:

> Designing often involves no technical change at all, but may simply result in a product with a different form, style, pattern or decoration.... Often, designing involves incorporating new components, materials or manufacturing methods into an existing product - for example, a washing machine with micro-electronic controls.... Designing is thus broader than invention and innovation because, while invention and innovation involve a technical advance in the known state-of-the-art of a particular field, designing normally involves making variations on that known state of the art (1992, p.26).

Three examples from India of *new* designs with *old* technology further illustrate the importance of design innovation. Among the most successful products in the Indian market in the last few years have been Titan watches, Videocon air-coolers, and TVS Scooties. Titan entered the watch market in the mid 80s, a market dominated by a public-sector firm which made reliable, though boring, watches and Japanese-brand smuggled digital watches. In five years, Titan became the leading Indian watch firm, mainly through design; Titan released an average of 100 new designs a year. Middle-class Indians went from wearing a smuggled Japanese watch to a Titan, and the watch became a fashion accessory one had several of. Air-coolers were long available in India, as sheet-metal affairs knocked together in small local workshops.[28] Videocon introduced air-coolers that were made out of moulded plastic components with a variable speed fan, an integrated water-circulation system and wheels to make the unit mobile. The combination of mobility, less mess and modern appearance greatly expanded the market for air-coolers. The TVS Scootie product is essentially a moped in scooter clothing. The two-wheeler market in India has a clear hierarchy of desirability from moped to scooter to motor-cycle. The Scootie provides a scooter look-alike at an in-between price.

All three examples are attempts to use new design within an existing technology-frontier to move up the value-chain. The air-cooler and the Scootie illustrate product development to meet the particular needs of a local market. All three products sold at higher prices than products with similar technology, design was used to add value and get a better quality product. Thus, a significantly new design can be seen as an intermediate point on the innovation continuum, as a jump in the capability of a product going beyond incremental improvement.

The leading Korean chaebol set out to acquire design capability as a part of the drive to develop their own higher value-added products. Kim shows how Hyundai consciously acquired style design capability in the 70s as part of its own car development: 'it selected a team of five design engineers to study literature related to auto styling, then sent them to Italy to participate closely in the design process with Italdesign engineers ... for a year and a half the highly motivated team shared an apartment near Italdesign, kept a record of what they had learned during the day, and conducted group reviews every evening ... . These engineers later became the core of the design department at Hyundai, and one became the Vice-President in charge of R&D' (1997a, pp.113-4). Hyundai has more recently established the Hyundai Styling Studio in Los Angeles 'to sense the needs of American consumers' (p.120). Similarly LG Electronics has a Design R&D Laboratory in Korea and the LG Design and Technology Center in Ireland. Samsung has been most active in acquiring design capability, establishing the Innovative Design Lab and the Samsung Art and Design

[28] An air-cooler is a cheaper alternative to the air-conditioner, selling for about one-fifth the cost. It does not have a compressor, being essentially a fan that blows through circulating water. The cost difference is greatly aided by the Indian government, which – deeming air conditioners a luxury good-tax compressors for air conditioners at around 200%.

Institute (in association with the Parsons School of Design in New York). Samsung also has an active collaboration with IDEO of Palo Alto, the world's largest product design firm to train its own designers. It also hired a designer from the British design firm Tangerine as its head of European design.[29]

[29] We are grateful to Kiyoung Ko, student at Stanford University, for research assistance on design capability acquisition in Korean firms.

7 *Design and "Soft" Quality*

If technology-followers push out the design frontier, won't they be subject to the same uncertainties, high cost and 'waste' of technology-leading R&D? While some waste will certainly be involved, design uses the need-finding technique as a systematic exercise to articulate user needs which are unmet and usually non-obvious. It is distinct from market research - asking customers what they *want.* Using multiple techniques ranging from market surveys, anthropological studies, partnering key customers, to building scenarios of the future, can lead to more 'imaginative understanding of user needs' and prediction of future frontiers.[30]

In carrying out need-finding exercises, focus on moving up the value-chain is vital - and the whole point of doing design. Adams[31] has identified several emotional dimensions of products that add value for customers, making the product higher quality. These dimensions include:

i. *Symbolism* - can the product symbolise something beyond itself? Consider the space shuttle, which symbolises something heroic to the US. The Scootie we spoke of earlier similarly symbolises a higher quality product than the equal capacity moped. One author has used Titan watches as his favourite choice of gift for friends abroad to symbolise the design capability of modern Indian industry.

ii. *Elegance and Sophistication* - product appeal that goes beyond words. The package that a product comes in conveys much about the product: Titan watches were the first in India to come in display boxes with clear plastic covers. Their higher-priced range went into a glossy sleeve – the package conveyed elegance.

iii. *Emotion* - how does the product appeal to the emotions. Closely related to the concept of elegance and sophistication, consider the thrills from roller-blading or from the world of fashion. When Telco launched its small car in January 1998, it took out full page advertisements in the national press saying 'Isn't it time for some Indian engineering?', a clear appeal to the emotions since its main competitor was a 50-50 joint venture between the Indian government and Suzuki of Japan.[32] Telco's publicity campaign, consciously pushing Indian

[30] See Leonard-Barton and Doyle, 1996, for a description of these techniques.

[31] Adams, Jim, February 1998, personal communication.

[32] 1998 saw a highly publicised squabble between Suzuki and the Indian government, with much rhetoric aired about Japanese technology. It is noteworthy that Telco's car was released by the Minister for Industry, the source of much of the rhetoric in the fight with Suzuki.

technology, proved hugely successful. When bookings for its new car, called, naturally, the Indica, began in January 1999, Telco hoped for orders of more than the 30,000 units planned for first year production. Booking involved paying 100% of the car and Telco was overwhelmed by 130,000 people depositing the full value - collecting more than the entire cost of the project.

iv. *Craftsmanship* - how does the product "feel", to the touch, for instance? Leather upholstery and wood in the most modern of cars, and phrases like "real workmanship" to describe office furniture.

v. *Consonance with global constraints* - environmentally friendly, for example, or building a whole business, as the Body Shop, around environmental concern. ISO 14000 provides a new international standard for environmental certification and companies work toward certification to be seen as being in synchronisation with global concerns as well as from actual environmental commitment. Taj Hotels of India have begun a "green" programme using re-cycled water, with little placards in each room talking of what they do.

vi. *Human fit* - including all of what used to be called ergonomics. An example is the many variants of the computer mouse - trackballs, touch-pads, trackpoints - and indeed of the mouse itself. The Videocon air-cooler adds value by being mobile and having an in-built water-circulation system. Hindustan Lever, the Indian subsidiary of Unilever, has long been one of the three largest private investors in R&D in India. The main objective of its R&D operation is to develop products particularly suited to the needs of Indian consumers. For example, some years ago, HLL developed a range of bar detergents suitable for use in cold water hand-washing, to suit Indian consumer preferences (Lall, 1987, p.167). More recently, HLL has supplied products like shampoo in small sachets to suit Indian preferences for smaller purchases.

vii. *Performance and Cost* - a feeling of getting more for less.

Thinking of quality as an emotion in NICs allows firms to target each of Adams' quality attributes to move up the value-added scale. But that means a firm must be able to define its own design specifications, and not take the given technology as a given. Instead, firms can use their absorptive capacity to learn from the technology leader, and then look for new designs by need finding to move up the value-chain. These quality characteristics provide a palette for a need-finding exercise to paint a new design.

Conclusions: From R&D to D&D

The argument above starts from a consideration of the kind of innovation key for technology-followers and suggests that the specific role of R&D rarely involves research aimed at generating new technological or scientific knowledge. The technology-following role for R&D requires that it be organised to maximise communication with the rest of the firm, to function as both gatekeeper for outside knowledge and storehouse of in-house knowledge. As firms try to add more value to their activity, product innovation becomes increasingly key, and the role of R&D includes building independent design capacity for the firm. The crucial distinction is between the design and technology frontiers - it is possible for firms to push out the design frontier without pushing out the technology frontier.

This discussion implies a trajectory applicable to all industries, and which all firms would choose to follow. Neither assumption is valid. Certainly design can add more value in industries with more differentiated products - consumer electronics more than steel, for example. Equally, the assumption that all firms will choose to follow a trajectory from learning to do what has been done elsewhere, to learn to do that efficiently, improve what has been done elsewhere, to pushing out the design frontier, is hardly valid. Indeed most firms in NICs appear to be quite content with local manufacturing based on a protected market or low wage cost. The m*aquiladora* industry in Mexico, for example, has been characterised by low learning and apparently little progression to higher value-added activities. However, many firms in NICs *have* chosen to build innovative capacity, both incremental and process, and design and product. Choosing to build technology-follower innovative capacity, and understanding the different role for and organisation of R&D is the first step in the process, with strong emphasis on pushing out the design frontier.

Most evidence in the paper is well known. But put together it suggests a fairly radical change in what firms and public policy makers need to do. As with the linear innovation model, knowing the alternatives does not make easy the transition. What should be done to encourage firms to develop their R&D infrastructure? We have mapped some of the practices that firms, even quite small firms, can and have used to reorganise and establish an R&D function, not just in NICs but in a wide range of less developed countries. We have also suggested that, although many of these practices are 'well-known', there is still much to do to mould the lessons learned for the specific use of innovative firms and those aspiring to be innovative. Indeed, there is a bewildering array of lessons and this paper has attempted to prioritise and sequence them. The R&D function of the follower-firm can act as the node point for such interactions.

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Table 1 R & D as a % of GDP (1987 and 1997)[33]

Country	1987	1997	Country	1987	1997
USA	2.9	2.5	S. Korea*	1.8	2.8
Japan	2.8	2.8	India**	0.9	0.8
Sweden	2.7	3.6	Taiwan*	0.9	1.9
Germany	2.6	2.4	Brazil	0.9	0.6
UK	2.3	1.9	Singapore*	0.5	1.5
Canada	1.5	1.6	Mexico	0.3	0.3

Table 2 Learning at HP Singapore

Late 1960s	Singapore identified by HP as a provider of low-cost labour
1970	HP Singapore begins operations stringing of computer core memories
1973	Move from component manufacture to product manufacture, assembling HP35 calculator
1977	Manufacturer of calculators, computer keyboards, solid state displays, IC's, isolators
1981	Manufacture of HP 41C programmable calculator; HP Singapore initiates cost- reduction exercise
1983	HP 41C redesigned to reduce manufacturing cost by 50%; HP Singapore sets up R&D operation (partly to get continued tax breaks from the Singapore government)
Manufacture of Thinkjet printers begins; sourcing components in Asia reduces cost by 20%	
1986	Design of new keyboards; Singapore assumes sole responsibility for design and supply of keyboards to HP worldwide Thinkjet manufacturing costs reduced by 30% through improvement of production process
1988	Thinkjet redesigned to further reduce manufacturing cost by another 30%
1990	Singapore initiates development of new product - a Japanese language inkjet printer
1991	Japanese language printer launched
1992	Singapore designs and introduces a colour Deskjet for Japan
Singapore undertakes the design of a whole new printer, the Deskjet Portable Very successful, and HP Singapóre is given full R&D, manufacturing and marketing	
Responsibility for the portable printer product line	
1993	Portable printer wins several design awards

[33] Source for 1987 figures: Business Mexico, June 1993, except * from Lall, 1990 for 1986, ** from DST. For 1997 figures: World Competitive Yearbook, 1999.

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