

Upgrading through innovation in a small network economy: insights from Taiwan's IT industry

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This paper analyzes the recent experience of Taiwan's information technology (IT) industry to explore the challenges and opportunities faced by a small economy that is deeply integrated into global networks of production and innovation. I introduce a conceptual framework to examine how specialization, learning ('absorptive capacity') and innovation enhance the potential for industrial upgrading. Finding the right balance between firm-level and industry-level upgrading and between domestic and international elements is a moving target and requires permanent adjustments to changes in markets and technology.

Three findings distinguish this paper from prior work. *First*, absorptive capacity is critical for Taiwan's attempts to upgrade its IT industry through innovation. *Second*, Taiwanese firms now must increase R&D to avoid diminishing returns of network integration. *Third*, integration into diverse networks of production and innovation may well provide new lower-cost opportunities for 'industrial upgrading through innovation'. 'Technology diversification', which combines incremental and architectural innovations, can serve as a complementary and arguably less costly option to 'technology leadership' strategies.

Keywords: globalization; internationalization of R&D; global innovation networks; global production networks; learning; innovation; innovation policies; industrial upgrading; Taiwan, IT industry

1. Introduction

This paper analyzes the recent experience of Taiwan's information technology (IT) industry to explore the challenges and opportunities faced by a small economy that is deeply integrated into global networks of production and innovation.¹ A defining characteristic of Taiwan's network economy is its integration into a diverse global network that includes both formal corporate and informal knowledge networks.² Equally important are domestic inter-organizational linkages with large Taiwanese business groups. Typically, Taiwanese firms have pursued different approaches in parallel, rather than concentrating exclusively on one particular linkage, reaping flexible network synergies.³

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I argue that, while network integration has facilitated the catching-up of Taiwanese firms as fast-followers, it now may become a mixed blessing, unless there are appropriate policies in place to develop absorptive capacity and 'innovative capabilities' both at the firm level and across the industry.

This proposition has relevance well beyond the case of Taiwan. The experience of this small network economy may in fact shed new light on the opportunities and challenges that innovation policies face today. Globalization transforms markets for technology, science, innovation finance and knowledge workers,⁴ intensifying technology-based competition. There is a growing recognition that current technology strategies at the firm level and technology policy at the industry level are showing diminishing returns and should be questioned and revised.

Much of these debates are focussed on the leading large economies, and the main concern is how to foster breakthrough innovations that can support technology leadership. Take for instance the recent book by Tasse (2007), entitled *The technology imperative*. Tasse (2007, 86) argues that, in the USA, the rapid globalization of science and technology has brutally exposed 'structural deficiencies in both the public and private sectors' and that it is necessary to rethink their roles and mechanisms. To sustain technological leadership, national governments need to become more active as competitors through massive investments in 'human science and engineering capital' and 'innovation infrastructure'.⁵

Tasse (2007, 86) acknowledges that these policies 'will have to be accomplished in the context of ongoing globalization of corporate strategies'. The new doctrine thus differs from 'techno-nationalism', which, as aptly described by Ostry and Nelson (1995), treats science and technology primarily as weapons to improve national balance of payments. Instead, an important objective is to improve the efficiency of a nation's innovation systems and to reduce the risks of innovation through 'more comprehensive growth policies implemented with considerable more resources and based on substantive policy analysis capabilities' (Tasse 2008, 2).

This paper on Taiwan's innovation strategy describes a similar agenda – aggressive, yet selective and continuously adjusted support policies, based on extensive industry-government dialog, that seek to enable Taiwanese firms to improve their position in diverse global networks. But the Taiwan story also indicates that there are alternative solutions with lower investment thresholds and opportunity costs that are within the reach of small network economies.

Three findings distinguish this paper from prior work.

First, absorptive capacity, defined as 'the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal 1990, 128) is critical for Taiwan's attempts to upgrade its IT industry through innovation. How fast and successfully Taiwanese firms internalize and translate the new, external information into their own innovative capabilities depends on their 'existing knowledge base or competence (most of it tacit knowledge), and the intensity of effort or commitment' (Ernst and Kim 2002, 1425). This supports Antonelli's (2006, 211) proposition that the diffusion of knowledge requires 'a process of creative adoption'.

A *second* finding reflects the rapid globalization of technology-based competition and the growing complexity of technology systems, which have raised the bar for innovation policy. Taiwan's 'global high-tech factory' model is now experiencing decreasing returns, in terms of value added, profit margins and job creation. This has forced Taiwan's corporate strategists and policy-makers to search for new ways to re-create the country's competitive edge.

This paper shows that Taiwanese firms now must increase R&D to avoid diminishing returns of network integration. This supports Cohen and Levinthal's (1990, 140) observation that, as 'greater technological opportunity', 'higher barriers to appropriability' and 'complex technology systems' ... (lead to) ... 'a more costly learning environment ..., R&D is more important to building absorptive capacity ...'.

A *third* finding describes responses by Taiwanese firms and policy-makers. Much of the debate has focussed on a strategy of 'industrial upgrading through innovation' (DoIT/MOEA 2008). But most firms and policy-makers are still groping in the dark what precisely that strategy requires, for the time being content with adopting a pragmatic trial-and-error approach until they find something that works. This paper seeks to establish what is necessary and feasible. I find that integration into diverse networks of production and innovation may well provide new lower-cost opportunities for industrial upgrading through innovation. I argue that 'technology leadership strategies' are not the only option. 'Technology diversification', which combines 'incremental' and 'architectural' innovations, can serve as a complementary and arguably less costly option.

The first part of the paper highlights characteristics and achievements of Taiwan's global high-tech factory model and reviews its structural weaknesses. In Section 2, I introduce a conceptual framework to examine how specialization, learning and innovation enhance the potential for industrial upgrading. Section 3 addresses the international dimension of industrial upgrading, exploring implications for learning and knowledge diffusion, and Section 4 discusses implications for Taiwan's upgrading through innovation strategy.

2. Taiwan's global high-tech factory model

2.1. Characteristics

Less than half a century ago, Taiwan was poor and underdeveloped. Yet, by the turn of the century, this small, resource-poor island at the margin of the world economy had established itself as an important global high-tech factory for PC-related products, handsets, wireless equipment, integrated circuits and flat panel displays. For global IT industry leaders, Taiwanese firms became preferred original equipment manufacturing (OEM) and original design manufacturing (ODM) suppliers.⁶

Taiwan's achievements in the IT industry would be impressive for any country – they are even more impressive for a country that is about one-third the size of New York State. With a population of about 21 million people, roughly half the size of South Korea, Taiwan lacked a large and sophisticated domestic market, specialized capabilities and support industries and the science and technology infrastructure necessary for developing a broad set of electronics products.

Like other small economies, Taiwan had to cope with a vicious circle of size-related disadvantages. The small domestic market places tight restrictions on the ability to function as a buffer against heavy fluctuations in international demand. It constrains the development of sophisticated 'lead users'⁷ that could stimulate innovation, and it also limits the scope for technological spill-overs.⁸ In addition, the limited size of the national knowledge and capital base restricts the choice of industries in which such small nations might successfully specialize.

This implies that, from the outset, Taiwan's IT industry had to rely heavily on international markets and access to foreign technology, tools and ideas. The key to Taiwan's success in this industry has been an early integration into diverse and constantly evolving network arrangements that include both formal corporate and informal knowledge networks.

Formal corporate production networks link Taiwanese firms to large global brand leaders (the customers), investors, technology suppliers and strategic partners through foreign direct investment (FDI) as well as through venture capital, private equity investment and contract-based alliances. Equally important are *informal* global knowledge networks that link Taiwan to more developed overseas innovation systems and knowledge communities, primarily in the USA, through the international circulation of students and knowledge workers.⁹ Finally, domestic inter-organizational linkages with large Taiwanese business groups complement these international linkages (Amsden and Chu 2003; Ernst 2001a).

The diversity of network arrangements provides the key to Taiwan's network economy. It has enabled Taiwanese firms to combine the speed and flexibility of smaller firms with the advantages of scale and scope that normally only large firms can reap. Taiwanese firms have been able to tap into the world's leading markets, especially in the USA, compensating for the initially small size of their domestic market. In addition, network participation has multiplied conduits for knowledge transfers to Taiwanese IT firms, broadening their scope for learning and capability development. This, in turn, has created new opportunities, pressures and incentives for Taiwanese network suppliers to upgrade their technological and management capabilities and the skill levels of workers.

2.2. Policies

Policies played an important role in strengthening absorptive capacity.¹⁰ As Taiwan's IT firms, almost without exception, have started out small and from very humble origins, they initially faced substantial entry barriers to network participation. Public policies and support institutions (like ITRI and the creation of Hsinchu Science Park) have played a critical role in overcoming the disadvantage of small size and limited resources (Shih 2005).

Over time, the focus of policies has shifted to education, infrastructure and capability development, as Taiwan's network integration has moved up from very simple OEM arrangements to increasingly complex ODM arrangements that involve product development. To stay on the networks, Taiwanese firms had to recruit highly skilled and experienced knowledge workers, and they needed quick access to core technologies.

Taiwanese policies provided ample tax incentives to enable firms to recruit top talent and to develop in-house technological capabilities. In addition, industrial support policies helped to disseminate market and industry intelligence and induced overseas Taiwanese engineers and managers to return home and/or to invest in Taiwan-based ventures (Schive and Chen 2004). Of particular importance has been the role played by 'institutional entrepreneurs' (especially ITRI) in establishing domestic and global linkages and in accelerating learning, knowledge diffusion and capability development (Shih 2005; Tu et al. 2006).

2.3. Achievements

A major goal of Taiwanese firms is to combine low-cost production and quick response to changes in markets and technology. Low-cost production was made possible by rigorous cost control management and the establishment of a low-cost supply base in China and Southeast Asia. Quick response relied on a flexible system of supplier networks characterized by temporary 'spider web' arrangements that are assembled for the duration of a particular project, and then dissolved.

To expand their position as network suppliers, Taiwanese firms had to move beyond the provision of only manufacturing services, and develop integrated service packages that include logistics and product development (Schive and Chen 2004, 158). For

instance, substantial improvements in supply chain management were implemented through extensive use of IT-enabled information systems and flexible adjustments of organizational structures.

Equally important, Taiwanese firms have made considerable progress in product development, especially in electronic design (Ernst 2008a). Since the late 1980s, Taiwan's leading PC firms have established R&D labs in Silicon Valley to gain early access to the product and technology road maps of the global industry leaders and to improve their product development capabilities. Already during the mid-1980s, Taiwan's semiconductor firms started to get involved in board level and application-specific integrated circuit (ASIC) design (Ernst and O'Connor 1992). This has given rise to a broad portfolio of design implementation capabilities, enabling Taiwanese semiconductor firms to compete on the speed, cost, flexibility and quality of providing these services (Chang and Tsai 2002; Ernst 2005a).¹¹ Much of this progress was made possible by the establishment of a highly integrated domestic semiconductor industry value chain, coordinated by ITRI.

2.4. Structural weaknesses

The downturn in the global electronics industry since late 2000 has exposed structural weaknesses of Taiwan's global high-tech factory model. Intense price competition from new lower-cost competitors in China has reduced profit margins of Taiwanese firms. This limits funds available for R&D and makes it difficult to sustain wage increases (T.J. Chen 2004). Furthermore, relocation of production to Southeast Asia and China has reduced the job creation capacity of Taiwan's IT industry.

2.4.1. Unequal network integration

These decreasing returns reflect fundamental structural weaknesses that result from Taiwan's unequal integration into 'fragmented' and hierarchical global production networks. Recent research demonstrates that a focus on the provision of OEM/ODM services has led to a combination of slow growth of value added and a decline of value-added ratios and domestic linkages.¹² There are concerns that, as long as the country sticks to this industrial development model, this will perpetuate a vicious circle of lock-in effects and development traps. The resultant reduction in learning and value creation could severely constrain the capacity of Taiwan firms to invest in upgrading through innovation strategies.

Taiwanese firms typically are under relentless pressure by global brand marketers to reduce cost and time to market for commodity-type products that are apt to penetrate mass markets. Taiwanese firms are thus stuck in a 'commodity trap' (Ernst 2001b, 146), with low value added and razor-thin profit margins that are insufficient to support investment in R&D, 'intellectual property' creation and branding.

Taiwan handset makers provide a telling example. To improve their profitability, they have all tried since around 2003 to increase their branded handset sales relative to their OEM/ODM business. Yet, with the possible exception of high-tech computer (HTC),¹³ practically all these attempts seem to have failed, with the result that Taiwanese handset makers are now switching back to the OEM/ODM model.¹⁴ The most spectacular failure has been the attempt by the BenQ group (a spin-off of the Acer group) to accelerate its global branding strategy by acquiring the mobile handset business of Siemens and its intellectual property.¹⁵ That failure is all the more remarkable, as Stan Shih, the founder of Acer and one of the most influential strategic thinkers of Taiwan's IT industry, had placed high hopes

that the acquisition of Siemens mobile handset business would allow BenQ to strengthen its own-brand business.¹⁶

2.4.2. *A focus on incremental innovation*

A second weakness of Taiwan's 'global factory' model brings us directly to the question of innovation. Earlier research by Western scholars has emphasized how OEM/ODM arrangements have enabled Taiwanese firms to develop technological and management capabilities.¹⁷ Mathews (2002, viii), for instance, argues that Taiwanese companies were able to overcome their initial disadvantages through strategies '... to leverage knowledge and technologies from their more advanced competitors ... (that) utilize the existing and latent inter-firm connections of the global economy'. And Saxenian (2006, 135) claims that, as long as 'Taiwan remains the world's most efficient and agile IT manufacturer, while the USA continues to define new standards, products and technologies', this will give rise to a mutually beneficial 'process of reciprocal regional upgrading'.

Yet, recent research by Taiwanese scholars¹² highlights the hidden cost of this type of reciprocity. It shows that, as specialized OEM/ODM suppliers, Taiwanese firms are heavily constrained in their capacity to develop new products and to shape technology road maps and standards. Taiwanese firms typically concentrate on incremental innovations within existing product architectures that are defined by global brand leaders who are charging hefty patent licensing fees. As a result, Taiwanese firms are caught in a 'patent trap' – with rising production volumes, they must pay higher royalties, further undermining their profit margins. High-patent licensing fees also constrain diversification into new product markets with higher profit margins.

2.4.3. *Constraints to the development of home-made intellectual property*

While Taiwan's patent filings at the US Patent and Trademark Office (USPTO) have grown rapidly, the quality of Taiwanese patents remains low (in terms of patent citation and 'science linkages'). Hence, Taiwan may find it difficult to reduce the deficit in its technology balance of payments, as transfer payments for royalties and patent infringements are likely to rise. A related concern is that a weak patent portfolio might severely constrain the bargaining power of Taiwanese firms in negotiations about patent swapping with global technology leaders.

US patent data analysis does provide evidence of a rapid quantitative growth – Taiwan is now the third largest patenting economy in the world, behind the USA and Japan (Wong 2006, 4). The same study also finds a substantial improvement in the quality of innovations – Taiwan's share of the most influential innovations in the world relative to their share of all patents has overtaken the UK's share and is approaching Germany's share (Wong 2006, 6).

But more in-depth research by Taiwanese scholars (D.Z. Chen 2006; Lin 2005; Liu 2001) paints a less optimistic picture. There have indeed been impressive quantitative improvements. Since 1999, Taiwan ranks second, ahead of Japan, in terms of the number of 'all patents' it has filed at USPTO for every million of its population. And Taiwan ranks third since 2000 for the more valuable 'utility patents' category.

But Taiwan's high USPTO patent count is highly concentrated, both in terms products ('technology classes') and patent holders ('assignees'). The largest number of Taiwan's US patents is in semiconductor manufacturing, and these patents are dominated by two companies (TSMC, Taiwan's leading patent filer in 2005 and, with a declining share, UMC). And Hon Hai, Taiwan's second largest patent filer in 2005, has pursued an aggressive strategy to file protective patents, especially for its connector technology. China has been

the main focus – since 1995, 61% of Hon Hai's patents were filed in China, against <18% in the USA.¹⁸

As for the quality of Taiwanese patents, Liu (2001, 230) for instance finds that there are only a few 'pioneer' or 'basic' patents and that most patents can only be used as tools for self-protection or cross-licensing. And more sophisticated measures, developed in Lin (2005) and D.Z. Chen (2006), document persistent weaknesses, in terms of patent citation, science linkages and technological capabilities.¹⁹

Equally noteworthy is the persistent concentration of Taiwan's most influential patents – TSMC has developed an overwhelming dominance, followed by Hon Hai, ITRI, Via, AUO, Macronix, UMC, Nanya and Siliconware (D.Z. Chen 2006).

Taiwan's IC design industry provides a telling example of the substantial constraints that the country is facing in its development of home-made intellectual property. Because of their role as specialized suppliers to global semiconductor and system companies, Taiwanese chip design firms have limited resources and incentives to close the technology gap relative to industry leaders. For instance, Taiwanese circuit design firms typically are not active at the leading edge of process technology and IC complexity.²⁰

In addition, Taiwanese design houses have not been able to develop complete solution packages through in-house development of a broad set of complementary capabilities (Ernst 2008a). For instance, in the important cellular chip-set market, only one Taiwanese design house (Mediatek) is offering a complete cellular chip-set solution. All other Taiwanese companies that seek to compete in this market (like Sunplus and Airoha) have focussed on specific building blocks and niche markets. In a market that is characterized by extremely rapid change and high unpredictability, such a focussed approach is clearly a high-risk strategy.

2.4.4. *Extensive internationalization*

Offshore outsourcing is imposing severe hollowing-out pressures on Taiwan's high-tech regions, as more and more manufacturing, support services and (most recently) R&D are moving to lower-cost locations in China and Southeast Asia. This is reflected in a domestic value-added ratio that is much lower than for the USA and Japan (Chen, Liu, and Lin 2005, 22). Furthermore, this ratio keeps declining.²¹

Chen, Ku, and Liu (1995) have demonstrated the 'defensive' nature of Taiwanese overseas investment in Asia. Taiwan's offshore outsourcing has been driven by the needs of the global brand marketers. The main objective was to retain the position as OEM/ODM suppliers, by neutralizing the rise in domestic labor costs and the appreciation of the NT dollar. Most Taiwanese IT manufacturers have widely adopted a strategy of 'receiving orders in Taiwan, shipping manufactured goods from China' (Chen, Liu, and Lin 2005, 25). For the more successful of Taiwanese OEM/ODM suppliers, this has given rise to 'a new cross-strait division of labor along the lines of pilot run vs. mass production'.

As offshoring is now being extended beyond manufacturing into product development, this is eroding competitive advantages that Taiwanese firms enjoyed while they were working only in Taiwan. Take chip design. As the production of computer, communications and consumer products has been moved mostly to China, Taiwan's IC design houses have been forced to follow suit to sustain close interaction with their customers (Ernst 2008a). Moving product development to China may erode their competitive edge – a combination of flexibility, low cost and timely service that was the hallmark of Taiwan's high-tech cluster.²²

In addition, once Taiwanese chip design companies have moved to China, they now are finding themselves exposed to intense competition from lower-cost China competitors.

In fact, Taiwanese chip design houses are in danger of losing their most fundamental competitive advantage, i.e. access to a pool of highly trained and experienced lower-cost engineers and managers. Taiwan's great strength was that it could recruit knowledge workers from diverse sources, especially from its overseas high-skill diaspora. But this advantage is now being eroded, as China's IC design firms can now draw on Chinese returnees who have studied and worked in the USA (Ernst 2008b, 2008c).²³ They can also draw on former employees of Taiwanese companies. Both groups are highly educated and experienced project managers who can make the best out of China's growing pool of local engineering graduates.

2.4.5. *Weak branding power*

In contrast to global brand leaders from the USA, Japan, Europe and Korea, Taiwanese IT firms lack strong global brands that they can leverage to penetrate China's rapidly growing market. This has provoked intense policy debates. Backed by substantial financial support, the government has launched a 'Branding Taiwan' campaign, encouraging local firms to establish global brands.

Branding is of strategic importance – as a device to create differentiation, branding can enable Taiwanese firms to create customer loyalty and to reap premium prices. Yet, as observed by Chen et al. (2006), much of these efforts are focussed on marketing. This neglects the systemic nature of Taiwan's weak branding power.

As specialized suppliers to global brand leaders, Taiwanese firms have rarely been directly exposed to the peculiar needs of final markets. In fact, the weak branding capabilities are a result of Taiwan's aforementioned structural weaknesses: unequal network integration, a focus on incremental innovation, constraints to the development of home-made intellectual property, as well as extensive internationalization. All of these weaknesses are inter-related, and hence are not easy to change at short notice. And to change just one of them without changing the others might be well-nigh impossible.

3. Industrial upgrading through innovation

To establish what is necessary and feasible, I introduce a concept of industrial upgrading, which links 'firm-level' and 'industry-level' upgrading with specialization, learning (absorptive capacity) and innovation.

3.1. *The challenge*

Taiwan faces a systemic challenge – it needs to address simultaneously all the above five weaknesses of its global factory model. The main challenge is to exploit the productivity-enhancing potential of innovation in order to avoid a race to the bottom, which is driven solely by cost competition. This explains why corporate planners and policy-makers are all seeking for ways to upgrade Taiwan's IT industry to higher value added, productivity enhancing and technologically more demanding products, services and production stages.

Of course, OEM/ODM contracts will continue to be an important source for economic growth and capability development. But there is a growing consensus that Taiwanese firms need to reduce gradually their reliance on the global factory model and complement it with a deliberate strategy of industrial upgrading through innovation.

It is important to emphasize that Taiwan's integration into global networks differs from the network integration of leading global high-tech regions. This implies that Taiwan's

approach to upgrading its IT industry must differ from upgrading strategies pursued in Silicon Valley and other first-generation high-tech regions.

Silicon Valley firms for instance are able to shape the strategic direction of such networks, as they control strategic assets. This contrasts with the weak network position of Taiwanese firms.²⁴ As specialized suppliers to global brand leaders, Taiwanese firms lack knowledge about customer needs and system definition, and hence struggle to improve their branding capabilities. As a result, their capacity to develop new product markets and to shape technology road maps and standards remains heavily constrained.

The concept of industrial upgrading will need to factor in those weaknesses.

3.2. *The concept of industrial upgrading*

In general terms, industrial upgrading is about linking improvements in specialization, local value added, and forward and backward linkages²⁵ with improvements in learning, absorptive capacity and innovative capabilities.²⁶

I distinguish two aspects of industrial upgrading that are of greatest policy relevance: firm-level upgrading from low-end to higher-end products and value chain stages, and 'industry-level linkages' with support industries, universities and research institutes.²⁷

In a small network economy, the challenge is to enable firm-level and industry-level upgrading to interact in a mutually reinforcing way, so that both types of upgrading will give rise to a 'virtuous circle'. Firm-level upgrading is the key dimension – without it, there is little hope that Taiwan can sustain and reinvent the success of its IT industry. In other words, Taiwanese firms must develop the capabilities, business models and organization that will allow them to strengthen their absorptive capacity and innovative capabilities. This requires important adjustments in corporate strategy.

But for firm-level upgrading to succeed, upgrading must take place simultaneously at the level of 'industry linkages'. As Powell and Grodal (2004, 57, 58) observe, 'collaboration across multiple boundaries and institutional forms' is the norm today, and innovation networks '... are now core components of corporate strategy'. This reflects the growing geographic mobility of knowledge (Ernst 2003) and the emergence of IT-enabled governance mechanisms to orchestrate distributed knowledge (Ernst 2005d). To broaden the pool of firms that are fit for sustained firm-level upgrading, Taiwan needs to foster strong support industries and dense linkages with universities and research institutes.

Industrial upgrading in Taiwan also faces a second challenge. As its companies are integrated into multiple global networks of corporate production and innovation and informal knowledge communities, it is obvious that international linkages are critical for industrial upgrading. Hence, we need to distinguish domestic and international elements.

Finding the right balance between firm-level and industry-level upgrading and between domestic and international elements poses a continuous challenge for policy-makers and corporate planners – the 'right balance' is a moving target, it is context specific and requires permanent adjustments to changes in markets and technology. I argue that all four elements hang together – a strategy that neglects one element at the detriment of the others is unlikely to create sustainable gains. The stronger the links between those four elements, and the better they fit, the greater are the chances that Taiwanese firms can shape markets, prices and technology road maps.

The international dimension of industrial upgrading will be addressed in Section 3. Our focus here is on the domestic elements. The next section explores how absorptive capacity and innovation hang together. We then turn to the role of specialization in products and types of production.

3.3. *Absorptive capacity and innovation*

A fundamental insight of innovation theory is that learning and innovation are ‘the two faces of R&D’ (Cohen and Levinthal 1989, 569). Learning by doing establishes the routines – ‘the firm becomes more practiced, and, hence, more efficient, at doing what it is already doing’ (Cohen and Levinthal 1989, 570). But a firm’s growth depends on a second type of learning (absorptive capacity) where a firm acquires external knowledge ‘that will permit it to do something quite different’.

For effective knowledge conversion to productive learning, two important elements are required (Ernst and Kim 2002, 1425): an existing knowledge base or competence and the intensity of effort or commitment. In fact, a critical prerequisite for absorptive capacity is that a firm conducts in-house basic research. This differs from the current trendy fashion of ‘open innovation’, which downplays the importance of a decline in corporate basic research debate. Cohen and Levinthal (1989, 593) demonstrate that a firm needs to sustain a critical mass of internal basic research, ‘to be unable to identify and exploit potentially useful scientific and technological knowledge generated by universities or government laboratories, and thereby gain a first-mover advantage in exploiting new technologies’. The same is true for ‘spill-overs from a competitor’s innovation’.

What exactly then is innovation? Schumpeter’s distinction between invention and innovation²⁸ and his focus on ‘new combinations of existing resources’ are a good starting point. To capture the role of innovation for industrial upgrading, I suggest a broad definition: innovation converts ideas, inventions and discoveries into ‘new combinations of existing resources’ that lead to new products, services, processes and business models. It is important to emphasize that innovation is more than research and product development; that users must perceive an advantage to pay for the innovation; and that ‘entrepreneurs’ are not just founders of Internet start-ups, but vary in terms of size, business model and organization.²⁹

Innovations differ with regard to opportunities and barriers to learning; they also differ in the capabilities that a firm needs to implement a particular type of innovation. I distinguish incremental, ‘modular’, architectural and ‘radical’ innovations (Ernst 2008b, drawing on Henderson and Clark 1990).

3.3.1. *Incremental innovations*

Incremental innovations take both the dominant component design and architecture for granted, but improve on cost, time to market and performance. Their purpose is to exploit as much as possible the potential of a given ‘design’, by introducing relatively minor changes to an existing product or process (Nelson and Winter 1982). These innovations do not require substantial inputs from science, but they do require considerable skill and ingenuity, especially complementary ‘soft’ entrepreneurial and management capabilities, as defined in Ernst (2007a).³⁰

3.3.2. *Modular innovations*

Modular innovations introduce new component technology and plug it into the fundamentally unchanged system architecture.³¹ They have been made possible by a division of labor in product development – ‘(m)odularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them’ (Baldwin and Clark 2000, 88). One consequence has been the disintegration of the innovation value chain as well as its dispersion across firm boundaries and geographic borders, giving rise to ‘innovation offshoring’ through global innovation networks (GINs) (Ernst 2006).

It is important to emphasize that, although modularity has created opportunities for industrial latecomers, the barriers to producing modular innovations are substantial. High technological complexity requires top scientists and experienced engineers in different fields. In addition, investment requirements can be very substantial (at least \$3 billion for a state-of-the-art semiconductor fabrication plant), as are risks of failure.

3.3.3. *Architectural innovations*

Architectural innovations are ‘innovations that change the architecture of a product without changing its components’ (Henderson and Clark 1990, 9). They use existing component technologies but change the way they work together. A defining characteristic is a capacity to leverage a deep understanding of market and user requirements, in order to break new ground in product development.

This implies that architectural innovations require strong ‘system integration’ and ‘strategic marketing’ capabilities, but they are much less demanding than modular and especially radical innovations, in terms of their needs of science inputs and investment thresholds.³²

At the same time, however, architectural innovations tend to have much more far-reaching implications for market shares and profitability of innovating firms. As highlighted by Henderson and Clark (1990, 9), architectural innovations can threaten incumbent market leaders – they ‘destroy the usefulness of the architectural knowledge of established firms, and since architectural knowledge tends to become embedded in the structure and information-processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct’.³³

3.3.4. *Radical innovations*

Finally, radical innovations involve both new component technology and changes in architectural design. They require breakthroughs in both architectural and component technology.³⁴ Radical innovations require dense interaction with leading-edge science – top scientists and engineers are needed who work at the frontier of basic and applied research in a broad range of disciplines. In addition, to implement radical innovations requires a broad set of complementary assets (as defined by Teece 1986 and investment thresholds tend to be extreme.

In short, such innovations are costly and risky, and failure can destroy even large, well-endowed companies. They are beyond the reach of most IT companies in Taiwan, but they may well be the subject of public–private consortia coordinated by ITRI.

3.4. *Innovative capabilities*

To determine what kind of innovative capabilities are required to foster industrial upgrading in a small network economy, we can draw on some building blocks provided in the literature. Patent data analysis can now be used as a proxy indicator for measuring progress in Asia’s innovative capabilities, as ‘patenting activities in the region appear to have grown to sufficiently high levels’ (Wong 2006, 11). Specifically, the analysis of patents filed at the USPTO can help to identify the location of an invention (address of the first-named inventor) and the nationality of the patent owner (location of assignee). US patent data analysis can also help to determine the quality and impact of patents (patent citations) and their complexity (science intensity); the clustering/geographic dispersion of patenting

activities (by measuring ‘hot spots’) and the knowledge exchange between inventors at different locations.

Particularly useful for our purposes is research that, based on questionnaire surveys and structured firm interviews, has developed operational data sets for measuring firm-level innovative and R&D capabilities.³⁵ For instance, a comprehensive taxonomy of firm-level capabilities was developed in a study, prepared for the United Nations Conference on Trade and Development (UNCTAD), which distinguishes capabilities required for production, investment, minor change, strategic marketing, establishing inter-firm linkages and major change (Ernst, Ganiatsos, and Mytelka 1998).³⁶

Building on this literature, I suggest to use a broad definition of innovative capabilities to emphasize that, in addition to R&D and patents, complementary soft entrepreneurial, management and system integration capabilities are of critical importance. I define innovative capabilities to include the skills, knowledge and management techniques needed to create, change, improve and commercialize successfully ‘artifacts’, such as products, services, equipment, processes and business models (Ernst 2007a).

Innovations in the IT industry require R&D capabilities. Yet, research on successful IT innovations demonstrates that ‘the technology is the easy part to change. The difficult aspects are social, organizational and cultural’ (Norman 1998).

In order to create products and services that customers are willing to pay for, the following soft innovative capabilities are critical:

- sense and respond to market trends before others take note (‘entrepreneurship’);
- recruit and retain educated and experienced knowledge workers who are the carriers of new ideas;
- global knowledge sourcing for core components, reference designs, tools, inventions and discoveries;
- raise money required to bring an idea quickly to the market (the litmus test of innovation);
- deliver unique and user-friendly industrial designs (which is of critical importance especially for fashion-intensive consumer devices such as mobile handsets);
- develop and adjust innovation process management (methodologies, organization and routines) in order to improve efficiency and time to market;
- manage knowledge exchange within multidisciplinary and cross-cultural innovation projects;
- participate in and shape global standard setting;
- combine protection and development of ‘intellectual property rights’;
- develop credible and sustainable branding strategies.

Each and every of these soft capabilities is important in its own right. But they also hang together. For instance, a narrow focus on brand marketing is insufficient. Branding efforts need to be supported by a broad mix of soft and ‘hard’ innovative capabilities. This implies that a capacity to provide ‘integrated solutions’ is arguably one of the most important prerequisites for industrial upgrading based on innovation.

According to Davies et al. (2001, 5), integrated solutions encompass four sets of capabilities: (1) *system integration*: to design and integrate components and subsystems into a system; (2) *operational services*: to maintain, finance, renovate and operate systems through the life cycle; (3) *business consulting*: to understand a customer’s business and to offer advice and solutions that address a customer’s specific needs and (4) *finance*: to provide a customer with help in purchasing new capital-intensive systems and in managing a customer’s

installed base of capital assets. By and large, US, Japanese and European electronics firms have sophisticated and proven strategies in place that can provide simultaneously these four complex integrated solutions services. The same is true for a handful of large Taiwanese IT companies such as TSMC, Honhai, Acer and UMC.

3.5. *Specialization and industrial upgrading*

We know from the study of ‘national innovation systems’ (Freeman 1987; Lundvall 1992; Nelson 1993) that *specialization* offers quite distinct possibilities for learning and innovation, and hence shapes the technological (or economic) performance of a country/region. Institutions, on the other hand, shape learning efficiency: they define how things are done and how learning takes place. An important concern is the ‘congruence’ (Freeman 1997, 3) of different subsystems, which is necessary to create a *virtuous* rather than a *vicious* circle.

This indicates that, on the domestic front, essential prerequisites for industrial upgrading are institutions and incentives that facilitate and that provide a sufficiently large pool of experienced and re-trainable knowledge workers with specialized skills.

The literature covers well the role of institutions and incentives for learning, innovation and the development of human resources support industries.³⁷ In what follows, I will examine how specialization in products and types of production may enhance the potential for industrial upgrading.

These differences in specialization give rise to divergence in the complexity of technology, demand patterns and market structures. Most importantly, differences in specialization shape a country’s (a region’s) upgrading potential, in terms of learning and innovation opportunities, capability requirements, value added and linkages.

For our purposes, a critical policy issue is to identify conditions under which specialization and upgrading potential are linked by a *virtuous* rather than a *vicious* circle. In fact, a narrow specialization on homogenous products or on ‘modular’ production may well make sense at an earlier stage of development, as it matches with the then prevailing competitive advantages. Yet, this very same specialization may later on hinder a transition to differentiated products or ‘integrated’ production and stifle innovation.

3.6. *Product specialization*

Table 1 shows how the link between product specialization and upgrading potential works.³⁸ Homogenous products (‘commodities’) face low-entry barriers, but price wars compress profit margins. Homogenous products only have a limited upgrading potential, in terms of learning and innovation opportunities, capability requirements, value added and linkages. While there is ample scope for learning by doing, incentives are weak to invest in absorptive capacity. The opposite is true for differentiated products. Take the PC industry, the historic focus of product specialization in Taiwan’s IT industry. As a commodity, the PC has very limited upgrading potential.³⁹ In contrast, the scope for differentiation is broader for high-end handsets (especially smart phones) and for the access network industry. Entry barriers are high in both industries, in terms of investment and technology. There are, however, strong incentives for investing in absorptive capacity. In addition, there are ample opportunities for new entrants to upgrade through innovation.

As demonstrated by Sha et al. (2006), the access network industry provides an example of successful upgrading in Taiwan through a shift in product specialization. High-entry barriers are accompanied by qualitative competition. This requires complex capabilities to understand customer needs and to provide integrated solutions. Without policy support

Table 1. Product specialization and upgrading potential.

Product specialization	Homogeneous (commodities)	Differentiated
	<ul style="list-style-type: none"> • Mature technology • Established design • Easy to replicate • Predictable changes in demand and technology • Limited interactions with customers 	<ul style="list-style-type: none"> • New technology • Fluid design • Difficult to replicate • Unpredictable changes • Close interaction with customers
Market structure	<ul style="list-style-type: none"> • Low-entry barriers • Price competition • Speed to market • Periodic over-capacity and price wars (commodity trap) • Low profit margins 	<ul style="list-style-type: none"> • High-entry barriers • Qualitative competition (customer needs; integrated solutions) • Premium pricing • High profit margins
Upgrading potential	<ul style="list-style-type: none"> • Learning by doing, but weak incentives for absorptive capacity • Limited opportunities for innovation • Limited capability requirements • Low value added • Limited forward and backward linkages 	<ul style="list-style-type: none"> • Many learning opportunities – strong incentives for absorptive capacity • Many opportunities for innovation • Demanding capability requirements • High value added • Extensive forward and backward linkages

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in industry-level upgrading, Taiwanese firms would have been hard pressed to cope with these demanding requirements. In fact, ITRI has played a critical role in providing core technologies, in training engineers and project managers and in linking Taiwanese firms with global R&D partners.

At the same time, this is an industry where premium pricing is possible, at least in some market segments. To the degree that this translates into high-profit margins, this facilitates investment in R&D. As system architectures and interface standards remain fluid and are evolving rapidly, there are many opportunities for learning and innovation, and Taiwanese firms are under considerable pressure to develop their innovative capabilities. Furthermore, the access network industry provides ample opportunities for creating domestic value added and for developing linkages (both domestic and international) with customers, suppliers of core components and technology and private and public R&D partners.

It is interesting to note that ITRI's strategy, while derived from a model developed by Stanford Research Institute (SRI) International, added an important modification (Sha et al. 2006, 10). For SRI, the focus was on the abstract concept of market needs. ITRI's strategy was driven by the search for realistic entry opportunities for Taiwanese firms. For ITRI, the key to success was a profound understanding of market needs that global industry leaders have neglected. The idea is to use such weak spots of global players to create economic value by providing a solution to unmet market needs. This concept provides an example of what is required to establish a *virtuous* circle between firm-level and industry-level upgrading.

3.7. Types of production

The potential for industrial upgrading also varies across different types of production. I suggest distinguishing between ‘routine’ and ‘complex’ production and between modular and integrated production.

3.7.1. Routine versus complex production

For routine production, the upgrading potential is obviously lower than for complex production, which needs to combine diverse technologies and which may require customization, quick responses to changes in market and technology and the provision of integrated solutions. The rewards for a transition to complex production can be high – if a firm successfully implements complex processes, it may benefit from premium pricing and significant profit margins, which in turn could provide sufficient funding for R&D. The downside, of course, is the substantially higher up front preparatory efforts. A successful entry into the more knowledge-intensive complex production requires substantial investment in absorptive capacity and innovative capabilities.

Take a chip design, where routine functions (‘design implementation’) are distinguished from ‘complex’ stages of design that center on conceptualization, circuit architecture and system specification. In Taiwan, design implementation remains an important strategic focus, but system specification is gaining in importance (Ernst 2008a).

Yet, the requirements for making this transition are quite demanding. Entry barriers are extremely high, as design costs at the 90-nm technology (the current best practice) can be as high as \$20–30 million (Ernst 2005a). Intensifying pressures to improve design productivity, combined with increasingly demanding performance requirements for electronic systems, has produced an upheaval in chip design methodology.⁴⁰ ‘System-on-chip (SoC)’ design has moved design from the individual component on a printed circuit board closer to ‘system-level integration’ on a chip. This implies that Taiwanese firms need to ‘unlearn’ old design methodologies and extend their absorptive capacity into uncharted territory.

These new challenges are likely to impose quite far-reaching changes on industry structure, business models and firm organization, illustrating again how closely inter-related are firm-level and industry-level upgrading. As a result, all major actors in Taiwan’s IT industry, from foundries to system companies and integrated circuit (IC) design houses and design service providers, are forced to reconsider their business models and strategies (Ernst 2008a).

3.7.2. Modular versus integrated production

Modular production has played an important role for Taiwan’s global factory model. The PC industry, the initial focus of Taiwan’s IT industry, has been an important breeding ground for this industrial organization model since the mid-1980s. Based on standard interchangeable components as well as the widely shared Wintel architecture, modular design has rapidly eroded the economic rationale for vertical integration.

Market-led standardization (through technical standards and ‘design rules’) of the interfaces between organizationally separate stages of production has made it possible to transform PCs and related products into fully modular or decomposable building blocks, enabling firms to focus on those activities (‘core competencies’) that generate the highest margins and which are critical for sustaining the company’s competitive advantage (Sanchez and Collins 2001). This has created ample opportunities for vertical specialization

(‘fragmentation’) of the PC value chain, giving rise to the OEM/ODM arrangements discussed in this chapter.

But modular production has been extended well beyond the PC industry. In fact, much of Taiwan’s success in the semiconductor industry was due to the decoupling of design and fabrication, which culminated in the well-known symbiotic fabless/foundry relationship, a relatively simple structure. As with earlier forms of modular production in the PC industry, decoupling between IC design and fabrication was based on shared interface standards and well-documented and automatically checkable design rules.

Yet, modular production now seems to give way to more integrated forms of IC production (Ernst 2005b). In fact, decoupling of design and fabrication became impractical once large, complex SoC designs had to be fabricated with the 90-nm process technology. This required a re-coupling of design and fabrication, giving rise to a much closer interaction between chip designers, design service providers, mask makers, foundries, electronic design automation (EDA) tool providers and intellectual property (IP) providers.

The important point for our purposes is that the shift to more integrated forms of production may well enhance the upgrading potential of Taiwan’s IC industry.

For design teams, the re-coupling of IC design and fabrication implies that they now have to learn new methodologies for ‘design for yield enhancement’. In other words, designers must now take into account the effects of fabrication process variations, which make the design even more complex. The greatest upgrading pressures are on EDA tool providers who are forced to come up with new integrated solutions under the heading of ‘design for manufacturing’, which would facilitate a close interaction. And Taiwanese foundries and design service firms are beginning to fill the gaps left by global EDA tool providers.

Taiwanese foundries arguably face the most radical challenges to their business model. TSMC and UMC are the global industry leaders, and fabrication was considered their core competence. To the exclusion of almost everything else, the focus was on driving up yield and driving down costs for standard CMOS fabrication processes. But both foundries now realize that they must move beyond the ‘pure play’ foundry model and develop multiple linkages and alliances. They are searching for ways to develop close links with key customers (such as TSMC’s link with Qualcomm). By guaranteeing access to capacity to preferred customers, foundries expect to share the huge cost of developing process technology, EDA and testing tools. These linkages with customers also provide substantial learning opportunities and catalysts for innovation.

Taiwanese foundries are also strengthening their relationships with EDA tool providers, to validate physical design and verification tool flows into their process technologies. Furthermore, foundries are actively developing links with major providers of design-building blocks, both for basic design intellectual property (such as cell libraries and memory generators) and more complex hardware (including standard bus interface blocks and embedded processors).

As the established ‘fabless/foundry’ model is being eroded, it is not yet clear which new model is likely to take its place. This complicates the challenge for upgrading through innovation strategies – learning requirements are a moving target and the precise nature of innovative capabilities remains fuzzy. This implies that flexibility in learning and innovation strategy is critical when technology roadmaps are messy and ill defined.

In fact, Taiwanese firms at different levels of the IC value chain are experimenting with diverse upgrading approaches. Some IC design firms, for instance, are focussing on lower-cost process technology, whereas others are emphasizing the development of broad-based ‘turnkey’ design implementation services (outsourcing of ASIC design). Others still are

exploring what new opportunities exist to move beyond 'one product' low-cost strategies to ASIC-based development of lower-cost, power-efficient processors.

4. The international dimension

This brings us to the critical importance of international linkages for industrial upgrading in a small network economy. As Taiwan's production and innovation systems are increasingly integrated into complex global network arrangements, it is obvious that industrial upgrading does not end at the national border. Nor should one assume that industrial upgrading occurs only if improved specialization generates dense forward and backward linkages *within* a particular region or within the national economy.

4.1. Evolution of global networks

A 'closed economy' assumption became unrealistic, once liberalization and IT had drastically increased the international mobility of trade, finance and investment, giving rise to geographically dispersed (fragmented) global production networks (Borras, Ernst, and Haggard 2000; Ernst 1997; 2002b; Venables 2006).⁴¹ Taiwan's integration into these networks has created cross-border linkages that need to be exploited by its industrial upgrading strategies.⁴²

Recent shifts in the global innovation system have further increased the importance of international linkages for industrial upgrading. As globalization has been extended beyond markets for goods and finance into markets for technology and knowledge workers, this has increased the organizational and geographic mobility of innovation.⁴³ Global corporations are at the forefront of these developments. Profound changes are transforming their innovation management – an increasing vertical specialization (fragmentation) of innovation gives rise to more open corporate innovation systems (Chesbrough 2003).⁴⁴

According to the US National Science Board, 'the speed, complexity, and multidisciplinary nature of scientific research, coupled with the increased relevance of science and the demands of a globally competitive environment, have . . . encouraged an innovation system increasingly characterized by networking and feedback among R&D performers, technology users, and their suppliers and across industries and national boundaries' (National Science Board 2004, vol. I, iv-36). As a result, global corporations are increasingly relying on innovation offshoring through GINs (Ernst 2006).⁴⁵

Much of the action now is in Asia (outside Japan). The region's main attractions include lower-cost knowledge workers, large and increasingly sophisticated markets and policies aimed at developing innovative capabilities. Global companies 'offshore' stages of innovation to Asian affiliates to tap into the lower-cost talent pool and innovative capabilities of the region's leading export economies. This has led to the establishment of *intra-firm* GINs. But global firms also 'outsource' some stages of innovation to specialized Asian suppliers as part of complex *inter-firm* GINs. In addition, firms from Korea, Taiwan, China, India and Singapore are also beginning to establish their own GINs.

4.2. Deeper network integration

This trend has added a new dimension to Taiwan's network integration, which is now moving beyond manufacturing to include research and product development.

An important aspect is inward R&D investment into Taiwan. Research has focussed on R&D labs, established by global firms in Taiwan, in response to the government's *MNC*

Innovative R&D Centers Program (Chang, Shih, and Wei 2006; S.-H. Chen 2006). Equally important, but still little researched, are R&D and other innovation projects that foreign firms are conducting in Taiwan as part of their established manufacturing, sourcing or marketing affiliates, as well as the role played by specialized third party R&D service providers.

Furthermore, Taiwan is now also emerging as a source of outward R&D investment. Liu and Chen (2006) find that, in China, R&D by Taiwanese firms typically is ‘home base exploiting’.⁴⁶ Little efforts have been made to tap into China’s innovative capabilities. But this seems to be changing. Recent interviews with leading Taiwan semiconductor firms show that both foundries and design houses are now seriously considering innovation offshoring, especially to India and China (Ernst 2008a). The main attractions are access to scarce lower-cost knowledge workers and China’s rapidly growing market.

These deeper forms of network integration through inward and outward R&D investments are likely to pose new challenges for Taiwan’s industrial upgrading, but they also might provide new opportunities. Will deeper network integration add new sources of learning and enhance opportunities for innovation, hence broadening Taiwan’s choice for upgrading through innovation strategies?

4.3. *A poisoned chalice?*

There are concerns that integration into GINs may be a poisoned chalice. It is feared that, apart from a few prestige projects that might provide limited short-term benefits, R&D by global corporations may not provide the means for upgrading the host country’s industry to higher value added and more knowledge-intensive activities.

Obviously, a small network economy like Taiwan faces massive challenges, before it can reap the benefits of deeper network integration. Foreign R&D centers may well intensify competition for the limited domestic talent pool (Chang, Shih, and Wei 2006). Inward R&D by global industry leaders may also give rise to a reverse ‘boomerang effect’ – providing global firms with precious insights into business models and technologies developed by domestic firms. Foreign R&D centers may also have limited interest in sharing knowledge with domestic firms and R&D labs, except as part of strictly hierarchical linkages between a global brand marketer and its Taiwanese OEM/ODM suppliers (Chang, Shih, and Wei 2006; S.H. Chen 2006).

Sometimes, the main purpose of foreign R&D centers is to act as bridgeheads for the ‘platform leadership strategy’ of global industry leaders who seek to enhance and control patterns of innovation in an industry. The over-riding purpose of these strategies is to shape the product and technology roadmaps of platform users. Intel and Microsoft provide two typical examples. Intel, for instance, attempts to extend its control over microprocessors by creating widely used architectural designs that increase the processing requirements of electronic systems, and hence the market for Intel’s microprocessors. And the Microsoft Technology Center in Taiwan provides access to its XML web service and .Net technologies to create a ‘vibrant ecosystem’ of Taiwanese application software developers.

In short, vigorous policies must be in place to reduce the potentially high opportunity costs of inward R&D investment that may result from ‘brain drain’ (both domestic and international), when global firms are crowding out the local market for scarce skills. Other costs discussed in the literature include a possible deterrence effect of global labs on local R&D; the acquisition by global firms of innovative local companies and the disproportionately high benefits that may accrue to a foreign parent company (UNCTAD 2005).

T.-J. Chen (2004, 17) raises a particularly troubling question. He argues that new competitive challenges that arise from shifts in the global innovation system may substantially decrease the returns that Taiwanese firms have been able to reap from network integration.

Specifically, Chen argues that, as global competition is centered increasingly on the development of superior knowledge, intellectual property (the commercial embodiment of knowledge) will become more and more intensely guarded. Hence, successful latecomers like Taiwan may now face severe 'IP barriers' – 'technologically advanced countries can effectively use IP as a barrier to block the attempts by latecomers to enter new industries that are presumably more lucrative but not yet subject to cost competition' (T.-J. Chen 2004, 17).

There is no doubt that the strength of their accumulated patent portfolios enables global industry leaders to pursue IP barrier strategies.⁴⁷

4.4. *New opportunities for learning and knowledge diffusion?*

But it is important to recognize that GINs may also create new opportunities for knowledge diffusion. In fact, integration into these networks may provide Taiwanese firms with better access to innovation management practices, tools, ideas and opportunities for innovation.

For instance, foreign R&D centers could become important catalysts for accelerated learning and capability development. Chang, Shih, and Wei (2006) find that exposure to state-of-the-art innovation management practices of global R&D operations can improve innovation management in Taiwan firms and force them to be 'more innovative'. And S.-H. Chen (2006, 15) shows that the R&D intensity of foreign-owned affiliates in Taiwan's manufacturing industry has increased from 1.5% in 2002 to 1.9% in 2003.⁴⁸

What matters for a small network economy like Taiwan is whether integration into GINs will help to expand knowledge diffusion. This would require that global firms have reasons to balance strategies to raise IP barriers to protect technology leadership positions against the potentially huge advantages that they expect to reap from innovation offshoring. In my view, there are four reasons why this is likely to happen.

First of all, underlying the move towards innovation offshoring are fundamental changes in competitive dynamics, especially in high-tech industries. For instance, new industries like R&D-intensive sectors of the IT industry are exposed to intense price competition from a very early stage in their product life cycle (Ernst 2002b).

Competition in these industries is driven by the speed of new product introduction, with the result that product life cycles become shorter and shorter.⁴⁹ Only those companies that succeed in bringing new products to the relevant markets ahead of their competitors thrive. Of critical importance for competitive success is that a firm can build specialized capabilities quicker and at less cost than its competitors (Kogut and Zander 1993).

In addition, the success of the shareholder revolution and the growing role of private equity investors are forcing global IT companies to maximize their return on investment (ROI) across the value chain. To issue 'buy' recommendations, analysts expect a firm's ROI to exceed, during each quarter, the adjusted market average. To achieve this goal, analysts have identified a new focus for restructuring strategies – firms must reduce the wide productivity gap between manufacturing and R&D, by drastically reducing R&D costs.

No firm, not even a global market leader like Intel, can mobilize internally all the diverse resources, capabilities and bodies of knowledge that are necessary to fulfil this task. As a consequence, global firms increasingly 'externalize' both the sources of knowledge and its use. They outsource knowledge needed to complement their internally generated knowledge; and they license their technology to enhance the rents from innovation.

A second reason for cautious optimism is that, for global firms, benefits from innovation offshoring are too important to neglect. Innovation offshoring allows global firms to reduce the rising costs of R&D and to gain access to new sources of innovation. In addition, innovation offshoring helps global firms to hedge against failures of internal R&D projects or against slippage in capacity expansion.

Third, global firms have been able to move to an open innovation system because an increasing division of labor in innovation has given rise to global markets for technology (Arora and Gambardella 2001). This has enhanced their capacity to engage in innovation offshoring. Global markets for technology imply that a firm's competitive success critically depends on its ability to monitor and quickly seize external sources of knowledge (Iansiti 1997). Global firms now must supplement the in-house creation of new knowledge and capabilities with basic or generic technologies developed elsewhere.

And fourth, global firms need innovation offshoring to improve their access to a limited global pool of knowledge workers. The shift to knowledge-intensive industries has increased the importance and scarcity of well-trained knowledge workers. At the same time, aging populations are reducing the available working populations in Europe, Japan and the USA.⁵⁰ For many high-tech companies, competing for scarce global talent thus has become a major strategic concern. Global sourcing for knowledge workers now is as important as global manufacturing and supply chain strategies. The goal is to diversify and optimize a company's human capital portfolio through aggressive recruitment in global labor markets.

5. Implications for Taiwan's upgrading through innovation strategy

We have seen that innovation offshoring through GINs might well expand the scope for learning and knowledge diffusion. For Taiwan, this implies that deeper integration into GINs might act as a powerful catalyst for accelerating the development and the diffusion of innovative capabilities, *provided* adequate policies and firm strategies are in place to enhance local innovative capabilities. But what precisely does this mean for Taiwan's upgrading through innovation strategy?

5.1. Technology leadership is not the only option

The global factory model has helped Taiwanese firms to perfect 'fast-follower' strategies that aim at entering a product market right at the beginning of its high-growth stage (Mathews and Cho 2000). Which model should Taiwan follow now?

Research on innovation strategies in industrialized countries (OECD 2000) points to technology leadership strategies that focus on radical innovations that involve both the use of new component technology and changes in architectural design.⁵¹ The objective is to become a prime mover of knowledge creation, by setting global standards during product introduction. Radical innovations challenge established market leaders, since they destroy the usefulness of the leaders' capabilities. This requires the creation of new intellectual property rights, especially a broad portfolio of frequently cited pioneer patents connected with important inventions and discoveries.

It is important to emphasize that attempts to compete head-on with global technology leaders necessitate a massive upgrading of absorptive capacity as well as innovative capabilities. To become a technology leader, a firm needs to have access to a broad base of applied and basic research. To develop such a broad research base takes time. It also needs very deep pockets to finance the massive increase of R&D. This in turn necessitates high profit margins based on premium pricing.

Most importantly, technology leadership strategies are extremely risky and market prospects are highly uncertain. The new products may reflect ingenious radical innovations. Yet, this does not guarantee that customers are willing to pay for these innovations. In fact, the more complex the technology, the more difficult to use are the resultant products and the more they are prone to breakdowns due to unproved technology.

In Taiwan's IT industry, only very few companies can master this game. But even they are sometimes forced to stretch their resources to the limits. Take TSMC, the world's leading IC foundry. Its success was built on pursuing a technology leadership strategy in IC process technology. This enabled TSMC to charge premium prices. But sustaining process technology leadership comes at an extremely high cost and risk.⁵² And staying at the frontier of process technology requires dense interaction with top scientists and engineers who work at the frontier of basic and applied research in a broad range of disciplines.

As a result, TSMC had to invest in a broad range of GINs with leading R&D partners. This includes leading labs in Berkeley, MIT and Stanford and at the Inter-University Microelectronics Center (IMEC) in Louvain/Belgium, as well as close partnerships with tool and IP vendors and key customers. The cost of establishing and sustaining such networks no doubt exceeds by far the resources of most Taiwanese IT companies.

Nevertheless, the future of Taiwan's IT industry critically depends on quick access to radical innovations, especially in generic technologies. For instance, Taiwanese firms need core component technologies and insider information on interface standards, in order to compete in the access network industry. The same is true for SoC design for wireless and optoelectronics systems and for embedded processors. And quick application of nano-technology research is critical for the upgrading of Taiwan's semiconductor and optoelectronics industries.

To move ahead in these areas obviously requires concerted industry-level upgrading efforts by the government and industry, along the lines described by Tasse (2007). Such efforts are needed to reduce the very substantial barriers that individual firms face when they try to move to technology leadership strategies. Taiwan has significant policy initiatives in each of the above areas.⁵³ The question is how quickly these initiatives will enable firms to develop successful products.

But even then, the risks are high. This implies that an exclusive focus on technology leadership strategies is unlikely to support a broad-based upgrading through innovation strategy.

5.2. Technology diversification as a complementary option

Technology diversification can serve as a complementary and arguably less costly option (Ernst 2005c). Defined as 'the expansion of a company's or a product's technology base into a broader range of technology areas' (Granstrand 1998, 472), technology diversification focusses on products that draw '...on several...crucial technologies which do not have to be new to the world or difficult to acquire' (Granstrand and Sjoelander 1990, 37). It requires strong research capabilities, but it is much more focussed than technology leadership on applied research that feeds directly into product development.⁵⁴

For Taiwan, technology diversification promises several advantages. By recombining (mostly known) component and process technologies, it generates technology-related economies of scope. Like for Japan, technology diversification could thus avoid the high cost and risk of a technology leadership strategy. Second, technology diversification can also build on Taiwan's existing strengths in process development, 'prototyping and electronic design', as well as on recent progress in the development of integrated solutions

capabilities. Third, Taiwan firms can build on their accumulated capabilities to implement, assimilate and improve foreign technologies, as technology diversification often involves the exchange of knowledge with foreign parties.

This brings us to a last, but critical advantage of technology diversification. By focussing on architectural innovations, this strategy allows Taiwanese firms to extract greater benefits from deeper forms of integration into GINs. As discussed earlier, architectural innovations use existing component technology, but change the way components are designed to work together, hence breaking new ground in product development.

Capability requirements are demanding, but they are within reach of Taiwanese companies that have been successful OEM/ODM suppliers. Of critical importance is a capacity to develop products and services that are less over-engineered and expensive than those of global market leaders, and that address 'effective customer needs'⁵⁵ that incumbent global market leaders have neglected. And barriers to implement that new architecture are limited. In fact, Taiwanese firms do not need to develop the necessary components, nor do they have to change them. The aforementioned deeper forms of integration into GINs have broadened the scope for Taiwanese firms to buy in the relevant component technology from specialized suppliers. Taiwanese firms also might engage in collaborative development of some of these components.

Recent field research shows that leading Taiwanese IT firms are now making serious efforts to catch up in the mastery of these most critical innovative capabilities (Ernst 2008d).⁵⁶ But they still have a long way to go. This requires conscious efforts of industry-level upgrading. The challenge for policy-making is to foster integrated solutions capabilities on an industry-wide level so that individual firms can access these capabilities without encountering the extremely high-cost burden of developing them in-house.

6. Conclusions

Taiwan's success as the global high-tech factory was made possible by a progressive integration into formal corporate production networks and informal global knowledge networks, combined with aggressive and flexible support policies. But that model is now experiencing decreasing returns, which reflect fundamental weaknesses. As specialized suppliers to global brand leaders, Taiwanese firms focus on incremental innovation and lack knowledge about customer needs and system definition. Hence, their capacity to develop new product markets and to shape technology road maps and standards remains heavily constrained, and they struggle to improve their branding capabilities.

I introduce a concept of industrial upgrading that seeks to factor in those weaknesses. At the center of this concept is the need to find the right balance between firm-level and industry-level upgrading and between domestic and international elements. This poses a continuous challenge for policy-makers and corporate planners – the right balance is a moving target, it is context specific and requires permanent adjustments to changes in markets and technology.

I emphasize that vigorous policies must be in place to reduce the potentially high opportunity costs of inward and outward R&D investment and to cope with the increasingly sophisticated IP barrier strategies developed by global industry leaders. But I also highlight potential benefits. Specifically, I explore how integration into GINs may provide Taiwanese firms with better access to innovation management practices, tools, ideas and opportunities for innovation.

I argue that, as technology leadership strategies are extremely costly and risky, only few companies in Taiwan's IT industry can master this game. Hence, technology diversification

can serve as a complementary and arguably less costly option. For Taiwan, technology diversification promises several advantages. By recombining (mostly known) component and process technologies, it generates technology-related economies of scope. And by focussing on architectural innovations, this strategy allows Taiwanese firms to extract greater benefits from deeper forms of integration into GINs.

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Notes

1. Unless noted otherwise, data on Taiwan's IT industry are from the author's original research (Ernst 2000a, 2000b, 2001a, 2008a, 2008d).
2. This supports the observation by Powell, Koput, and Smith-Doerr (1996, 120) that 'beneath most formal ties lies a sea of informal ties'.
3. This analysis contrasts with the story told by Hobday (1995) of a linear sequential network evolution, which is focussed on corporate production networks. This analysis also highlights an important weakness of research that, like Saxenian (2006), focusses on the role of informal knowledge networks, but neglects how these informal networks interact with formal corporate production networks.
4. 'Knowledge workers' are defined to include science and engineering personnel, as well as managers and specialized professionals (in areas like marketing, legal services and industrial design) that provide essential support services to research, development and engineering.
5. Innovation infrastructure is defined as an 'ubiquitous set of infratechnologies (measurement and test methods, process control techniques, science and engineering data, data formats and interface protocols) which often become industry standards' (Tasse 2008, 11). Its main function is to lower entry barriers reduce risks and improve productivity.
6. An OEM contract refers to arrangements between the brand name company (the customer) and the contractor (the supplier), where the customer provides detailed technical blueprints and most of the components to allow the contractors to produce according to specifications. In ODM arrangements, the contractor is responsible for design and most of the component procurement, with the brand name company retaining exclusive control over marketing.
7. Von Hippel defines 'lead users of a novel or enhanced product, process, or service' as those that '... face needs that will be general in the market place, but ... (who) face them months or years before the bulk of that marketplace encounters them ...' and who will '... benefit significantly by obtaining a solution to those needs' (Von Hippel 1988, 107).
8. According to Zander and Kogut (1995), large countries will benefit more from an investment in R&D than smaller countries, where some of the spill-overs of R&D are likely to benefit its trading partners.
9. Between 1987 and 2003, this small island has been the fifth largest nation of the origin of international students in the USA (Guo 2005, 142). In the peak year 1993–94, 37,581 Taiwanese students were enrolled in 921 colleges and universities in the USA. Many of the senior managers of Taiwanese IT firms have studied in the USA and have accumulated professional experience in US companies (Ernst 2008a; Saxenian 2006).

10. Industrial development policies are necessary but not sufficient to explain Taiwan's success. Network integration provides the missing link. This is where I differ from Robert Wade's otherwise interesting analysis (Wade 1990) and other more recent analyses with a statist bias.
11. Board-level design today covers very complex multi-layer boards. Combined with the experience in detailed product design and engineering that Taiwan firms have accumulated in the fabrication of ICs, board-level design has given rise to a broad portfolio of design implementation capabilities. Taiwanese firms have also moved well ahead in system specification and in the complexity of circuit and system design. As discussed below, there remains a persistent technology gap of Taiwanese circuit design firms relative to global industry leaders.
12. Important sources are S.-H. Chen (2002); Chen, Liu, and Lin (2005); Chen et al. (2006); Sha et al. (2006); Poon (2004) and Amsden and Chu (2003).
13. HTC has successfully developed own-brand touch-screen smart phones, initially based on Microsoft's Windows Mobile operating system, but now also on an open-source platform.
14. Taiwan own-brand handset vendors switching to OEM business, *DigiTimes*, 4 October 2006.
15. Less than one year after the acquisition, the German subsidiary, BenQ Mobile GmbH & Co OHG, was closed amid continuing huge losses at the subsidiary. BenQ's share of the Taiwan handset market now languishes around 8%. To survive, BenQ is outsourcing handset production to Taiwanese contract manufacturers (*DigiTimes*, 20 September 2007).
16. BenQ spin-off to help realize own-brand success: Q&A with Stan Shih, *DigiTimes*, 25 August 2006.
17. Hobday (1995); Ernst (2000a); Mathews and Cho (2000); Mathews (2002); Berger and Lester (2005) and, most recently, Saxenian (2006).
18. However, Hon Hai is now expanding its USPTO patent portfolio, accounting for almost one-third of Taiwan's growth in 2004 USPTO patent filings (Lin 2005).
19. For instance, Taiwan's patents are less 'original' than Korea's i.e. they are less frequently cited within a technology class. Taiwan's patents also have less impact than Korea's, they are less frequently cited in other technology classes. As for science linkages, Taiwan's patents, even for semiconductors, are less frequently cited in scientific journals than Korea's patents. A particularly disturbing finding is that, since 2001, the citation index of Taiwan's utility patents has declined. According to Lin (2005), possible explanations are a decline in the number of frequently cited semiconductor patents and an increasing number of 'low originality' patents.
20. According to a recent survey (Teng 2006), only a small number of Taiwanese firms for instance are using 130-nm process technology (11% for digital designs, 2% for analog designs and 5% for MS designs). The exceptions are test chips for foundries in 90-nm process technology, as mentioned by Faraday and Global Unichip, and leading-edge designs by Alchip Technologies for Sony's game consoles. In fact, the share of Taiwanese companies that offer full system design and IP services is substantially smaller than for Korean companies. The same picture emerges for IC complexity – 70% of Taiwanese respondents are designing ASICs with less than 1 million gates.
21. To some degree, this hollowing-out effect, and the resultant job displacements, may have been reduced by the growth of Taiwanese exports to Asia (especially China) of increasingly sophisticated production equipment.
22. Frequent travel between Taiwan and China is a waste of time and money, especially as long as there are no regular direct flights. And speed and flexibility suffer, once design, mask production, foundry services, assembly and test can no longer be concentrated in one cluster (i.e. Hsinchuh Science Park).
23. Close to 800,000 Chinese students have gone abroad since the government first started sponsoring them for overseas study in 1978. While less than a third have come back so far, the rate at which they are returning seems to accelerate. In 2005, for instance, about 35,000 returned to China, three times the amount in 2000 (National Science Board 2006).
24. As discussed below, there are a few exceptions – TSMC and UMC (the world's largest silicon foundry service providers), Honhai (the world's leading OEM/ODM supplier that has amassed huge scale and scope economies), as well as Acer, AsusTek, Mediatek and HTC.
25. As defined by Hirschman (1958, chap. 6).
26. By focussing on learning, knowledge and innovation as major sources of economic growth, our approach is consistent with the concept of *absorptive capacity* (Cohen and Levinthal 1989, 1990), the concept of *localized technological change* (Antonelli 2008), *endogenous growth* theories (Romer 1990) and evolutionary economics (Nelson and Winter 1982; Penrose 1959/1995).

27. The other three forms of industrial upgrading discussed in the literature are: (i) inter-industry upgrading proceeding from low value-added industries (e.g. light industries) to high value-added industries (e.g. heavy and higher-tech industries); (ii) inter-factor upgrading proceeding from endowed assets (i.e. natural resources and unskilled labor) to created assets (physical capital, skilled labor, social capital) and (iii) upgrading of demand within a hierarchy of consumption, proceeding from necessities to conveniences to luxury goods. See Ozawa (2000) for a discussion of upgrading taxonomies. Most research has focussed on a combination of the first two forms of IU, based on a distinction between low-wage, low-skill 'sun-set' industries and high-wage, high-skill 'sunrise' industries. Such simple dichotomies, however, have failed to produce convincing results, for two reasons: first, there are low-wage, low-skill value stages in even the most high-tech industry, and high-wage, high-skill activities exist even in so-called traditional industries like textiles. Second, both the capability requirements and the boundaries of a particular 'industry' keep changing over time. An example is the transformation of the personal computer industry from an R&D-intensive high-tech industry to a commodity producer that depends on the optimization of supply chain management.
28. In his 'Business Cycles', Schumpeter (1939, 84) pushes this distinction to the extreme, arguing that '... innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation'.
29. This broad definition is in line with Peter Drucker's classic statement: 'The test of an innovation, after all, lies not in its novelty, its scientific content, or its cleverness. It lies in its success in the marketplace' (Drucker 1985, viii).
30. Examples of incremental innovations are improvements in the organization of manufacturing, distribution and support services, like Dell's 'direct sales' model and its integration of factory automation and supply chain management. Other examples are new approaches to subcontracting arrangements, pioneered especially by Taiwanese IT firms, like ODM, foundry services (for integrated circuit fabrication) and design implementation services. Incremental innovations may also involve continuous improvements in industrial design that help to attract the attention of customers and that enhance the user-friendliness of a product and its performance.
31. This type of innovation has been a defining characteristic of the PC industry – within each generation of the Wintel architecture (combining Microsoft's Windows operating system and Intel's microprocessors), specialized suppliers have introduced new component technology, for instance for memory, storage and display devices.
32. Examples include Apple's iPod and RIM's Blackberry which created new markets for mobile consumer and business gadgets, and smart phones that combine performance features of the phone, the Internet, the camera and audio-video equipment.
33. The authors use the decline of Xerox and RCA to illustrate the destructive power of architectural innovations.
34. Examples include the discovery of new drugs, or the invention of the Internet.
35. Important contributions include Lall (1992); Ernst and O'Connor (1992); Hobday (1995); Ernst, Ganiatsos, and Mytelka (1998) and Jefferson and Kaifeng (2004).
36. This taxonomy, which suggested a sequential ordering of priorities for capability formation, was largely confirmed in that study's comparative analysis of how electronics and textile firms have developed their capabilities in Taiwan, Korea, Thailand, Indonesia and Vietnam.
37. For Taiwan, ITRI's role as an 'institutional entrepreneur' that enables industry-level upgrading is examined in Shih (2005); Tu et al. (2006) and Sha et al. (2006).
38. See Table 1.
39. According to the chairman of Acer, 'Intel and Microsoft are in almost complete control of the standards and technologies', with the result that return on innovation for PC vendors is low, while the cost of innovation is high (J.T. Wang, chairman of Acer, quoted in 'Acer aspires to an alternative to Dell method . . .', *DigiTimes*, 23 August 2005, 3).
40. 'Design methodology' is the sequence of steps by which a design process will reliably produce a design 'as close as possible' to the design target, while maintaining feasibility with respect to constraints.
41. Trade economists have demonstrated that (i) production is increasingly fragmented, with parts of the production process being scattered across a number of countries, hence increasing the share of trade in parts and components and (ii) countries and regions which have been able to become a part of the global production network are the ones which have industrialized the fastest (Feenstra 1998; Jones and Kierzkowski 2000).

42. Empirical research on Asia's leading export economies documents that progressive integration into global production networks has typically increased intra-industry trade, giving rise to growing 'input imports', i.e. purchases of components and machinery from overseas sources, primarily in Japan and the USA (Ernst and Guerrieri 1998; Ng and Yeats 2003). And specifically for Taiwan's IT industry, Chen, Liu, and Lin (2005) find that defensive overseas investment in China has increased Taiwan's exports of components and production equipment, extending the value chain across the Taiwan Strait.
43. The following draws on Ernst (2002a, 2003, 2005a, 2005b, 2006, 2007b).
44. For instance, a study conducted by IBM Global Business Services with leading global corporations finds that a combination of suppliers, partners and customers is a more significant source of innovations than a company's employees and far more important than in-house R&D (Chapman 2006).
45. Since the turn of the century, these networks are extended well beyond the traditional high-tech regions in the USA, the EU and Japan. Global corporations construct GINs to improve the productivity of R&D by recruiting knowledge workers from cheaper, non-traditional locations.
46. According to Kuemmerle (1996), 'home-base-exploiting' overseas R&D seeks to transfer knowledge from the corporation's home base for commercialization in overseas markets. The key requirement is the adaptation of products, services and production processes to local needs and resource endowments. By contrast, 'home-base-augmenting' overseas R&D seeks to tap into new knowledge at overseas innovation clusters, to transfer that knowledge back to the home base, and to combine these diverse technologies to create new products and processes.
47. In 2002 for instance, all 15 leading companies with the best record on patent citations were based in the USA, with nine of them in the IT sector (CHI/MIT 2003). And 86% of global R&D takes place in industrialized countries, with the US occupying the leading position with 37% (Dahlman and Aubert 2001).
48. He uses four case studies of foreign R&D centers to explore why this might have happened. Chen argues that foreign-owned subsidiaries with high export intensity and which rely on Taiwanese OEM/ODM suppliers 'may need to devote more effort to R&D in order to effectively interact with their local suppliers' (T.-J. Chen 2004, 16). In turn, this requires that domestic R&D has reached a critical threshold so that it can 'serve as a complement to, rather than a substitute for, the R&D activities of foreign affiliates.'
49. On average, a new product generation is introduced every 9 months, and for high-end handsets the cycle can be as short as six months, almost as short as for fashion-intensive garments.
50. Aging is also expected to become a serious challenge after 2010 for Asia's leading exporting countries (with the exception of India).
51. See taxonomy of innovation in Part Two.
52. Establishing a state-of-the-art factory ('fab') that is capable of producing chip from 12-inch wafers with 90-nm process technology requires an investment of up to \$4.5 billion.
53. On SOC design, the government has initiated a 'National SOC Research Program'. On Nanotechnology R&D, the government has committed substantial funds, while ITRI and the National Science Council have signed an agreement to conduct joint research with the National Research Council of Canada. And Sha et al. (2006) describe ITRI's role in the industry-level upgrading of Taiwan's access network industry.
54. Empirical research on Japanese, USA and Swedish companies has demonstrated that technology diversification plays a more important role than technology substitution, as seen from the larger number of old technologies in a current product generation, compared with the number of obsolete technologies (Granstrand, Patel, and Pavitt 1997).
55. I define effective customer needs as those customers are willing to pay for.
56. For instance, HTC, Taiwan's leading own-brand handset vendor, has developed highly successful commercial smart handsets and it uses an open-source platform for its partners to collaborate. And Asus, among other interesting projects, has used a loosely coupled global product development network to bring to market at record speed the first commercially viable ultra-low-cost laptop.

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