Mathews, John A. and Cho, Dong-Sung (2001) Combinative capabilities and organizational learning in latecomer firms : the case of the Korean semiconductor industry *Journal of world business*, Vol. 34, No. 2, p. 139-156

Access to the published version: http://dx.doi.org/10.1016/S1090-9516(99)00013-9

To appear in *Journal of World Business*, Vol. 33, No. 4, Dec 1998

Combinative capabilities and organizational learning in latecomer firms: The case of the Korean semiconductor industry

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Abstract

The emergence of firms from East Asian countries in advanced high-technology sectors such as semiconductors, is one of the striking features of world business developments over the course of the past decade. Explanations for the successes of such firms are commonly given in terms of transient, external or contingent factors, such as low costs or government subsidies or just plain luck. In this paper an alternative account is given, based on resource leverage and organizational learning undertaken by the latecomer firms themselves. The paper develops a model of technological learning by latecomer firms, and then demonstrates its applicability in the case of the creation of a semiconductor industry in Korea. Data is presented to support the proposition that it is indeed single-loop and double-loop organizational learning that underpins these firms' successful entry strategies. This approach sheds light on the strategies to be followed by firms in advanced countries when they seek to enter knowledge-intensive, high-technology sectors.

Combinative capabilities and organizational learning in latecomer firms: The case of the Korean semiconductor industry

The dynamic of world business is expressed in the shifts in competitive advantage between firms and nations. But what accounts for these shifts? How do some newly industrialized countries like Korea or Taiwan successfully generate completely new high technology industries like semiconductors? Behind these shifts in national competitive advantage, what are the strategies of firms in the emerging industrial centers? To what extent do their successes depend on their own internal organizational capabilities in acquiring and harnessing advanced technologies?

The global semiconductor industry provides the outstanding test case of technological catch-up by firms in previously under-developed parts of the world. In the space of little more than a decade, Korean firms, led by Samsung, Hyundai and Goldstar, have become major players in the production of integrated circuits, in particular memory chips (Dynamic Random Access Memory chips, or DRAMs). Samsung was the first, with modest sales in the mid-1980s. Hyundai entered the market in a significant way in 1990, while Goldstar did the same with a product largely sourced from the Japanese firm Hitachi. By the early 1990s, Samsung had caught up with the world's leaders with its 4M DRAM, and in 1994 it led the world in mass production of the 16M DRAM, which by the late 1990s was the biggest source of revenue for semiconductor producers. Samsung has surely arrived as a serious player in the semiconductor industry, in the space of no more than a decade. It is closely followed by its Korean domestic competitors, Hyundai and Goldstar (now LG Semicon).

These Korean producers, whose success is clearly not transient, are all what we shall call in this paper "latecomer firms." They started with meager resources and competitive disabilities -- yet they have managed to turn these to their advantage in devising catch-up strategies that have brought them to the world's technological frontier. Early accounts of the successes of these firms tended to focus on external, contingent factors such as an initial low-wage advantage, or government handouts, or just plain luck (for example, the Koreans approaching the US market in 1986, just after the signing of the US-Japan Semiconductor Trade Agreement which limited Japanese access and set a floor under prices). Such accounts hav little salience when the success of the latecomers is more than transient. A more satisfactory account of latecomer success focuses on how such firms were able to rapidly acquire and internalize the technical and knowledge resources needed to break into the high-technology world of VLSI integrated circuits. Thus, the focus of our analysis is the technological uptake, or "technology leverage" capabilities of the Koreans, as exhibited in their capacity to combine technologies from disparate sources in a sequential process of organizational learning. Such an approach is very much in line with recent contributions to the literature which see the firm as a repository of knowledge and the principal task of the firm as "knowledge integration" (Kogut & Zander, 1992; *ibid*, 1993; Winter, 1987; Grant, 1996; Spender 1996). Moreover improvements in these “combinative capabilities” can, in principle, be measured; such measurement would constitute one of the rare empirical demonstrations of double loop organizational learning (Argyris & Schon, 1995/1978).

Our exposition will proceed through the following steps. First we define our central category of the latecomer firm, and distinguish it from other variants such as “late entrants” and “start-up” firms. We then introduce the key concepts we use to make sense of the strategies and practices of latecomer firms in acquiring technological and market capabilities, namely 1) resource leverage and its use to develop “core competences;” 2) the integration and internalization of these competences through the exercise of “absorptive capacity” and combinative capabilities; and 3) the enhancement of these capabilities through single and double loop organizational learning. We synthesize a model of latecomer firm organizational learning out of these conceptual ingredients, and then demonstrate the workings of the model in the case of the Korean semiconductor industry. Our central proposition, that Korean semiconductor firms utilized double loop organizational learning in order to become adept players in the global semiconductor industry, is supported by data from the Korean industry which are assembled and published in this paper for the first time.

The category of the latecomer firm

The idea of a “latecomer” turning disadvantages into sources of advantage, was formulated most clearly by the historian, Alexander Gerschenkron. It was he who studied the rise of “late industrializing” countries in Europe in the 19th century (eg. Germany, Austria) and saw them as being able to secure advantages by entering industries utilizing the most advanced technologies, at a greater scale of activity, and without the hindrance of institutional forms (such as established trade associations and professional training systems) which acted as a brake on the innovative potential of earlier industrializers (Gerschenkron, 1962). The case of Germany, which caught up with Britain as a steel and textiles producer, and rapidly moved to a position of leadership in science-based industries such as chemicals, provides a compelling instance of Gerschenkron’s argument.

The rise of East Asian countries in the 20th century, starting with Japan and then in the post-war era moving to encompass Korea, Taiwan, Hong Kong and Singapore, provides a more recent instance of Gerschenkron’s general thesis. It is now widely agreed, including by the World Bank (1993), that these countries have behaved in classic “latecomer” fashion in utilizing state agencies to engineer their entry into export markets and then into high technology sectors.

The category of the “latecomer firm” developed in this article is the analogue of Gerschenkron’s latecomer nation, applied at the level of the firm. The emphasis is the same in both cases. Latecomer firms, like latecomer nations, are able to exploit their late arrival to tap into advanced technologies, rather than having to replicate the entire previous technological trajectory, and can accelerate their uptake and learning efforts utilizing various forms of collaborative processes and state agencies to assist with the process, bypassing some of the *organizational inertia* that holds back their more established competitors.

The latecomer firm (LCF) is defined by reference to its initial difficulties. It lacks resources above all, and therefore it lacks the capabilities that can be built from resources. In its initial form, it is isolated; it lacks skilled personnel; it lacks access to technologies and markets (Hobday, 1995). How is such a firm to become a player in the world of high technology industry?

It is in recognizing its deficiencies that the LCF secures its first "competitive advantage." It formulates a strategy commensurate with its deficiencies and limitations. It harbors no illusions as to its own capabilities, and looks instead to the wider world for sources of technology, knowledge and market access. It is in securing access to these resources, for example through low-cost contract manufacturing and technology licensing, that it secures a foothold in the world's production chains. Like a mountaineer scaling a precipitous rockface, the latecomer is then able to use this foothold to leverage further resources and turn them into further capabilities, gradually increasing the quality and reliability of production, and the range of functional capabilities. Thus, it is through "resource leverage" (Hamel & Prahalad 1994), or leverage of external technologies and knowledge, that the latecomer acquires capabilities.

Three features mark out a distinctive conceptual and theoretical space for the LCF. It is defined as a firm which meets the following three conditions:

- Strategic goal — The LCF is a fast follower, with catch up as the goal;
- Mode of operation — The LCF is an imitator rather than innovator, utilizing various forms of resource leverage;
- Organizational learning — The LCF is a fast learner, shifting the basis of its competitive posture towards more sophisticated levels of activity, and accelerating its uptake of capabilities through institutional supports.

These conditions are deliberately couched in general terms, without regard to time and place. But clearly the "latecomer firms" from East Asia which have made their mark in the semiconductor and information industries, satisfy these conditions. Other firms do so as well. Two caveats are introduced to clarify this definition.

The Latecomer Firm is not a "Late Entrant"

The latecomer firm as defined needs to be clearly distinguished from a firm which makes a late entry into an industry or market as a matter of strategic choice. Such "late entrant" firms are discussed in the "order of entry" literature (eg Miller, Gartner & Wilson, 1989) and "management of imitation" literature (Schnaars, 1994). In many cases these are very well established and well-endowed firms which delay entry until technological and market trends are clear -- and then move in with superior forces to take the lion's share of the market.[1] This is a rational "followership" strategy, a matter of strategic choice. The LCF by contrast has no such choice; it is condemned

[1] This is more or less what IBM did in relation to the Personal Computer market in the early 1980s, when it waited until the trends were clear, and then moved in with its own very successful PC brand in 1982.

to be a latecomer by history. But it is not condemned by history to be a follower forever.

The Latecomer Firm is not a "Start-Up"
Another distinction worth making is that the LCF is not a "start up" firm, which although having to create its own competitive position from ground zero, frequently does so as a spin-off from an existing venture, and with some considerable capabilities already endowed in the initiating entrepreneur and initial staff. Indeed, much of the literature on industrial evolution and dynamics, reveals how new entrants have overcome incumbents precisely because of their start-up advantages (Tushman & Anderson, 1990). While the start up venture shares certain features with the LCF, such as its having to tailor strategy to resources and constraints initially, it generally does not suffer from the isolation and lack of capabilities that mark the typical LCF.

Combinative capabilities and the resource-based view of the latecomer firm

The acquisition of competences by a firm, underpinning its strategic position in the marketplace, is best described as a process of organizational learning. It is organizational in the sense that it transcends the acquisition of knowledge by individuals; it is a learning process that is embodied in the acquisition of organizational routines and procedures that are accessible by organizational members generally.[2] The recent literature on the sources of firms' competitive advantage has sought to highlight the significance of organizational competences, as underpinning the competitive position of firms - in contrast to the traditional strategic analysis, which focused on the characteristics of products and markets and the firm's chosen position within them. Grant (1991) provides a succinct account of this approach (the resource-based theory of competitive advantage) and draws its implications for strategy. A firm starts by examining its resource base, appraising its strengths and weaknesses relative to competitors, and then looks at how these resources may be combined or integrated into capabilities, which can in turn underwrite the firm's ability to sustain its advantages in a chosen market or technology. The loop is closed with an analysis of where capabilities and their underlying resources are lacking, and how they can be filled.

The literature on this topic almost always assumes that the firm in question is an advanced exponent of product and process technologies and that it is engaging in learning in order to improve its already considerable position. None of these conditions apply of course to the case of the latecomer firm engaging in catch-up - like the Koreans in the semiconductor sector. Such a firm initially lacks capabilities, and is engaged in a race to acquire them. Yet this fact by itself makes the framework of "competence acquisition" or organizational learning a compelling one for such firms.

The acquisition of competences through resource leverage by a catch-up firm such as Samsung is as much an organizational as a personnel issue.[3] While Samsung and the other Korean firms had to recruit skilled engineers in order to make an entry into

[2] For a recent review of organizational learning, see Dodgson (1993).
[3] See Prahalad and Hamel (1990) for the major exposition of this idea, as well as the chapter on 'resource leverage' in Hamel and Prahalad (1994).

semiconductors feasible, this on its own would have been no guarantee of success. The critical factor was an ability to acquire and internalize technical competences rapidly, and then to apply them in the setting up and improvement of chip fabrication systems. Such firms need a basic platform of competence in order to build further competences. They need to be able to master the mass production of simple products before tackling more complex products, for example. This straightforward idea is captured variously by the notion of “absorptive capacity” (Cohen and Levinthal 1990) or “combinative capability” (Kogut and Zander 1992). Both concepts, while derived separately and for different purposes, refer to the “receptivity” of a firm to external sources of knowledge or technique. This is central to understanding the long period of organizational apprenticeship undertaken by Korean firms, in mass production and contract manufacturing of electronic products, before launching themselves into the semiconductor mainstream.

Technological uptake as organizational learning by catch-up firms

While all firms when faced with competitive markets must adapt their approaches and acquire new competences (ie learn) the imperative for latecomer firms engaged in catch-up is to do this rapidly while acquiring the competences from external sources and internalizing them. Using a strategy of resource leverage, the catch-up firm acquires knowledge and technological competences from a variety of sources (eg through technology licensing, through purchase of equipment, through hiring of competent engineers) and faces the challenge of rapidly assembling, or *combining*, these disparate elements into a coherent production and marketing system. Successive studies have documented this process in the case of Korea (Amsden, 1989; Kim, 1995, 1997b). The core capability needed by the firm to make a success of such an enterprise, is in fact a combinative capability that enables the firm to put together, for example, equipment bought from Japanese and US manufacturers and “tweak” it to provide superior performance. This rapid “learning by doing” or single-loop learning needs to be accomplished within each product generation; the faster the firm is able to improve its performance (eg productivity, yield, quality) the more quickly it can secure a return on the huge investments made.

However there is nothing special about single-loop learning; it is widely observed as “learning by doing”. Single-loop learning on its own will never provide sufficient leverage for a catch-up firm. Where its real “combinative capability” is called for is in moving rapidly from one product generation to another, internalizing the competences acquired in one generation in the assembling of process technology for the next, and moving into mass production *at higher and higher levels of performance* with each generation. This is in our view best understood as a form of “double loop” organizational learning, since it entails a capability of assembling the pieces of process technology more and more effectively and efficiently with each product generation. Double loop learning engages with the learning loop itself, subjecting the goals of learning to critical inquiry; it has been described aptly as “learning how to learn”. Although the impression is created in the literature that such double loop learning is relatively rare, we maintain that it is in fact exceedingly common, and underpins the business success of firms which are able to adjust their operating structures and processes as circumstances change.

Thus we view the *knowledge* of the latecomer firm as consisting of the routines and methods learned and which are integrated through the exercise of its "combinative capabilities" needed to assemble disparate items of process technology and bring them to a high level of coherence and performance in mass production, in time to catch the market for a new product before the technological frontier moves on. At any one time these competences constitute the firm's "absorptive capacity" which is further enhanced by the next round of leverage and learning, providing a platform for further development. Since the institutional setting within which this takes place is developmental, we use the term "developmental resource leverage" as the defining framework for the process of technological catch-up.[4] We summarize this discussion in the form of three propositions which are susceptible to empirical demonstration or testing.

P1: *Latecomer firms seeking to enter a new industry by catch-up will demonstrate various forms of learning via the leverage of external resources and their internalization, based on their prior levels of "absorptive capacity"; the more active this process of leverage as an active sourcing of technologies that leads to their uptake and utilization in production activities, the more successful is likely to be the firms' entry.*

P2: *External resources are assembled into the functional attributes of production systems, and integrated through the exercise of combinative capabilities; the faster the learning by doing (single loop learning) within each product generation, the more successful the entry strategy is likely to be.*

P3: *Combinative capabilities themselves can be improved with use, from one product generation to another; the faster the improvement in single-loop learning, for example in pilot production prior to handover to mass production, the more successful the entry is likely to be. This improvement in performance from one product generation to another is best described as double loop organizational learning.*

Taken together, these propositions constitute a "model" of technological catch-up by latecomer firms utilizing organizational learning. The model is displayed graphically in Figure 1.

Insert Fig 1 about here

Figure 1 shows how the LCF starts (at time period t0) with a small set of functional capabilities (spanning such activities as manufacturing, product development and efficiency improvement) and a small endowment of combinative capabilities, and through leverage from external sources it expands its functional capabilities as well as the combinative capabilities needed to integrate them (time period t1). Through this process the external resources are internalized, in a sequential pattern of organizational learning. The development of the firm's knowledge accumulation can be depicted as an expanding cone of capabilities enhancement.

[4] See Mathews (1995; 1996a; 1997a;b) for further explication of developmental resource leverage, and Mathews (1996b) for its application to the semiconductor industry in East Asia generally.

The semiconductor industry as candidate for catch-up

The semiconductor industry is like no other on earth. It is the exemplar of Schumpeter's restless, technology-driven capitalist enterprise where the competition is intense, where product life cycles are short and where there is relentless pressure on price within each short cycle.[5] Consider the case of DRAMs, the commodity-like, standardized memory chips, which have gone through five generations since the Koreans became seriously interested in becoming involved. As Chart 1 shows, the size of the global market for each generation of DRAM has expanded, from the relatively small market for 64K devices, to the much larger market for 256K, 1M and 4M devices, to the huge market envisaged for the 64M device which was being introduced commercially in 1995. Samsung, followed by Goldstar and Hyundai, moved closer to the leaders with each successive generation, attaining parity with the Japanese in the introduction of the 4M DRAM, and leading the world with the 16M generation. With each successive cycle, the Koreans have taken an increasingly large share of the DRAM market - from a negligible portion of the 64K DRAM, to an estimated 40 percent of the world market for 16M DRAMs.

Figure 2 about here

It is this rapid product turnover, and the necessity for new process technology investments to be made with each new generation of DRAM, that has provided the opportunity for newcomers to make their mark. What were once seen as barriers to entry, have been turned into windows of opportunity for late developers. It was this character of the semiconductor industry that was exploited first by the Japanese, with their assault on the US DRAM market in the early 1980s. The Koreans repeated the process in the 1990s, by engaging in a struggle against the Japanese. Other DRAM producers from East Asia were coming on stream in the mid-1990s, from Taiwan, Singapore and Thailand - all capitalizing on the opportunities created by the restless product turnover in this sector, and the availability of dedicated equipment for fabrication.[6]

Korean firms’ leverage strategies and organizational learning

The Koreans brought several elements to their bid to enter the semiconductor industry as serious players. Firstly, they had already perfected their skills in manufacturing management in the simpler products of consumer electronics, such as TV sets, radios, hi-fi systems and microwave ovens. Secondly, they understood the value of marketing, and had existing marketing channels to draw on. From the outset, the Koreans' approach was to take their DRAMs to the world market. Their focus on standardized commodity chips held two clear marketing advantages: firstly it meant that they were free of worries about conflicting standards or product loyalties, and

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[5] For the original description of capitalism as a system driven by relentless technological change, see Schumpeter 1946; for a more recent description of the phenomenon, see Tushman and Anderson 1986.

[6] See Mathews (1995) for the cases of Korea and Taiwan; see Cho & Rhee (1994) for the case of Korea; and Mathews (1997a) for the case of Taiwan. The entire experience of East Asia in the creation of a semiconductor industry is reviewed in Mathews and Cho (forthcoming).

secondly they could seek customers with minimal interaction, merely providing them with standard products produced according to standard specifications but at excellent levels of quality, delivery and price. They drew on their existing global marketing channels, to create marketing and sales support offices in North America, then Europe, then Japan and South East Asia. Behind this excellent marketing lay a steady supply of Original Equipment Manufacturing (OEM) contracts which acted both as a means of sharpening the technical skills of Korean producers, and as a means of keeping incipient over-capacity at bay. OEM contract work is now combined with offering smaller chip design houses silicon foundry services, and exchanging capacity with competitors through alliances. It was the means through which the Koreans acquired their "absorptive capacities".[7] Thus, the Korean firms had long memories and considerable resources to bring to their leap into semiconductors.

Technology leverage in the entry into semiconductors

The key precondition that governs successful entry through resource leverage into a high technology industry is the availability of product and process technologies, for example through licenses or equipment vendors. In earlier stages of the semiconductor industry, these technologies tend to be embodied in proprietary designs and equipment that were the source of competitive advantage of the industry pioneers. But as the industry matured these were increasingly embodied in products that are available on the open market. This provided the key to the Koreans' strategy.[8] Samsung was able to purchase the designs for a 64K DRAM from the US firm Micron, then still a struggling start-up in Boise, Idaho. A little later, Hyundai was able to likewise license designs for a 16K and 64K DRAM from the Californian start-up Vitelic, and for a 64K SRAM from MOS Electronics. Goldstar was able to secure designs for telecomm ICs from its US joint venture partner, AT&T, and later in the form of a comprehensive technology transfer agreement, from Hitachi.

Process technology was likewise available, for a price. Samsung was able to purchase CMOS technology from an American firm, Zytrex, for $2.1 million; the Japanese firm Sharp, was likewise a supplier of this technology. Equipment such as steppers and aligners could be bought from US suppliers like Applied Materials, or from Japanese suppliers such as Canon and Nikon. The Koreans were spending large sums in 1984 and 1985 as they built their fabrication lines, and were able to exploit the competition between the Japanese and US equipment suppliers to secure good prices and, even more significantly, assistance in integrating their production systems, through enhancement of their combinative capabilities.

The technologies leveraged by the Koreans in their assault on the semiconductor industry, are shown in Figure 3. This reveals the extent of the Korean dependence on external sources of knowledge. The point is, however: what were they able to do with these leveraged technologies?

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[7] On Korean technology uptake strategies generally (what we are calling leverage) see Simon and Soh 1994; Westphal et al 1985; Amsden 1989; and Kim 1995, 1997b.

[8] On the Korean semiconductor industry and its development, see Byun and Ahn 1989; Choi 1996; Hobday 1989; 1995; Mody 1990.

Figure 3 about here

While the case of Samsung is relatively well known (Choi, 1996; Kim, 1997a) the comparable efforts made by Hyundai and LG have received less attention in the world business literature.

How Goldstar produced the 1M DRAM

Goldstar became a 'late' late starter in memory chip production in Korea. It took advantage of this position to enter a comprehensive technology transfer agreement with Hitachi, with whom the LG group had enjoyed close relations for many years. A new company, Goldstar Electron (GSE) was formed in December 1989, bringing together all Goldstar's existing semiconductor activities (including the AT&T joint venture) and establishing a new fabrication facility for memory chips at Chungju.

The agreement with Hitachi was the most comprehensive technology transfer agreement yet entered into by a Korean with a Japanese company. Hitachi transferred technology, know-how, equipment suppliers, and technical assistance, offering virtually a 'turn-key' system for production of 1M DRAMs. Indeed Don Chun, head of GSE's semiconductor memory division, stated that 'We are virtually duplicating the Hitachi wafer fab'.[9] The agreement did not come cheap. GSE had to agree to pay several million dollars upfront as an initial licensing fee, plus royalties on sales of between 1 percent and 3 percent of revenues over a period of three years. GSE was thus able to enter the 1M DRAM market in 1990 as a mass producer, with a lag of 18 months after Samsung and level with Hyundai. What Hitachi gained from this arrangement was the financial flow of royalty fees, and a secure second source for its DRAM products. The agreement blossomed, and GSE co-produced a 4M DRAM with Hitachi in 1991/2, and a 16M DRAM in late 1993. By 1995 the two companies were jointly developing the 64M and 256M DRAMs – but no longer under the stringent terms of the original technology transfer agreement. Thus the emergence of LG Semicon as a world-class player in the mid-1990s is the result of a series of resource leverage initiatives going back to the early 1970s, and involving links with many firms including AT&T, NS and Hitachi.

Meanwhile Hyundai was struggling. The company had spent freely to establish its own fabrication facility in Korea to produce the items in its first memory chip product portfolio. But the road to semiconductor success was not easy for this Korean *chaebol*. It would prove to be ten years before Hyundai could turn a profit on its semiconductor investments. How Hyundai was able to soldier on, and eventually break through to successful production with the 4M DRAM in the early 1990s, is a story as dramatic and as instructive as anything in Korea's remarkable high technology experiences.

How Hyundai produced the 4M DRAM

The development of the 4M DRAM in 1990 was a make or break issue for Hyundai. The company had been in the semiconductor business for nearly eight years, in hot pursuit of Samsung, but had yet to turn a profit. It had purchased both product and process technology for its first efforts, the 64K and 256K DRAMs, from US start-ups such as Vitelic, but was having trouble internalizing these technical

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9 *Far Eastern Economic Review*, 24 August 1989: 50-51.

capabilities. Being late to the market with these products meant that sales were meager. Hyundai had built large fabrication plants with the latest equipment, but its slow product development meant it was unable to utilize its capacity. Then OEM orders from Texas Instruments for its 256K DRAM, and from Japanese firms such as Ricoh, helped Hyundai to utilize its capacity and sort out its process technology, as well as earn some revenue. Hyundai was late again with the 1M DRAM, which it developed along parallel pathways, on the Samsung model, with one development team working with a design acquired once again from Vitelic, and another seeking to build on earlier experiences to produce their own product. Impatient to catch the market, Hyundai put the Vitelic design into production in 1988. This chip turned out to give very low yields, and its production was abandoned after a year of frustration. By then the internally developed product was ready, and it proved to be more stable in production. But again precious time was lost, and so Hyundai caught very little of the 1M DRAM market, and the company was still a distant second to Samsung and even further behind the Japanese. Things had to improve with the 4M DRAM or the company would in all likelihood be forced out of the semiconductor business.

Process technology for DRAMs was constantly evolving, and after the 1M DRAM generation, the planar process for laying down ‘sandwich’ layers on silicon to form transistors was being improved in two quite different directions. American firms, led by IBM, were expanding the surface area of the chip by drilling ‘trenches’ in the silicon, while Japanese firms such as NEC were pursuing a different strategy of constructing corrugated ‘stacks’ on top of the silicon surface. Hyundai development engineers had been unable to decide which direction to move in, and by 1990 they still did not have a ‘working die’ of the 4M DRAM to put into production.

Senior management were looking for yet another product licensing source, desperate for a product to bring to market in time to catch the wave of innovation. At this point, Hyundai got a break through hiring Dr Wi-Sik Min, who had been working at Intel for the past six years, and had a wide experience of semiconductor technology. Dr Min immediately got down to business at Hyundai’s sprawling Ichon complex, in the cramped R&D Lab. The first item on the agenda was to choose a technical direction, and his solution to this problem was elegant: let two teams work in parallel to produce both a ‘trench’ and a ‘stack’ 4M DRAM, and test them to see which could be produced most efficiently. Working at a frenzied pace, the two teams of around ten engineers each scoured the world for information, and produced designs that they then put through their paces on the R&D Lab’s wafer lines, updated with the latest equipment. By early 1991, it was clear that the stack solution could be produced with fewer and simpler processing steps, with higher yield levels, and this was the solution adopted. Samsung had already adopted this solution in its own development efforts.

The parallel teams concept was simply one of a number of important organizational innovations which enabled the Hyundai R&D Lab to sustain a punishing pace of development at this time. Process technology was developed in parallel with the product development, as at Samsung, thus squeezing the overall development time. Regular morning briefings were held, attended by up to twenty of the Lab’s hundred or so engineers. The meeting would go over the previous day’s results, and plan the next day’s work. The group would invite junior engineers to present their results, providing them with much needed acknowledgment – or with punishing criticism. But the emphasis of the meetings was on results, and organizational learning, not on personalities.

Hyundai ramped its 4M DRAM into full mass production by April 1991 – only six months behind arch-rival Samsung. The initial yields were higher than 50 percent, and then were raised successively as production experience was gained. Yields of between 80 and 90 percent were being achieved within six months, in 1991. Indeed yields were *higher* than on the lines producing 1M DRAMs for Texas Instruments, to TI specifications under an OEM contract, *within the same fab*. Such was the measure of Hyundai's learning from product generation to the next. Revenues achieved from the sales of 4M DRAMs in 1992 and 1993 brought Hyundai into cumulative profit. Its investment in semiconductors had at last begun to pay off – thanks to the compressed and accelerated learning that had gone on in both the R&D Labs and fabrication lines.

Evidence of double loop organizational learning

Let us now step back from these specific details to look at the more general and fundamental organizational learning processes involved. Our account provides a framework for the demonstration of the validity of the propositions advanced above. *Proposition one* asserts that evidence of technological leverage should be clearly demonstrable in the strategies of Korean latecomer firms seeking to enter the global semiconductor industry. *Proposition two* suggests that there should be evidence of Korean firms being able to improve their yields of ICs within each product generation (single loop learning). *Proposition three* suggests that successful entry should be associated with successive improvement of learning from one product generation to another. An example of such an empirical result would be yields (of good chips per silicon wafer) in the integrated circuit industry; evidence of double-loop learning or improvements in "combinative capabilities" would be found if initial yields - as firms moved from development to mass production - improved with each product generation.

Data collected from the industry, through own original research in Korea, can be assembled and displayed as shown in Figure 4. This figure shows successive improvements in initial yields of DRAMs, as the firm switched over from development to mass production in each generation of DRAM. [10]

Fig 4 about here

In each new product generation, there is a period of operation of the fabrication process on pilot or R&D fabrication lines, where the aim is to improve yields up to something approximating commercial efficiency, before handing the process over to the production department, for mass production. We see from Figure 4 how this Korean semiconductor firm improved the yield *at the point of handover* from pilot operation to mass production *with each product generation*. This implies that there was learning by the firm as to how to improve efficiencies, from one product generation to the next. The firm was "learning how to learn" to improve yields faster and with greater reliability. This is consistent with what Argyris and Schon (1995) call "double loop learning", as outlined above; it concerns the organizational capability of improving operations over time, so that the results of earlier experiences

[10] To the best of our knowledge, this is the first occasion on which such data has been released by Korean firms for analysis in the international business literature.

are embodied in later organizational routines. It is also consistent with the literature on "experience curves" and improvements in yield data in the global semiconductor industry.[11]

Concluding remarks: management lessons from Korean success

When Korean chips were first encountered on the US market, there was much astonishment and not a little skepticism. How could a country that most people still put in the "developing" basket produce such high-tech products and in such competitive fashion? There had to be something behind it - either government subsidies, or intellectual property rip-offs, tax breaks, or some other form of cheating. We have suggested that such responses are inaccurate and inappropriate. They simply do not come to grips with the dynamics of the creation of competitive advantage by Korean firms. The creation of competitive advantage through processes of accelerated organizational learning, appears to be one of the most impressive economic achievements of the East Asian latecomer industrializers; it goes beyond what the World Bank (1993) describes as the "East Asian miracle." We have sought to capture the spirit of this dynamic in our three propositions, and offered empirical evidence as to the plausibility of these single and double loop organizational learning approaches as underpinning Korean success.

The significance of this result in fact transcends the catch-up firms in East Asia. If our account is accurate, it depicts the processes which virtually all firms will have to undergo, wherever they may be found, as they seek to enter new technology-intensive sectors. The reason is that resource leverage provides a rapid trigger for organizational learning processes for any firm which does not command mastery of a market or technology, or for any firm wishing to diversify or extend its range based on its existing competences. It turns out then, that the "catch-up" strategies of Korean latecomer firms in semiconductors might have much more general applicability than appeared to be the case.[12]

Acknowledgment: The authors would like to acknowledge the assistance of executives from the semiconductor industry in Korea in providing insights for this paper. Professor Mathews wishes to acknowledge the financial support of a grant from the Australian Research Council: "High-technology industrialization in East Asia."

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[11] Our results are consistent with findings from the literature on "experience curves," such as the survey by Dutton and Thomas (1984), where they found that the slope of the experience curve, ie the extent of single-loop learning, in some 200 studies, reflected not just technological characteristics but managerial input. More specifically, Bohn (1995) examined yield data from five semiconductor plants and found that (single-loop) learning varied greatly, again reflecting managerial capacities and inputs. The finding by Nye (1996) of weak firm-specific learning by Japanese semiconductor firms, we take to indicate weak single-loop learning; it is not inconsistent with our claim of strong evidence of double-loop learning on the part of Korean firms.

[12] Consider for example the case of mass production of liquid crystal displays, used in laptop computers, where US and European firms at present lag their competitors in Korea and Japan. This is a case where such US and European firms might well need to employ 'resource leverage' strategies in order to 'catch up' with their East Asian rivals. For an extended treatment of this industry, see the special issue of *Industry & Innovation* edited by Wong and Mathews (1998).

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Figure 1: Technological learning of the latecomer firm

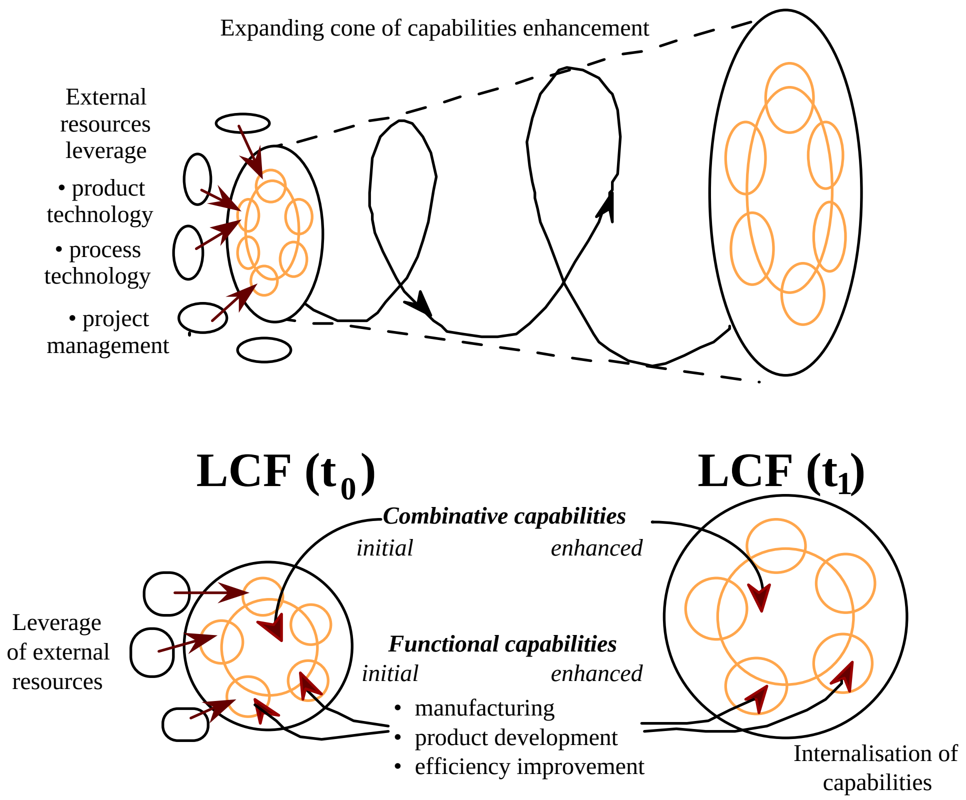
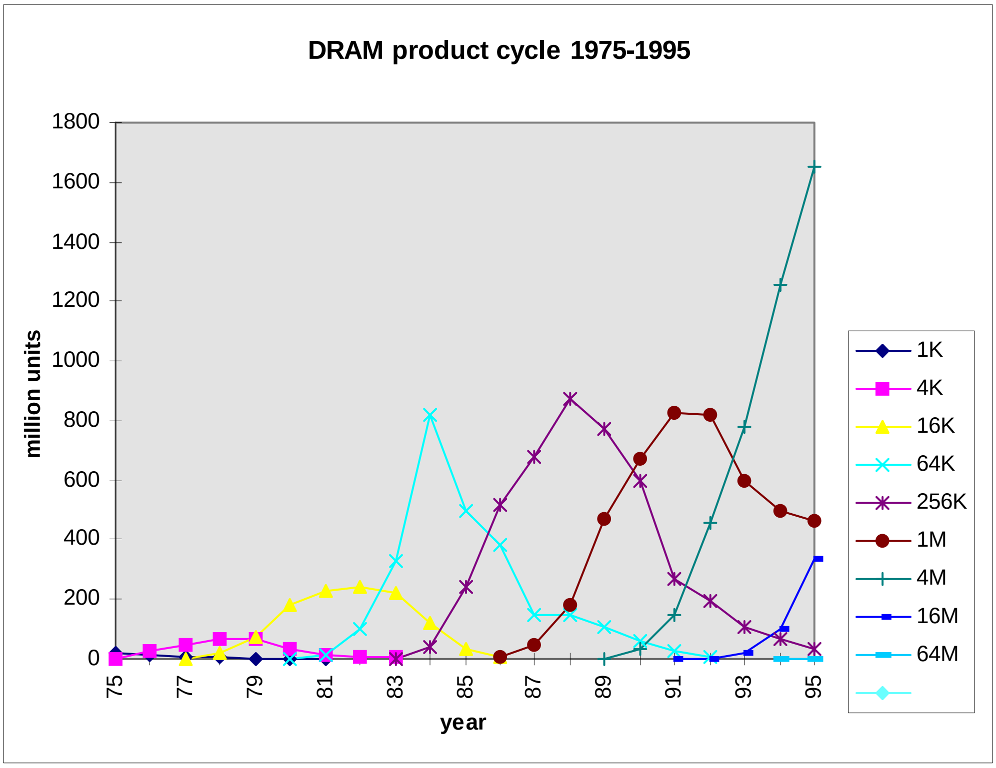


Figure 2: Successive product generations: DRAMs 1983-1999



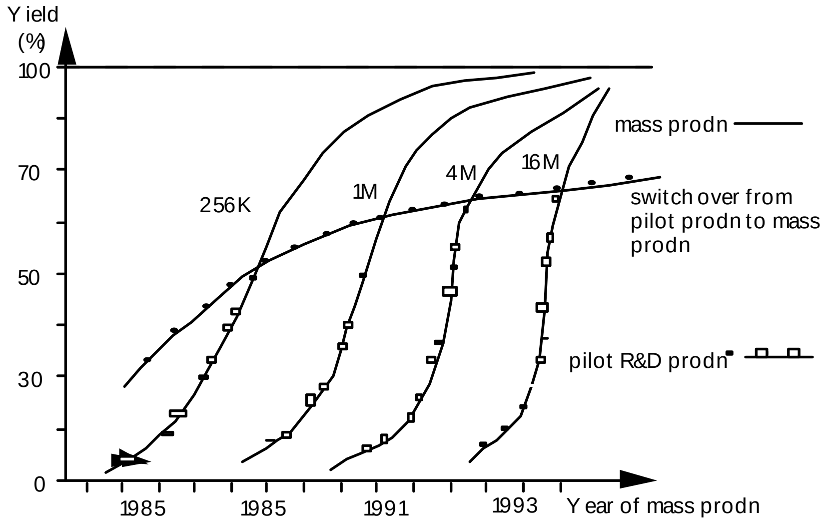
Source: ICE

Figure 3: Semiconductor technology licensing agreements with Korean firms, 1982-1988

Company	*Year*	*Technology*
Samsung and:		
ITT	1982	telecom ICs
Micron	1983	64K DRAM
Sharp	1983	CMOS process
Zytrex	1983	high-speed CMOS process
Zilog	1984	8-bit microprocessor
Intergraph	1984	32-bit microprocessor
Exel Micro	1985	16K EEPROM
Goldstar and:		
AT&T	1984	telecom ICs
Zilog	1985	Z80 microprocessor
AMD	1985	64K DRAM
United Microtek	1985	256K SRAM
Hitachi	1988	1M DRAM
Hyundai and:		
WDC	1984	8-bit 6502 MPU
Vitelic	1985	256K DRAM
Mosel	1985	64K, 256K SRAM
Vitelic	1986	1M DRAM
LSI Logic	1985	Gate arrays

Source: Mathews and Cho (forthcoming)

Figure 4: DRAM yield improvements over successive product generations -- switchover from pilot to mass production



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