United Nations Conference on Trade and Development

World Investment Report

2005 Transnational Corporations and the Internationalization of R&D

CHAPTER V
DRIVERS AND DETERMINANTS

United Nations
New York and Geneva, 2005

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DRIVERS AND DETERMINANTS

The expansion of R&D by TNCs in some developing countries reflects changes in the drivers and determinants of R&D internationalization. In view of increased competitive pressures, shorter product life cycles and the need to innovate more at lower costs, firms are compelled to search for new ways of organizing their R&D. At the same time, some developing-country governments have been able to vastly improve the supply of relevant skills – often costing much less than comparative human resources elsewhere. R&D internationalization is not confined to TNCs from developed countries; developing-country firms are also setting up R&D activities abroad to access these foreign markets and centres of excellence.

This chapter analyses these trends from three perspectives: the changing drivers of R&D internationalization; the locational determinants; and factors affecting the mode of R&D internationalization. The annex to this chapter presents a case study of the expansion of chip design in Asia.

A. What drives the internationalization of R&D?

R&D is one of the least mobile of TNC activities; there are several reasons for its locational "stickiness" (Lall 1979). The complex and tacit nature of advanced technical knowledge makes it difficult and costly to fragment R&D and to locate the different segments in different places. Researchers often need face-to-face interaction to exchange information and ideas. Moreover, research skills tend to develop in a cumulative manner, so that centres that start early often retain or increase their lead; history shows that "centres of excellence" in technologies tend to survive for long periods. R&D also has extensive spillovers – ideas and people flow between innovating firms, with significant synergies – creating strong cluster or agglomeration advantages. Where reputable public research institutes and universities are present as part of the cluster, the advantages of a particular location are even greater.

These factors tend to anchor innovative activity in specific locations or clusters within an economy, mostly in the home country (Patel and Pavitt 1991). However, recent trends in R&D internationalization suggest that these factors are changing, leading to greater dispersion of R&D activities (box V.1). Although many TNC innovators still keep their core innovation activities in one location, most large companies, particularly those with multi-plant operations and diverse products, now have dispersed R&D units. What determines whether TNCs locate these units at home or abroad?

In general, TNCs prefer to retain R&D at home when the costs of communicating knowledge across national borders are high. These costs rise with geographical, economic, cultural and linguistic distance (Fisch 2003, Jones and Teegen 2001).[1] Moreover, TNCs are reluctant to locate R&D abroad when they want to maintain greater control over the innovation process and its outcome. Due to the risk of technology leakage, they are also reluctant to place R&D in locations where there are weak intellectual property rights (IPR) regimes. The size of the firm and the industrial structure also matter. Larger TNCs tend to have more far-flung operations as well as greater experience and organizational skills, thus finding it easier to set up R&D overseas. Small firms may have a greater need to tap into foreign R&D centres, but often lack the organizational resources to set up and manage dispersed R&D systems. Oligopolistic industries, with a small number of competing TNCs, may have firms trying to match each other's R&D activities in a kind of herd reaction.

Adaptive R&D to support foreign production and customize technologies to local conditions has been the main form of R&D abroad (see also chapter IV). Even today, local adaptation remains the dominant type of foreign R&D undertaken by TNCs (Edler et al. 2002, OECD and Belgian Science Policy 2005, Roberts 2001, Ambos 2005). But even local adaptive R&D in a foreign affiliate is economical only under certain conditions (Voelker and Stead 1999). The host economy must be sufficiently different from the home economy to make a major adaptive effort necessary; the scale of operations (a large domestic market or production aimed at export markets) must be sizeable enough; and the host country must possess the necessary human resources and institutional framework. TNCs from developing countries also undertake adaptive R&D abroad. For instance, Huawei Corporation of China has set up a large R&D facility in Bangalore, India, to undertake software design, while Indian software companies like Infosys and Satyam have set up development centres in China to adapt products to the local market.

Technology sourcing or monitoring is an increasingly important reason for TNCs to place R&D facilities in countries with centres of excellence that can serve as monitoring outposts to keep track of new technological developments (e.g. Cantwell and Janne 1999, Kuemmerle 1999, Patel and Vega 1999, Roberts 2001, Le Bas and Sierra 2002). Such R&D internationalization aims at augmenting the technological assets of the parent company. This is why many electronics and information technology firms have established R&D facilities in Silicon Valley and pharmaceutical R&D units cluster around Boston. Technology sourcing and monitoring have also become important drivers for R&D internationalization by enterprises from developing countries (chapter IV, von Zedtwitz 2005).[2]

Box V.1. The case for dispersing R&D from a centralized base

Enterprises practically always launch R&D near the headquarters and/or their main production facilities. The first step towards internationalizing R&D is to disperse it from one location to several, which involves overcoming the inherent costs of transferring tacit knowledge and coordinating research over distances. Firms have to weigh several internal and external factors before deciding whether to keep R&D centralized or to disperse it.

Internal factors concern scale economies in R&D, the need for close interaction between R&D and other corporate functions, along with the desire to control and manage the R&D process from headquarters (Gertler 2003, Fisch, 2003). In general, where R&D involves high minimum investment in equipment and personnel, or requires geographical proximity to headquarters or the main production plant in order to be effective, there is a strong case for centralization. The case is strengthened if communication costs are high and the company lacks the managerial and organizational skills to handle dispersed units.

However, centralization of R&D can also generate costs. Facilities over a certain size may lose flexibility and lose contact with parts of the firm located elsewhere.[a] Moreover, some decentralization is inevitable in a multi-plant firm to the extent that the R&D conducted is supporting production – production that is itself dispersed. New communication technologies and management practices are reducing the transaction costs of managing dispersed R&D units. In addition, new research methodologies permit greater codification of scientific knowledge and standardization of some R&D work, which facilitates the dispersal of R&D units (Patel and Pavitt 1991, Prencipe et al. 2003).

External factors affecting R&D location are the relative availability and cost of technical skills and knowledge institutions and the proximity of innovation clusters (Carrincazeaux et al. 2001, Cantwell and Janne 1999, Porter and Stern 2001).

Source: UNCTAD.

[a] There is also a need to separate research from development (von Zedtwitz and Gassmann 2002). Science-oriented research may have to be separated from engineering-oriented development work to improve efficiency. This is particularly the case in industries where product development is highly science-based, as in pharmaceuticals and biotechnology.

A study of over 200 TNCs from the United States, Europe and Japan identified nine reasons for internationalizing R&D (Edler et al. 2002). The three *most important motives* for the sample firms were to adapt foreign technologies to local markets, to access skilled research personnel and to learn from foreign lead markets and customers.[3] The four motives of *medium importance* were to take advantage of technologies developed by foreign companies, to keep abreast of foreign technologies, to support local production and to comply with local market-access regulations and pressures. Finally, the two *least important motives* were to take advantage of public R&D programmes in host countries and to evade an inappropriate R&D environment at home. This survey was conducted at the end of the 1990s and related to R&D offshoring in other developed countries. It more or less confirmed what previous studies of R&D internationalization had found (Mariani 2002, Jones and Teegen 2003, Roberts 2001).

The recent expansion of R&D outside the Triad (chapter IV) suggests that a new set of drivers – the *cost and the availability of research manpower* – has become increasingly important. Rising R&D expenditures, along with intensifying pressures to cut costs and to bring products quickly to the market, are forcing TNCs to look for ways to do research more quickly, outsource non-core work (see next section) and locate R&D in countries with low-cost and ample scientific manpower. This becomes even more important when companies fail to find a sufficient number of skilled people in their home base, especially in science-based activities. For example, it has been reported that the European Union lacks 700,000 scientists and engineers needed to meet its target of devoting on average 3% of GDP to R&D.[4] A study of R&D in Asia concluded that:

> "[o]ne main reason for offshore outsourcing is that very often there isn't enough talent in the company's own home country... the personnel available for specific tasks does not have the sufficient qualifications, where programmers and scientists from countries such as India do have the right qualifications and skills to match the outsourcers' needs" (Frost and Sullivan 2004, p. 8).

As the internationalization of manufacturing production and IT-based services reveals its cost advantages, firms are starting to apply the same principles to innovation. Many companies accept that, all else being equal, the cost and availability of researchers are now important drivers for internationalizing R&D, particularly in industries relying on new technologies. A survey of foreign companies' R&D activities in India noted that for companies in conventional technology industries, proximity to manufacturing and to the Indian market were the two main motives for undertaking R&D in India (Reddy 2000).[5] Conversely, for companies in new technology industries availability of R&D personnel and low costs of doing R&D topped the list. Moreover, for this category of companies a shortage of R&D personnel in the developed countries was perceived as a relatively important driver, whereas it was unimportant for companies in conventional industries. This observation is in line with the dominance of electronics, ICT and software industries among the globally oriented R&D labs that have been established in various Asian economies in the past decade (chapter IV).

Other recent surveys and media reports confirm the growing relevance of cost reduction and the importance of accessing talent pools abroad:

- A survey of German companies found that the lower cost of R&D manpower abroad was the second most important reason, after production support, to locate R&D abroad (DIHK 2005b).
- A survey of 104 senior executives noted that: "[in] industries where a constant stream of high-tech innovations is crucial to survival, companies will go wherever they must to access top R&D talent. A total of 70% of executives in the survey see the ability to exploit pools of skilled labour as a very important or critical benefit of globalized R&D, making this a more significant driver than cost control or the desire to accelerate innovation cycles" (EIU 2004a, p. 2). Moreover, more than half said that lower costs were an important benefit of globalized R&D. Cost benefits came from cheaper labour and lower land and office rents, as well as from favourable tax regimes.
- Cost reduction has been identified as one of the main drivers of expanding TNC R&D in China (Armbrecht 2003).
- In a survey of product engineering companies in California conducted by the Indian company, Wipro Technologies, the top reasons for outsourcing were to reduce

the time it takes from product development to sales ("time-to-market"), as well as overall R&D costs.[6]

- The need for cost reduction has also been an important driver for the offshoring of chip design to Asia (Ernst 2003, see also annex to this chapter).

Cost advantages derived from conducting innovative R&D in developing countries can be significant. A recent report on the pharmaceutical industry compared the cost structures of India with those of developed countries (Goldman Sachs 2005). It concluded that the cost of clinical development in India was 45%, drug manufacturing 30%, and R&D related to drug discovery only 12.5% of the corresponding work conducted in a developed country.

While costs matter, the expansion of innovative R&D in Asia has also been driven by various supply-oriented factors. Concerted efforts on the part of many of the countries in that region have increased the supply of skills, notably in the areas of science and engineering. In some cases, researchers, engineers and managers of the diaspora have returned to their home countries and brought with them new capital, skills, networks and their reputation. Policy interventions include new incentives to promote R&D, more effective IPR regimes, improved public research activities and the establishment of science and technology parks (chapter VII). For some industries such as electronics, the fact that manufacturing activities have already been globally organized is making it easier – and sometimes even necessary – to disperse R&D activities internationally. It is no coincidence that East and South-East Asia are over-represented among the "winners" in export competitiveness in the same product areas in which TNCs are scaling up their R&D work in the region.[7]

Finally, it is important to consider a few technical and organizational advances that are reducing the constraints to the cross-border exchange of knowledge and compelling firms to internationalize their R&D (Zanfei 2000, Ernst 2003). First, liberalization and technological progress have made competition more intense, forcing TNCs to invest more in R&D without allowing costs to spiral out of control. Companies that are unsuccessful in curbing development costs tend not to be rewarded by the stock market. Thus they look for more economical ways of boosting innovation. Second, advances in ICTs allow for faster, cheaper and denser information exchange across long distances. Third, in "new technology" industries the proximity to basic science makes it possible for countries that have an ample supply of scientists and engineers to host R&D work of TNCs, even if their industrial experience is otherwise lacking (Reddy 2000). Fourth, the "modularization" – or finer specialization of the R&D process into separate activities – of some types of R&D is allowing firms to fragment the development process (of products and services) to raise efficiency and cut costs (Baldwin and Clark 2000).

In summary, most R&D internationalization is driven by the need to adapt products and processes to local markets. However, the need to tap into foreign centres of excellence and source foreign technology is gaining in importance, especially in the case of R&D set up in developed countries. But to understand the expansion of innovative R&D units in some developing countries, it is necessary to consider a complex mix of driving forces encompassing demand factors, supply factors and various enabling factors. For TNCs, especially in new technology industries, developing economies offer new opportunities to reduce costs, access skills that are not readily available at home in sufficient supply or at attractive costs, and speed up the development of new goods and services.

B. Host-country determinants of R&D location

Given the pressures inducing TNCs to internationalize R&D and the factors making this possible, what determines *where* TNCs locate R&D in the developing world? The global map of R&D shows that its spread is uneven. R&D in host developing countries is mainly concentrated in Asia and in a few large economies in Latin America and the Caribbean. The present section relies on survey evidence from developed countries and qualitative evidence from developing ones. The picture that emerges is fairly clear and persuasive.

While some basic determinants are common, different types of R&D (chapter IV) – adaptive R&D, innovative R&D linked to production for local/regional markets, global innovative R&D for new product/process development or basic research, and technology monitoring – are attracted by different factors. The general investment climate – comprising, for example macroeconomic and social stability, security, transparency, administrative rules and regulations – is as important for R&D location as it is for FDI in general. Similarly, the type of R&D that may be attracted depends on the economic structure of the location, including the industrial structure, market size and growth, culture and language, natural resource endowments, living conditions and physical infrastructure. Most of these factors are "created", rather than natural, assets and therefore can be altered through government intervention. Hence, host-country policies play a significant role in determining a country's ability to participate in the international restructuring of R&D activities by TNCs (chapter VII).

Adaptive R&D is typically closely related to production and involves the adaptation of imported technologies. This is the dominant form of R&D by foreign affiliates in Latin America and in Africa (chapter IV). The location of such development work is determined by the need to support production and adapt technologies, to be near customers, to cooperate with local partners, to access markets, to improve the local "image" of a company, to launch a product simultaneously, to facilitate rapid scale-up in manufacturing and to overcome protectionist barriers against imports (von Zedtwitz and Gassmann 2002, p. 584). The larger the host market, the greater the need for local adaptation of goods and services. As national markets become regionally more integrated, some countries may become the preferred base for adaptation, not only for the local market but for the region as a whole. In this case, appropriate skills and other aspects of the national innovation system (such as the technical and economic infrastructure, proximity to suppliers/key customers) become more important. Depending on the industry, adaptive R&D needs technical and engineering skills that are specialized in the technologies used in production. Cost factors are likely to be of secondary importance.

Innovative R&D has emerged as a feature of some foreign affiliates in parts of South, East and South-East Asia as well as in some transition economies (chapter IV). Internationalization of such R&D for global markets is driven by the search for advanced skills in relevant areas of science-based technologies. Such R&D work can be intended for regional or global markets and is determined primarily by the quality of the national innovation system (NIS). In China, adaptive R&D has evolved into more advanced forms of innovation, with the local market serving as a test-bed for new products for regional or even global markets (Sigurdson 2005b; chapter IV). The precise features of a host country that are needed to attract innovative R&D depend on the industry and activity involved. Key determinants in host developing countries for attracting innovative R&D include a large pool of scientific and technical manpower, a well functioning NIS featuring strong public research institutions, science parks and an adequate system of IPR protection, and government incentives (von Zedtwitz and Gassmann 2002, Reddy 2000, Toh 2005).

The availability of the right kinds of scientific and engineering skills is probably the most critical factor in attracting innovative R&D, especially in new, science-based technology industries. The importance of researchers and scientists covering a broader range of disciplines is not new. What is new is that competitive pressures are forcing companies to pay greater attention to *wage costs* and *availability of scientists and engineers in large numbers*. With wage rates for skilled researchers in developing-country R&D locations significantly lower than those in developed countries, the attractiveness to TNCs is compelling. But wages *per se* are not the main location determinant. TNCs value the ability to set up a research facility rapidly and tap into an existing knowledge centre where they can find skilled researchers (often in the hundreds) at short notice. This gives a "critical mass" advantage to countries that combine low wages with good education systems that turn out large numbers of well-trained researchers. As their low ranking in the *UNCTAD Innovation Capability Index* (chapter III) shows, China and India are not the most attractive locations in terms of human resources normalized by population size. However, when TNCs need to recruit researchers in large quantities, these countries offer a growing body of skilled people at low cost.

The global distribution of tertiary enrolments has changed dramatically (box V.2).[8] Developing Asia has emerged as the main source of new university graduates, and this trend appears to be continuing. This is one of the main reasons why, for example, a growing number of TNCs are turning their attention to China and India for innovative R&D work. China is expanding its tertiary education system at an unprecedented rate.[9] The total number of students enrolled in tertiary education increased to more than 19 million in 2003, a 100% increase over 2000.[10] It has been estimated that the accumulated number of university graduates in China could exceed 120 million by 2020 (Sigurdson 2004). If realized, this expansion would pose a competitive challenge to other countries, developed and developing. India is expanding more slowly and the tertiary enrolment rate is relatively low (at around 10% of the age group), but the absolute numbers are large. Meanwhile Latin America, a richer region overall, lags behind in enrolments of engineers and scientists. This further constrains its R&D performance, inducing a significant number of its researchers to seek work in North America.

Of course, not all tertiary students are candidates for work in the R&D labs of TNCs. A recent analysis of the supply of skilled people in various developing countries and economies in transition (including the new EU members) found that only a small proportion of potential job candidates in "degree specific" occupations were qualified for work in TNCs (McKinsey Global Institute 2005).[11] The research, which was based on interviews with human resource managers in 83 TNCs, found large differences among the countries investigated. For example, while 50% of engineers in Poland and Hungary

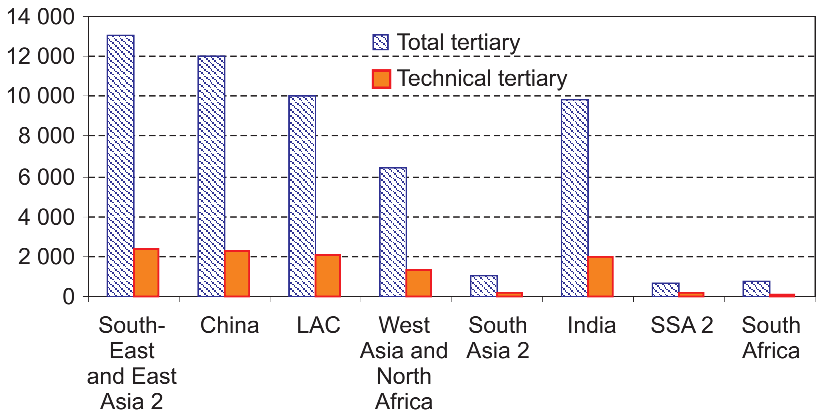
Box V.2. Tertiary enrolments by region and country

In 2000/01, developing countries accounted for 62% of global tertiary enrolments overall, and for 52% in technical subjects (pure science, engineering and mathematics and computing). Transition economies (including new EU members) accounted for 16% and 20%, and developed countries (excluding the 10 new EU members) for 22% and 28% respectively. Box figure V.2.1 shows the number of total and technical tertiary enrolments across developing regions. Box figure V.2.2 displays the shares of technical tertiary enrolments by region. The first figure also separates the main outliers from the totals of each subregion: China in South-East and East Asia, India in South Asia, and South Africa in sub-Saharan Africa. The data on technical enrolments are particularly important for R&D location as these are the primary skills involved in such work.

In tertiary technical enrolments, China, the Russian Federation and India led the world, ahead of the United States (which had the highest number of total tertiary enrolments in 2001) (annex table A.V.1). The Republic of Korea was fourth in the world in technical enrolments, which is impressive for a country of only 47 million people.[a] Indonesia, Mexico and Brazil followed among developing countries, Ukraine and Poland among transition economies, and Germany and Japan in the developed world. Both Germany and the United States saw a decline in the total number of tertiary students, while the number in Japan increased.

In tertiary technical enrolments, China accounted for 50% of the total for South-East and East Asia in 2001; it had more students than the whole of Latin America and the Caribbean (LAC) and sub-Saharan Africa combined. India accounted for 90% of the total for South Asia; it was slightly behind LAC as a whole but ahead of West Asia, North Africa and sub-Saharan Africa together. Some African countries have also expanded their tertiary

Box figure V.2.1. Total and technical tertiary enrolments across developing regions, 2000-2001
(Thousands)



Source: UNCTAD, based on annex table A.V.1.

Note: South-East and East Asia 2 excludes China. South Asia 2 excludes India. SSA 2 is sub-Saharan Africa excluding South Africa.

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were suitable to work for TNCs, the corresponding number for India was about 25%, and for China and the Russian Federation only 10%. The results underline the need to focus not only on quantity but also on quality in education programmes.

The agglomeration of R&D activity in a specific part of a country often reflects the concentration of skilled manpower in that location. For example, most software companies in India are located in the five states that account for nearly half the diploma-granting technical institutions in that country as well as for two-thirds of all diplomas awarded by private training institutions (D'Costa 2003 p. 216). In China, Beijing, Shanghai, Guangzhou and Shenzhen account for 85% of all R&D units set up by foreign companies in China, mainly because they are close to local universities and research institutions (Zhang 2005; box IV.5). Some 50 TNC R&D organizations have been set up in the Zhongguancun area of Beijing (Zhang 2005).

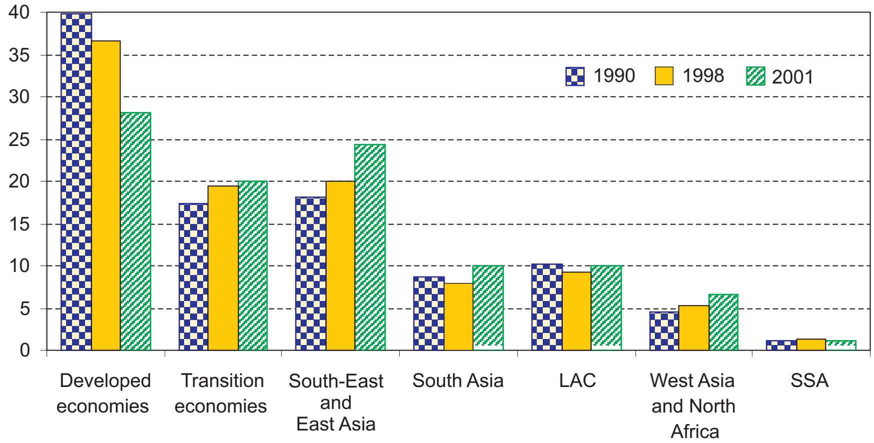
While the absolute number of skilled people plays an important role in R&D location, it is nevertheless possible for small economies with high levels of technical skill to attract global R&D as long as they also have a large TNC presence in technology-intensive activities and can offer specialized R&D competence. Ireland, Singapore and Hungary are good examples of small newcomer countries that have attracted a large TNC research presence.[12] By the same token, countries with large skill pools may not attract much TNC R&D if other conditions are not met, as is the case for Japan and the Russian Federation.

An important structural determinant of innovative R&D location is the strength of a country's NIS (see also chapters VI and VII). The NIS includes knowledge institutions (R&D labs and universities as well as standards, quality and metrology institutes) and other R&D performing enterprises (local or foreign), along with an institutional framework for R&D and innovation. A strong NIS, where knowledge institutions have

Box V.2. Tertiary enrolments by region and country (concluded)

education system rapidly, but from low levels. For example, in the United Republic of Tanzania the number of technical students increased from 1,000 to 6,000 between 1990 and 2000; in Ghana the corresponding rise was from 2,000 to 14,000; and in Egypt from 70,000 to 290,000. However, the number of people with tertiary education remains very small in most of Africa.

Box figure V.2.2. Shares of global technical tertiary enrolments
(Per cent of total)



Source: UNCTAD, based on annex table A.V.1.

Note: Transition economies here comprise South-East Europe and the CIS as well as the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Slovenia.

[a] In the Republic of Korea, as of 2004, 40% of people in the age group of 25-34 years were university graduates. Every year the country produces some 70,000 engineering graduates, which is equal to the number produced in the United States (KICOS 2004).

tight links with production enterprises and other firms that perform world class R&D, is a major draw to TNCs looking for new R&D locations. The presence of dynamic science parks can be an additional attraction to R&D that requires interaction with a diverse range of firms and institutions (chapter VII). Basic research calls for an even stronger NIS, featuring science institutions that are able to produce world-class research and publications and undertake contract research work for industry.[13]

The IPR regime is also part of this framework. Its role in attracting R&D by TNCs tends to differ by industry and type of R&D.[14] Adaptive and production support R&D may not require strong IPR protection, but it may be essential for other types of R&D (box V.3).[15]

Do government incentives help attract R&D by TNCs? The question is important especially in light of the increased use of R&D incentives around the world (section VII.C). In general, incentives are effective only when other,

Box V.3. IPR regimes and R&D location

IPR regimes are often mentioned as a factor that might influence the location of TNC R&D. However, the evidence is mixed. Surveys suggest that the role of IPR regimes in attracting FDI in general may be limited, but that it is an important factor for R&D-related FDI. Protection of intellectual property generally improves the environment for innovative R&D, but its role varies by industry (Maskus 2005). For industries in which technologies are easy to imitate, IPR protection may be essential for attracting international R&D; for other industries it may be a less important factor.

A study of IPR protection and FDI, using a sample of 94 firms from the United States, 45 firms from Japan and 35 from Germany found that IPR protection was not a critical locational determinant for most types of FDI, but that it did affect R&D-related investments. The percentage of firms stating that IPR protection is important was particularly high in the chemicals and pharmaceuticals industry (Mansfield 1994 and 1995).

Econometric analysis of United States TNCs found that IPR protection was a significant determinant of where foreign R&D activities were performed, but not a significant factor between different developing-country locations (Kumar 1996). It even suggested that a strong IPR regime could discourage TNCs from undertaking R&D in developing countries.[a] However, another study found that R&D spending by the affiliates of United States TNCs increased after IPR reform in host countries (Branstetter et al. 2004). This study also noted that the level and rate of change of non-resident patenting increased in the post-IPR-reform period, while there was no corresponding reaction in resident patent filings.

Some developing countries like Brazil, China and India have attracted significant amounts of FDI in R&D; despite being perceived as having relatively lax IPR regimes. There are four main reasons why IPR protection may have a limited impact on the location of TNC R&D:

- R&D may be conducted for a completely different market. For example, it has been noted that IPR issues for TNC R&D labs in China are mostly handled in the home country as these labs work on technologies aimed at world markets (Zhao 2004). Since a patent gives its assignee a monopoly on both production and sales, the TNC can protect its intellectual property by obtaining patents in the countries for which the product was developed rather than in the country where the R&D is undertaken.
- A technology may be highly firm-specific and thus of limited value to others. For example, if different technologies developed by a firm are complementary to one another and can only be used jointly, a particular innovation in the host economy may have little value on its own.[b] TNCs may structure their international R&D activities so that a foreign affiliate in a country with weak IPR protection undertakes only R&D with strong complementary elements.
- TNC R&D in a host economy may deal with technologies that are too advanced for local competitors to copy and use commercially.
- Certain types of technology involve tacit and uncodifiable elements that are difficult for outsiders to imitate without intimate knowledge gained by working with that specific technology.

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more important determinants are in place. By reducing costs, government incentives may induce TNCs to expand or deepen their R&D activities. However, if the necessary skills and research capabilities are lacking, incentives may induce firms merely to re-label routine technological activities and report them as R&D (chapter VII). Indeed, countries with ample and low-cost scientific skills are likely to attract international R&D without offering incentives.

A diverse industrial structure, with technologically complex activities, is likely to provide clusters with the skills and linked suppliers and buyers that can support innovative R&D. Countries with strong technological specialization tend to attract TNC R&D in similar areas, and TNCs tend to internationalize innovative (asset-augmenting) R&D to complement their strengths (Patel and Vega 1999, Le Bas and Sierra 2002, Guellec and van Pottelsberghe 2001 and 2004b).

The fact that developing Asia has emerged as the production base for many globally oriented industries (*WIR02*) has also led some TNCs to conduct more R&D in the region so as to be closer to their actual manufacturing activities (see annex to this chapter). In Malaysia, some foreign affiliates in electronics have obtained a mandate from their parent companies to design, develop, manufacture and market products for global markets. This has allowed them to undertake all stages of innovation. Toyota's decision to place one of its global R&D labs in Thailand was likewise facilitated by the presence of a relatively strong automotive cluster in that country (box IV.7). In the case of India, proximity to manufacturing has been an important driver for R&D by foreign affiliates in "conventional technology" industries, but not in new technology industries (Reddy 2000).

Finally, R&D with the aim of monitoring or sourcing technology is mainly drawn to countries boasting world class clusters of technological and industrial activity (Porter and

Box V.3. IPR regimes and R&D location (concluded)

The design of IPR regimes may play a less direct but nevertheless important role. For instance, providing effective means of IPR protection may act as a signalling device to international investors. Strengthening the regime may show that the country is willing to "play by the rules" and provide a hospitable investment climate. Internationalized R&D often involves activities where strong protection matters: pharmaceuticals and software – the two major areas of TNC R&D in India – are good examples.[c] For recent R&D investments in developing Asia by pharmaceutical companies such as Roche and GlaxoSmithKline the question of IPR protection was a key consideration.[d]

The role of IPR protection must of course be assessed not only from the perspective of attracting FDI in R&D. For example, many economies have taken advantage of their weak IPR regimes to build up indigenous technological capabilities. Imitation, copying and reverse engineering have been important sources of learning in much of East Asia. However, in the cases of the Republic of Korea (Kim 2003) and Taiwan Province of China, they have subsequently become innovators rather than imitators of new technology, and now need more effective IPR regimes to promote domestic innovation. At this advanced stage of their development, IPR protection is important for both local and international R&D. Even countries at lower levels of technology development like China and India are fostering local innovation and may benefit from stronger IPR protection (Lall 2003).

Source: UNCTAD.

[a] Sanyal 2004 reached the same conclusion.
[b] For example, Microsoft Research Asia developed AutoMovie for Movie Maker, Mobile HTML Optimizer for Front Page and the Ink Parsing technology for tablet PCs. These were considered major contributions to the Microsoft products, but alone they are of little value to potential imitators (Zhao 2004).
[c] It may be noted that India as of 1 January 2005, introduced the possibility to patent pharmaceutical products, reflecting obligations under the TRIPS Agreement. According to the Ministry of Commerce and Industry, this is intended to help the Indian pharmaceutical industry protect the results of its rising R&D efforts (www.pib.nic.in/release/).
[d] "Eastern rebirth of the life sciences", *Financial Times*, 10 June 2005.

Box V.4. Why are companies setting up R&D in China?

A recent study on R&D investment by major TNCs in China, conducted for the Industrial Research Institute in the United States highlights some of the perceived advantages of locating industrial R&D in China, many of which are the result of government policies (Armbrecht, 2003):[a]

- The supply of talented manpower exceeds demand, at least by foreign firms;
- Universities and research institutes are eager to get funding from private firms;
- The possibility of entering into IPR agreements with top Chinese universities;
- A large number of high-technology parks;
- Incentives; and
- The potential for cost reduction across all stages of the R&D value chain.

The study emphasized that while cost savings matter, TNCs expand R&D in China primarily for strategic reasons: to tap the vast pool of talent and ideas and to stay abreast of competitors in the increasingly sophisticated markets of China and Asia. It predicted a further increase in TNC R&D in China and argued that the focus of these R&D labs would shift from support and adaptation to full-scale R&D work using China's emerging technologies and talent pools.

The following taxonomy describes the evolution of TNC R&D in China (box table V.4.1). "Satellite" R&D laboratories, the least developed type, have relatively low strategic importance for the companies and are vulnerable to budget cuts by TNC headquarters, while "contract" R&D laboratories show vertical specialization within global innovation networks. Within the latter, China's role is presently confined to the provision of lower-cost skills, capabilities and infrastructure. While dense information flows link these labs with R&D teams at headquarters and at other affiliates, knowledge exchange remains tightly controlled and unequal. The highest stage – (more) "equal partnership" laboratories – is comprised of TNCs' R&D facilities that are charged with a regional or global product mandate. For these labs, barriers to knowledge exchange are lower and are eventually expected to give way to mutual knowledge exchange.

Satellite and contract laboratories still dominate TNC R&D in China (von Zedtwitz 2004, Gassmann and Han 2004, Li and Zhong 2003), but there are examples of (more) equal partnership arrangements, especially in the development of China's alternative standards in mobile telecommunications, open source software and digital consumer electronics (Ernst and Naughton 2005).

Box table V.4.1. Taxonomy of TNC R&D laboratories in China

Satellite laboratories	• Act as listening post to detect ideas, incentives and innovations that reflect local market characteristics • Adapt existing products and processes • Are vulnerable to budget cuts
Contract R&D	• Exploits lower cost skills, capabilities and infrastructure • Implements a specific module of a global research project • Closely interacts with R&D teams at headquarters and at other affiliates • Requires tight mechanisms to control IPR leakage • Has dense information flows, but unequal knowledge exchange
(More) equal partnership	• Full integration into TNC R&D strategy • Centre has regional or global product mandate • No barriers to fully-fledged knowledge exchange

Source: UNCTAD, based on Walsh 2003 and Ernst 2005.

Source: UNCTAD.

[a] The membership of the Industrial Research Institute includes more than 240 leading global manufacturing TNCs that perform over two thirds of the industrial R&D in the United States.

Stern 2001). Technology sourcing R&D is undertaken predominantly in developed countries. A study of the pharmaceutical industry in Europe and the United States noted that European pharmaceutical TNCs were more likely to set up such R&D in the United States than vice versa, possibly reflecting the size and profitability of the United States market, its scientific competence and the close links there between industry and university research (Ramirez 2003).

Many factors thus interact to determine the attractiveness of a site for FDI in R&D (see box V.4 for the case of China, box V.5 for the case of India), but the effective functioning of a country's NIS is critical (chapter VII). Most of the countries in Asia that have successfully attracted R&D by TNCs have applied deliberate

Box V.5. Why TNCs set up R&D in India

TNCs performed R&D in India already in the 1970s, but it was then limited to adaptation or product development for the Indian market. Such R&D was conducted mainly in response to government regulations and to certain unique characteristics of the Indian market. Since the mid-1980s the scope and characteristics of TNC R&D have changed.

Starting with Texas Instruments (1986) in semiconductor design, followed by Astra (1987) in biopharmaceuticals, more TNCs have set up globally oriented R&D units in India – mostly without local links to manufacturing activities. The 1990s saw the entry of TNCs in diverse industries: for example Motorola (telecommunications software), Microsoft (computer operating systems), STMicroelectronics (semiconductor design), Daimler-Benz (avionics systems) and Pfizer (biometrics). Since 2000, other entrants include Intel (semiconductor design), GE (e.g. aircraft engines, white goods and medical equipment) and Pfizer (veterinary medicines).

These TNCs were attracted for several reasons (Reddy 2000), the most important being the availability of qualified scientists and engineers.[a] For instance, in 2004, more than 340,000 students were admitted to bachelor degree education in engineering.[b] India annually produces about 120,000 chemists and chemical engineers.[c] A second attractive feature is the existence of internationally reputed R&D institutes such as the Indian Institute of Technology, Indian Institute of Science, Indian Institute of Chemical Technologies and Centre for Drug Research. Many of the TNC R&D units in India collaborate with these institutes and several TNCs that do not have an R&D presence in India outsource R&D to them.

Thirdly, several Indian firms have become global players and are forming R&D alliances or subcontractual relationships with other TNCs. The Indian software companies TCS, Wipro and Infosys, for example, have alliances with Ericsson, Nokia and IBM. Similarly, Indian pharmaceutical companies, such as Dr. Reddy Laboratories and Ranbaxy, have R&D alliances with Novo Nordisk, Novartis and GlaxoSmithKline.

In a survey conducted at the end of the 1990s, the availability of R&D personnel was ranked by TNCs as the most important reason for locating R&D in India (4.12 out of 5) (Reddy 2000). For TNCs in new technology industries this factor was even more important (4.31), followed by low costs of performing R&D in India (3.25). Conversely, for conventional industries, proximity to manufacturing (4.56) and to the Indian market (4.06) were more important reasons. Government incentives were relatively unimportant for both groups of companies (1.78).

The use of English as the business language and medium of instruction for technical and managerial education in universities is an added benefit. It facilitates communication of technical specifications and requirements between TNC headquarters and their Indian R&D units. In general, as regard the IPR regime, the first Indian Patent Law was enacted as early as 1856. In response to obligations under the WTO Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS Agreement), the Patent Act of 1970, which offered only limited protection to inventions in certain industries, has also been replaced and the revised IPR regime is now in compliance with the international regulatory framework.

Source: UNCTAD, based on Reddy 2005.

[a] See also “Silicon subcontinent: India is becoming the place to be for cutting-edge research, *New Scientist*, 19 February 2005. “Prescription for change: A survey of pharmaceuticals,” *The Economist*, 18 June 2005.

[b] See www.nasscom.org/articleprint.asp?art_id=1260 (accessed 21 June 2005).

[c] See “Prescription for change: A survey of pharmaceuticals,” *The Economist*, 18 June 2005.

policies to strengthen their innovation systems and create an environment that is conducive to such investment.

C. How to internationalize R&D

Once a firm decides to carry out R&D abroad, it has to make some choices: between internal and external modes of operations abroad, (i.e. whether to conduct the R&D at an affiliate or outsource it to an independent firm); and for internalized R&D, between establishing a greenfield facility and acquiring or merging with a host-country firm.

1. R&D outsourcing is growing

R&D internationalization can take the form of in-house work within foreign affiliates or outsourcing to independent local firms or research institutions in a host country. A company usually opts for keeping an activity in-house when strict control of that activity is crucial, when high transaction costs are involved, or when proprietary knowledge and information is sensitive, tacit, expensive to produce, complex or idiosyncratic yet easy to replicate (Dunning 1989). Moreover, the more strategic the service function is, and the closer it is to the core competence of a firm, the less likely it is to be outsourced to unrelated firms. R&D functions generally meet these criteria and therefore could be expected to be kept in-house.

Still, R&D outsourcing to foreign locations is growing within developed countries and is now common in some industries such as pharmaceuticals. Basic research has long been contracted out to public laboratories and universities; the recent trend is for *other* forms of research (traditionally performed in-house by manufacturing or service firms) also to be farmed out (Jankowski 2001, Engardio and Einhorn 2005). R&D services provided on a contractual basis constitute one of the fastest growing service industries in some developed countries, led by the United States.[16] As noted in chapter IV, R&D work is also increasingly being outsourced to firms in developing countries, especially in Asia.

What drives firms to outsource R&D? The main forces are the rising costs and risks of R&D, the growing complexity of innovation (calling for more diverse skills, knowledge and equipment) and intensifying competitive pressure to bring out new products more quickly (Howells 1997, Roberts 2001, Engardio and Einhorn 2005). New research methodologies that make tacit knowledge more codifiable also facilitate contracting R&D to other firms. The same applies to software that standardizes research and testing processes. By specializing in these activities, which often require expensive equipment and skills, contract R&D firms are able to reap economies of scale and scope while offering customized products to firms – rather like contract manufacturers in electronics manufacturing (*WIR 2000*). Their customers can reduce in-house laboratory staff and equipment while speeding up the process without losing control of core innovation.[17]

In some industries, product development is becoming so complex and multidisciplinary that firms with different specializations are required to handle the different stages (Pavitt 1999). This makes outsourcing these stages not only more attractive but also, in some cases, necessary (see annex to this chapter). In those industries, no firm, not even a global market leader like IBM, can mobilize all the resources, capabilities and knowledge it needs internally. In-house creation of new knowledge and capabilities needs to be supplemented by external knowledge sourcing. The increased dependence on external sources of technology is among the most important changes in technology management in recent years, especially in new technology industries (Roberts 2001). In some industries there are pressures to reduce in-house basic and applied research in order to focus primarily on product development and the absorption of external knowledge (Chesbrough 2003, Arora et al. 2000). This externalization of innovation does not stop at the national border – firms increasingly tap sources of knowledge overseas (Ernst 2002). Thus,

> “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" (United States, NSF 2004, volume I, p. IV-36).

The transformation of IBM (box V.6) shows that in an "open innovation system", both the source and the use of knowledge can be external to the company. A firm can create ideas for both external and internal use, accessing ideas from the outside as well as from within. Firms can move to an open innovation system because of the increased mobility of knowledge (Chesbrough 2003).

There are similar trends in the pharmaceutical industry. The cost of bringing a new drug to market was around $800 million in 2004, rising to $1.7 billion if commercialization costs were included.[18] Firms see outsourcing as one way to reduce these costs. They currently outsource about 26% of their drug discovery and development; this could rise to 36% by 2008. Over 20% of the $5 billion annual expenditures on new drug development was paid to contract R&D companies and this share was set to increase (Malek 2000).

The growing number of R&D providers also facilitates outsourcing. The privatization of public research laboratories and increasing cost pressures on universities in many countries has induced companies to enter the market and set up spin-offs. Some large manufacturing firms have hived off their research arms into independent companies. In addition, new entrepreneurs with specialist knowledge, data, skills or equipment have also entered the market.

R&D outsourcing has its limits. Firms are unwilling to outsource the core of their technological advantage: contract R&D cannot replace all in-house R&D (Narula 1999, Engardio

Box V.6. From closed to open innovation: the case of IBM

Starting in 1964, when IBM bet its future on the development of the 360 product family as the global standard for mainframe computers, it pushed vertical integration to the extreme. It internalized practically all stages of the value chain: it developed the basic components, assembled them into subsystems, designed systems out of these components, manufactured the systems at its own factories, distributed and serviced the systems themselves, and even handled the financing of the systems (Flamm 1988, Ferguson and Morris 1993, Campbell-Kelly and Aspray 1996).

Over time, IBM abandoned this strategy. The recession of the early 1990s had exposed the weaknesses of the "closed" system of innovation. For the first time since 1946 the company experienced three years of declining revenues, shrinking profit margins, and even losses in 1991-1993 (Lazonick 2005, p. 38). In response IBM transformed itself from a hardware producer to a supplier of integrated solutions, with the objective of leveraging its broad portfolio of intellectual property (IP), not only to exclude rival firms but also to generate new and highly profitable sources of growth.

IBM had to go beyond its own R&D and find the best technologies wherever they existed, combining them into integrated solutions. An important facilitator was the adoption of open standards in a variety of areas, including the Linux operating system and the Java programming language. IBM realized that it could no longer exercise tight control over its component technologies, as specialized knowledge was spread across companies and countries. This led to a substantial decline in its in-house R&D intensity.

Furthermore, the focus of IBM's innovation management shifted towards aggressive licensing of intellectual property. Since 1993 IBM has emerged as the leader in United States patent applications, up from 9th position in 1990 (Lazonick 2005, p. 40). Licensing of technology has been much more profitable for the company than sales of products in some areas. Its licensing revenues grew from $30 million in 1990 to $1 billion in 1998, generating more than 10% of its net profits, and to $1.9 billion by 2001. IBM also used its status as the leading patent holder in the United States to develop a new market for integrated solutions.

Source: UNCTAD, based on Ernst 2005.

[a] The share of R&D in IBM's sales fell from an annual average of 9.8% during 1983-1992 to an average of 6.1% during 1994-2003 (IBM annual reports). Goldstein and Hira (2004) document IBM's decline among the world's top 50 R&D spenders.

and Einhorn 2005). Too much outsourcing can lead to a firm's loss of knowledge (and good researchers) and can create powerful competitors for the outsourcing firm. Another aspect is that IPRs may not always be enforceable, even with the most efficient legal systems. Managing and integrating R&D among different firms, with different work cultures and languages, can be extremely difficult. A distinction is emerging between "mission critical" R&D, kept in-house, and "commodity" R&D, which can be contracted out efficiently without damaging the competitiveness of the company. As stated by the head of Motorola in an interview: "You have to draw a line: core intellectual property is above it, and commodity technology is below".[19]

These distinctions are, however, changeable. R&D outsourcing is evolving rapidly. Enterprises may start by contracting out "commodity" R&D. If this succeeds, they may realize the benefits of greater specialization and learn how to manage better the contractual and integration process. With time they may develop trust in their collaborators and establish durable knowledge networks. This process can continue, pushing back the limits of what is acceptable at any given time. The emergence of new methodologies and competitive pressures may accelerate the push. Box V.7 lists the main determinants of R&D outsourcing.

Another way of externalizing R&D work is to establish a strategic alliance with competitors, suppliers or clients. Data show that as of 2001 (the last year for which data are available), cross-border R&D alliances had proliferated (chapter IV). To some extent the drivers for strategic R&D alliances resemble those that have led to increased outsourcing of R&D activities. Alliances can be seen as a way of sharing the risk involved in R&D, accessing complementary proprietary assets and coping with situations where patenting may not be an effective option (Dunning and Narula 2005, p. 133). R&D alliances tend to emerge when partner companies share complementary capabilities, and these alliances create a greater degree of interaction between the partners' respective paths of learning and innovation (Mowery et al. 1998, Cantwell and Colombo 2000, Santangelo 2000). Another reason to form an alliance in the area of R&D is to explore new technological developments more rapidly than what would be possible independently. Strategic alliances may here provide "an attractive organizational form for an environment characterized by rapid innovation and geographical dispersion in the sources of know-how" (Teece 1992, p. 20).

2. Greenfield versus acquisition

If a company opts for the internalized route to R&D internationalization, it still needs to decide whether to set up a new "greenfield" activity or to acquire one that already exists. The preferred mode here depends on several factors, including the purpose of the R&D, the availability of suitable targets, the competitive situation and other features specific to the industry. Greenfield investment tends to dominate in R&D expansion abroad (chapter IV).

Greenfield entry is the most common mode when setting up adaptive R&D abroad, as such R&D is closely attached to the production activity. However, if for example a company acquires a production unit with the aim of advancing its market position in the host-country market, some R&D activities may be included in the transaction. Such takeovers have contributed to the higher level of R&D internationalization of many companies (von Zedtwitz and Gassmann 2002). In this situation the R&D strategy of the acquiring firm, as well as the quality of the R&D work taken over, will influence whether or not R&D is centralized and moved to the parent company (or to a sister company), or whether it remains and perhaps expands in the host country (see also chapter VI).

In the case of technology-sourcing (or asset-seeking) FDI in R&D, acquisition may sometimes be the only way to access a foreign technology (or other attractions such as brand names and government contacts). Studies of foreign affiliates of Japanese TNCs have found that acquired units tend to have higher R&D intensity than greenfield establishments, possibly suggesting that technology sourcing has been an important driver for the acquisitions (Belderbos 2003).

If the sourcing strategy involves the establishment of a listening post in a foreign centre of excellence, many firms may prefer to set up a local company from scratch. In order to channel knowledge effectively to the parent, the R&D unit in the host economy needs to be well integrated with the rest of the TNC.

Most takeovers of R&D activities have been undertaken in developed countries. This is not surprising, as the number of target R&D units can be expected to be considerably larger in these countries. This also resembles the pattern prevailing for cross-border M&As in general (*WIR2000*). The higher the level of innovative capabilities in companies considered for acquisition, the more attractive the M&A option becomes. The predominance of developed countries in this area may also reflect similarities in specialization between firms in the home and host countries. TNCs seeking to invest in R&D abroad are more likely to choose acquisition if local firms with strong and similar competencies are available.

Finally, industry-specific features influence the choice of entry mode. A more concentrated market structure (globally or in any given market) may induce TNCs to acquire one of the lead players. Indeed, many mega mergers that have taken place in the pharmaceutical and automotive

Box V.7. The determinants of the make/buy decision in R&D

The following are the main determinants of whether a firm chooses to maintain R&D in-house or outsource it.

- *The tacit nature of the knowledge and the extent of coordination needed*. Segments of R&D where knowledge is highly tacit may be kept in-house if the cost of transfer and coordination is significantly higher than the potential benefits from outsourcing. However, the "separability" of processes may rise as knowledge becomes more codified, research methodologies evolve, technologies become standardized and coordination becomes easier.
- *The degree of outsourcing of manufacturing*. As companies specialize in core activities and outsourced production, there may be a parallel increase in the need for external sourcing of innovation.
- *The significance of the R&D to the company's core advantages*. Critical activities will not be outsourced so as to protect competitiveness, core skills and the company's reputation for innovation. The costs of losing an innovative edge may be huge for a market leader. The line between critical activities and others will, however, vary according to corporate strategy, the IPR regime and the level of trust between the principal and the contractors.
- *The need for specialized skills and equipment*. Where product innovation becomes very complex and modular, involving a broad range of skills and expertise (as in semiconductor design), it becomes impractical for a single firm to undertake R&D for all stages and functions. Product innovation then has to be "vertically disintegrated" among several enterprises (Ernst 2003).
- *The increasingly multidisciplinary and multi-technology nature of innovation*. "The increasing cross-fertilisation of technologies across disciplines and resultant broader portfolio of competences has become fundamental to the competitiveness of technology-based firms" (Narula 2001, p. 366). This is particularly true of manufacturing processes where several technologies interact, leading to a need to find external sources of knowledge and innovation.
- *The need for expensive routine engineering and testing*. This is a significant incentive for outsourcing, particularly where the facilities needed are capital-intensive. Outsourcing then becomes a way to cut fixed costs and reduce risk.
- *The need for rapid innovation*. In several fast-moving technologies, competitive success depends on the ability of firms to get products (or modifications) rapidly onto the market. The availability of contract research facilities that can respond at short notice is a major advantage.
- *The need to cut costs*. In many consumer goods industries like electronics, lead firms have to provide and constantly update a whole range of products. For example in the case of digital cameras, "to get shelf space at a Best Buy or Circuit City often means brand-name companies need a full range of models, from a $100 point-and-shoot digital camera with 2 megapixels, say, to a $700 8-megapixel model… competition can reduce hit products to cheap commodities within months. So they must get out the door fast to earn a decent margin… Such pressures explain outsourcing's growing allure. Take cell phones, which are becoming akin to fashion items. Using a pre-designed platform can save 70% of development costs off a new model." (Engardio and Einhorn 2005, pp. 56-57).

Source: UNCTAD.

industries have been motivated by a desire to achieve synergies in marketing and distribution, but also in R&D work. In industries characterized by oligopolistic competition, there may be strategic motives for firms to acquire technological assets of rivalling firms in a bid to pre-empt other firms (*WIR2000*). The M&A route is more attractive where speed in accessing the technology or innovative strengths in a host economy is an important consideration.

* * *

To sum up, the main driver for R&D internationalization by TNCs remains the need to adapt products and processes to conditions in host-country markets. However, the recent increase of R&D by TNCs in selected developing countries, especially in Asia, is driven by a complex set of factors:

- *pull factors*, such as a growing market, availability of large talent pools at favourable costs and developing Asia's emergence as a global production base in some industries;
- *push factors*, such as shortages of skills in specific categories in home countries, rising costs and complexity of R&D, greater competitive pressure that forces TNCs to innovate more without increasing costs;
- *policy factors*, such as host-country efforts to strengthen their NISs, to invest in education and to use targeted investment promotion and incentives;
- *enabling factors*, including advances in ICT, investment and trade liberalization, all of which make it easier for firms to restructure their operations internationally, while at the same time adding competitive pressure on firms to do so.

As a result, this new form of R&D internationalization can be seen as a logical next step in the increasingly globalized production systems of TNCs. The process greatly resembles the kind of international restructuring that has taken place in export-oriented manufacturing (*WIR02*) and services (*WIR04*) where TNCs seek to improve their competitiveness by exploiting the different locational advantages of countries. In the annex to this chapter the case of the semiconductor industry is used to illustrate how the interaction of the various factors has led to the growth of chip design in Asia. As noted in the next chapter, this trend offers important benefits to countries that are affected, but may also give rise to concerns.

Annex to chapter V

THE RISE OF CHIP DESIGN IN ASIA: A CASE STUDY

Chip design is a good example to illustrate the complex interaction of factors currently favouring the expansion of innovative R&D in developing countries (Ernst 2003, 2005a). Chip design not only creates the greatest value in the ICT industry while requiring highly complex knowledge, it also involves a generic technology that affects a large number of user industries, including high-value services. The chip industry was one of the earliest to globalize production and it has been one of the most dynamic in world trade. Now it appears that design and development work in this industry is following on the heels of manufacturing by moving towards Asia.

Chip design has recently moved from centres of excellence in the United States, Europe and Japan to sites in some developing countries, notably in South-East and East Asia. From practically nothing during the mid-1990s, this region's share of semiconductor design reached around 30% in 2002 (iSuppli 2003, p. 21). South-East and East Asia are now the fastest growing markets for electronic design automation tools, expanding by 36% in the first quarter of 2004 compared to 5% for North America (which has 60% of the world market), 4% for Europe, and -2 % for Japan (EDA Consortium 2004). Developing Asia is not only undertaking more chip-related R&D, but also the levels of complexity are rising in terms of the line-width of process technology (measured in nanometres), the use of analogue and mixed-signal design (substantially more complex than digital design), the share and type of system-level design (e.g. system-on-chip) and the number of gates used in these designs.

This section explores the main drivers behind the offshoring of chip design, drawing on interviews with 60 companies and 15 research institutions in the United States and Asia involved in designing integrated circuits, as well as systems (Ernst 2005). The sample includes global and regional carriers of chip design in Asia, including specialized research institutes and nine strategic groups of firms that participate in global design networks.[20] With the exception of some Chinese companies, all the sample firms are TNCs.[21] Their design activities are concentrated in a handful of clusters in Taiwan Province of China (Hsinchu and Taipei), the Republic of Korea (Seoul), China (Beijing, Shanghai, Hangzhou, Suzhou, Shenzhen), India (Bangalore, Hyderabad, Noida/New Delhi), Singapore and Malaysia. The TNCs interviewed emphasized the diversity of functions performed by their Asian design centres, from routine (engineering support, adaptation, listening posts for "technology marketing") to highly strategic tasks (global development mandates for specific IT products, components and services). The tasks assigned to a design centre depend on its locational characteristics, especially on the quality of the regional and national innovation systems.

The expansion of chip design in Asia has been the result of the synergistic effects of pull factors, policy factors, push factors and enabling factors.

1. Pull factors

The cost of employing a chip design engineer in Asia is much lower than in the United States – typically only 10-20% of the cost in Silicon Valley (table V.1). But this is not the only pull factor; demand factors are equally important. TNCs need to locate design near the rapidly growing Asian markets for communications, computing and digital consumer equipment in order to interact with the lead users of new products. China is already the world's largest market for telecom equipment (wired and wireless) as well as a critical test bed for the third- (3G) and next-generation wireless communication systems. It is also among the most demanding markets for computing and digital consumer equipment. As most of the equipment is produced in China, the country has become the world's third largest market for semiconductors, generating substantial demand for chip design. To the extent that China succeeds in setting alternative standards for 3G mobile communications, the need for undertaking chip design locally may increase to address the specific requirements of such standards. In this context all major global system companies in mobile communication systems are expanding their Asian chip design centres to establish their own designs as *de facto* standards in the region.

Table V.1. Annual cost of employing a chip design engineer, 2002
(Dollars)

Location	Annual cost[a]
United States (Silicon Valley)	300 000
Canada	150 000
Ireland	75 000
Republic of Korea	<65 000
Taiwan Province of China	<60 000
India	30 000
China (Shanghai)	28 000
China (Suzhou)	24 000

Sources: UNCTAD, based on PMC-Sierra Inc., Burnaby, Canada (for Silicon Valley, Canada, Ireland, India) cited in Ernst 2005.

[a] Including salary, benefits, equipment, office space and other infrastructure.

2. Policy factors

Policies cover a wide range of factors, such as incentives, regulations, infrastructure and education – all designed to attract R&D and other TNC innovative activities, including chip design, to particular locations (Ernst 2005, Armbrecht 2003, von Zedtwitz 2004, Walsh 2003).[22] TNCs interviewed expressed concern about obscure and unpredictably changing regulations in some Asian countries as well as weak IPR regimes.[23]

In terms of their home-country design activities, Asian firms interviewed acknowledged that policies had played a powerful catalytic role in building the critical infrastructure, supporting industries and design capabilities that allowed them to invest in and upgrade chip design (see also chapter VII).[24] The progress in chip design has owed much to concerted efforts by both governments and leading companies to establish new sources of innovation and global standards. In telecommunications, the four leading players in the Republic of Korea (Samsung, SK Telecom, KT, LG) are all trying to become major platform and content developers for complex technology systems, especially in mobile communications. These efforts build on considerable capabilities accumulated in public research labs (like the Electronics and Telecommunications Research Institute, ETRI), as well as in R&D labs of the *chaebol*, to develop complex systems. China's attempt to develop an alternative 3G digital wireless standard has created a powerful incentive to expand Asian electronic design activities.[25] Thus government procurement has been a powerful tool in driving innovation.

3. Push factors

A number of factors in developed countries are also greatly contributing to pushing firms to expand chip design in Asia. Three such push factors can be distinguished:

- Changes in the methodology and organization of chip design;
- More outsourcing and multiple design interfaces; and
- Changing skills requirements.

a. Changes in design methodology and organization

Since the mid-1990s growing pressures to improve design productivity, combined with increasingly demanding performance features of electronic systems, have produced turmoil in chip design methodology.[26] So-called "system-on-chip design" combines "modular design" [27] and design automation to move design from the individual component on a printed circuit board closer to "system-level integration" on a chip (Martin and Chang 2003). A key driver behind these changes has been a widening productivity gap between design and fabrication. While the productivity of chip fabrication grew at an annual compound rate of 58% from the 1980s until 1998, that of chip design reached only 21% (SIA 1999).

Chip design is also becoming increasingly complex. First, progress in manufacturing technology ("miniaturization") has made it possible to fabricate millions of transistors on a single chip. This increased complexity needs to be matched by a dramatic improvement in design productivity (ITRS 2004, pp. 13-14). Second, the convergence of digital computing, communication and consumer devices has raised the requirements for essential features of electronic systems – they need to become lighter, thinner, shorter, smaller, faster and cheaper, as well as more multifunctional and less power-consuming. These features are expected to continue to improve. At the same time companies are forced to speed up time-to-market as product life cycles have been reduced to only a few months for some products. Time compression is therefore key in designing chips for such systems.

These changes in methodology have increased complexity at two levels of chip design: on the chip ("silicon") and on the "system".[28] With growing design complexity, verifying at an early stage whether the design can be used to produce chips at acceptable yield and performance has become critical. Some 60-70% of all system-on-chip hardware design time now goes into verification, leaving only 30-40% for actual device development. This has inflated the cost of design. For instance, the overall development cost for complex system-on-chip design can be as high as $100 million, a cost level few design companies and chip users can afford.

b. More outsourcing and multiple design interfaces

Until the mid-1980s, system companies and integrated device makers did almost all their chip design in-house. Since then system-on-chip design has fostered vertical specialization in project execution, enabling firms to disintegrate the design value chain and disperse it geographically. This has given rise to complex, multilayered global design networks with variable configurations, depending on the needs of a specific project (box V.8).[29] Until the early 1990s, design networks retained a relatively simple structure. Over time, however, vertical specialization increased the number and variety of network participants, business models and design interfaces, bringing together design teams from companies that drastically differed in size, market power, location and nationality.

A possible network might be comprised of the following players: a Chinese system company for the definition of the system architecture; an electronic manufacturing supplier from Taiwan Province of China; a United States integrated device manufacturer; a European "silicon intellectual property" firm; design houses from the United States and Taiwan Province of China; foundries from Taiwan Province of China, Singapore and China; chip packaging companies from China; tool vendors for design automation and testing from the United States and India; and design support service providers from various Asian locations.

Box V.8. Global design networks: the key players

Three layers can be distinguished in global design networks:

- The *network core* encompasses five strategic groups of firms: the system company, which defines the concept, but may well outsource everything else. The *system-on-chip design* may take place within the "system company", an integrated device manufacturer, or a fabless design house (or a combination of these).[a] Finally, chip fabrication and assembly, may be outsourced to specialized suppliers.
- A secondary layer of the design network consists of *suppliers of tools* (for electronic design automation, electronic design automation; verification; and chip testing), silicon intellectual property licensors and design implementation services.
- The third layer may involve *system contract manufacturers* (both electronic manufacturers services and original design manufacturers).

Source: Ernst 2005.

[a] Fabless companies do not manufacture their own silicon wafers. Rather, they concentrate on the design and development of semiconductor chips.

Vertical specialization within design networks has transformed the structure and the competitive dynamics of the global semiconductor industry. It has also increased the organizational complexity of the networks. A typical system-on-chip design team now needs to manage at least six types of design interfaces with: system designers, silicon intellectual property providers, software developers, verification teams, electronic design automation tool vendors and foundry services (fabrication). These design communities are rarely located in the same place, which makes coordination difficult. As design teams become larger and geographically dispersed, more formal interfaces are necessary for effective communication between them.

With product life cycles often as short as a few months, system design requirements keep changing rapidly. Communication problems between hardware and software designers are particularly serious. Hence *proximity and face-to-face contact* become critical: global design networks increasingly need to locate in Asia those chip design stages that closely interface with local companies in mobile communications and digital consumer electronics. As most of the world's leading chip contract manufacturers ("foundries") are in Asia, this creates powerful pressures to locate important stages of chip design in this region. New processes and changes in design methodology require closer interaction between designers and process engineers.

c. Changing skills requirements

Geographic proximity (in the established centres of excellence in the United States or Europe) has sometimes been a disadvantage for design projects that require a large number of contributors with diverse knowledge sets and capabilities. For TNCs involved in chip design, it has become costly to bring together a large group of diverse design communities in one location and keep them there. This is another reason for TNCs to offshore chip design to Asia.

Meanwhile, skill requirements and work organization are growing in importance as push factors. Some TNCs interviewed expressed concern that the supply of scientists and engineers in the United States and Europe is inadequate. As noted above, some Asian governments have pursued policies that increase the availability of well-educated engineers, scientists and managers. Engineers in some Asian countries are trained to use the latest tools and methodologies, and the main electronics exporting countries in Asia have also set up training institutions dedicated to chip design. These efforts are especially advanced in India and East Asia.

The expansion of chip design in Asia appears also to have been influenced by a perceived inflexibility on the part of design engineers in the United States and Europe to adapt to a more structured ("automated") work organization (termed "innovation factory"). TNCs have likewise sought to lower design costs by increasing the workloads and capping the design engineers' salaries, which rose rapidly during the boom of the 1990s. Cost considerations clearly favour design work in Asia.

4. Enabling factors

Finally, new ICTs facilitate the internationalization of chip design. Coordinating specialized design networks in Asia vertically can involve high communication costs because of geographical distance combined with differences in levels of development and economic institutions (labour markets, education systems, corporate governance, legal and regulatory systems as well as IPR protection). New ICT-enhanced information management has helped reduce such costs, codify knowledge, enable remote control and allow more knowledge to be shared via audio-visual media.

A second enabling factor is the spread of "transnational knowledge communities", such as professional peer group networks, along with Asia's large diaspora of skilled migrants and "IT mercenaries". These networks help share complex design knowledge and provide experience and links with markets and financial institutions.

* * *

In sum, in the case of chip design a combination of pull, push, policy and enabling factors is creating a compelling case for TNCs to shift more of their design work to Asia. The trend is still at an early stage but is set to deepen. Over the past few years all interviewed TNCs made substantial investments in chip design in Asia and are planning further expansion.

Notes

1 "The establishment of international R&D networks and the management of transnational R&D projects are non-trivial and risky endeavours. The principal challenges are imposed by physical distance among R&D units, as well as between R&D units and corporate headquarters. Distance impacts communication in terms of frequency and quality, raises transaction costs, and introduces principal-agent related difficulties" (von Zedtwitz and Gassmann 2002, p. 570).

2 For example, the Chinese automobile manufacturer, Dongfeng Motors, has established listening posts in the United States, Germany, United Kingdom and France for the purpose of being close to major competitors and their technological bases (von Zedtwitz 2005).

3 Similar conclusions were drawn in another study of the largest R&D spenders. Adapting products to local requirements, learning from foreign lead markets and customers, keeping abreast of foreign technologies, and gaining access to skilled researchers and new talent were the major reasons for internationalizing R&D (Roberts 2001).

4 "Innovative Asia: how spending on research and development is opening the way to a new sphere of influence", *Financial Times*, 9 June 2005.

5 Conventional technologies included chemicals, pesticides, fertilizers, pharmaceuticals, engineering, hygiene and health-care products, and branded

consumer goods. New technologies included electronics, ICT, software, biotechnology and solar energy (Reddy 2000).

6 "Wipro: R&D budgets falling, interest in global outsourcing rising", *Information Week*, 1 April 2005 (www.informationweek.com/story/showArticle.jhtml?articleID=160401375).

7 For a review of changes in the export competitiveness of countries, see *WIR02*.

8 See annex table A.V.1 for data by country.

9 China's tertiary enrolment rate rose from 5% of the age group in 1995 to over 20% in 2004.

10 According to China, Ministry of Education 2004.

11 The professional groups included engineers, finance and accounting specialists, analysts, life science researchers and professional generalists.

12 Proximity to regional markets has been the most important factor attracting foreign R&D activities to Singapore. The second most important factor, however, has been the availability of personnel that can be sourced freely within the country and from abroad (Toh 2005, p. 16).

13 Public research institutes are traditionally averse to such contract work and have to be restructured, upgraded, and given "hard budget" constraints to change their orientation in order to respond to the shorter-term, practical needs of industry. This has been accomplished in India (chapter VII).

14 The connection between IPR regimes and the broader category of FDI is ambiguous.

15 See also chapter VII for a discussion of how developing countries may use IPR systems to benefit more from TNCs' internationalization of R&D.

16 In 2001, the United States contract R&D industry spent $14.2 billion on R&D (about 7% of total industrial R&D and 20% of services R&D). Its R&D spending has been growing very rapidly, doubling over the period 1998-2001 (United States, NSF 2004). In the United Kingdom, the contract R&D industry accounted for £428 million of R&D in 2000, up from £142 million in 1992 (Morgan 2002). In 2000, contract R&D accounted for 22% of services R&D in the United Kingdom, about one-third in Canada, Germany and Sweden, 65% in Italy and 77% in the Russian Federation (United States, NSF 2004).

17 As noted in a study of DuPont's outsourcing of chlorofluorocarbons (CFC) research: "DuPont may have outsourced $5 million of the $400 million it spent on CFC research, but the company saved that amount many times over by not doing the research in-house" (Paul 1998, pp. 1-2).

18 See report by Ernst and Young at http://www.ey.com/global/content.nsf/International/Progressions:GlobalPharmaceuticalReport2004.

19 See Engardio and Einhorn 2005, pp. 53-54.

20 These are system companies; integrated device manufacturers (IDMs); providers of electronic manufacturing services and design services (the so-called ODMs, or "original-design manufacturers"); "fabless" chip design houses; "chipless" licensors of "silicon intellectual properties" (SIPs); chip contract manufacturers ("foundries"); vendors of electronic design automation tools; chip packaging and testing companies; and design implementation service providers.

21 Interviews were conducted with both parent companies and foreign affiliates of firms from the United States, Taiwan Province of China and the Republic of Korea, while for Chinese and Malaysian firms, interviews were conducted only with parent companies. In China the sample included State-owned enterprises, collective enterprises and private technology firms.

22 Most firms refer to aggressive incentives implemented in China. For example, in 2002-2003 chips designed by foreign and domestic companies in China were eligible for a 14% value-added tax (VAT) tax rebate, which lowered the effective tax rate to 3% from the nominal VAT of 17% on sales of imported and domestically produced chips. This policy created an artificial cost advantage for domestically designed chips, and was later abandoned.

23 More research is needed, however, on whether and how weak IPR regimes prevent TNCs from upgrading their design labs in Asia, or if other motivations override these concerns.

24 This supports earlier findings in the literature. See, for example, Shen 1999, Lu 2000, Naughton and Segal 2002, Mathews and Cho 2000, Hobday 1995, Ernst, Ganiatsos and Mytelka 1998, Ernst and O'Connor 1992, Ernst 1994 and 2000.

25 The TD-SCDMA standard was developed by Datang Telecom, a Chinese State-owned enterprise, and the Research Institute of the Ministry of Information Industry, with technical assistance from Siemens. To accelerate implementation, Datang has formed a series of collaborative agreements: a joint venture with Nokia, Texas Instruments, the Korean LG group and Taiwanese original design manufacturing suppliers; a joint venture with Philips and Samsung; and a licensing agreement with STMicroelectronics that will provide the Chinese company with access to critical design building blocks (Ernst and Naughton 2004).

26 "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.

27 In "modular design", "parameters and tasks are interdependent within units (modules) and independent across them" (Baldwin and Clark 2000, p. 88).

28 "Silicon complexity" refers to malfunctions that result from the growing scale and density of the circuit and the introduction of new materials or design architectures. "System complexity" on the other hand increases with the transition to system-level design with "exploding" multiple functions, an in smart phones (ITRS 2002, pp. 82-83).

29 For instance, designing an embedded micro-controller for a mobile handset requires a different global design network configuration than the design of a graphic chip.