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PART I

The globalization of R&D

The globalization of R&D: key features and the role of TNCs

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A commitment to R&D can be seen as logically central to the dynamic developmental needs of both TNCs and individual national economies. Early analysis and evaluation of TNCs and FDI saw the location of R&D as being the developed home countries of these firms and the internationalization of their operations based around processes of outward technology transfer. The immediate developmental implications of this for developing host countries were then seen as relating to the quality of this transferred technology; its appropriateness and the ability of local economies to assimilate and utilize it effectively. The potential for poorer host countries to escape from the implications of such a technological dependency would then be limited to such relatively minor localized adaptations of products and processes as TNCs' competitive needs impelled them to carry out. Beyond this, such early thinking argued, the persistence of an R&D/innovation hegemony of a small group of TNC home countries could impose an inherently non-dynamic hierarchical stratification on the global economy (Hymer 1972).

Perhaps the single most important element in the changing understanding of the practicalities of TNCs' strategic behaviour over the past 30 years or so has been the perception of a breakdown in such an immutable home-country orientation of creative (competitiveness generating) activity and moves towards globalized programmes for innovation and R&D. Thus, the tendency to see TNCs' organizational structures as

[1] The views expressed in this study are those of the author and do not necessarily reflect the views of the United Nations, its Member States, or the Institutions to which the author is affiliated.

predominantly hierarchical has been replaced by attempts to analyse them in terms of heterarchy (Hedlund 1986, Birkinshaw 1994) or, as dynamic differentiated networks. This places a decisive emphasis on two factors; TNCs' responses to heterogeneity in the form of various differences between locations (their potential and needs) and a dynamic, ever evolving, structure in their global networks that can alter, quite quickly, how they operate in different countries and regions (from export processing zones to creative knowledge-based clusters).

The aim of this paper is to elaborate on relevant aspects of this strategic restructuring in TNCs, and then provide some detail on how this is operationalized in terms of the increased decentralization of their R&D programmes. The aim of this analysis though, is to provide a basis for discussion of the implications of these more differentiated and dynamic strategic orientations in TNCs for the host countries in which they operate, with particular emphasis on countries at early stages of competitiveness development and, on economies in transition. The strategic changes in TNCs now involve them with creative resources (R&D, technology stocks, market research, entrepreneurial management) in national economies in a way not envisaged 40 years ago. However in doing this do TNCs necessarily strengthen these creative attributes of host countries? Even if they do, does this mean that these creative attributes necessarily improve the competitiveness of the local economy and, thereby, provide a basis for sustainable development or, can TNCs use the flexibility of their global networks to apply new technologies and competitive capacities that are generated in one country, in supply operations in another? When TNCs use R&D and other creative inputs in several locations to support improvements in their global competitiveness, are individual locations that contribute to this fairly rewarded (in terms of improved efficiency and economic growth; Pearce 2002)?

1. Technology/R&D/innovation needs of TNCs

It is useful to characterize the strategic positioning of the contemporary TNC "as one of seeking to use the increasing freedoms of international transfer, reflecting the essence of economic globalization, to leverage the differences between economic areas" (Pearce forthcoming). Three types of diversity or heterogeneity can then be suggested as relevant to the strategic postures of TNCs today.

- Firstly, availabilities of standardized inputs to mature production processes. Differences in these sources of comparative advantage between countries (or regions) can determine which TNC goods are produced where, and therefore patterns of intra-group technology transfer and, possibly, technology adaptation.
- Secondly, differences in demand conditions between countries (i.e. market heterogeneity). An important understanding of the forces of globalization, which has emerged in recent years, is that in many industries and product groups this has not led to demand standardization but often instead, to an increased willingness to manifest localized taste differences. Thus, the in-depth research of Bartlett and Ghoshal (1989) showed that many successful TNCs benefited from a willingness to respond to local taste differentiation, rather than seeking to override it (perhaps in pursuit of economies of scale). In fact, the ability of TNCs to benefit from acknowledgement of market heterogeneity can go beyond willingness to differentiate existing product ranges. Here, especially in industries oriented towards demand-driven innovation processes, it is the unmet wants of customers that can be crucial when accessed by good quality market research. Such ideas for major new products can emerge unpredictably, at any time, in any country at almost any level of income.
- Thirdly, it may be that one of the crucial forces conditioning the patterns of development in the era of

globalization has been a systemic deepening of technological heterogeneity. Thus, increasing numbers of countries have sought to generate the knowledge sources for economic development through commitment of resources to R&D and support of a distinctive NIS. However, analysis has suggested that an outcome of this is that individual national economies have become scientifically and technologically stronger in increasingly differentiated ways. Individual national science-bases have become increasingly specialized, acquiring international leadership in a small and focused range of scientific disciplines, whilst accepting a concomitant relative weakness in many others. Forces of agglomeration, including very notably the R&D and innovation strategies of TNCs to be discussed here, tend to reinforce these patterns of technological and research heterogeneity across the evolving global economy.

Against this background the modern TNC faces, with increasing intensity, two basic competitive pressures. Firstly, the tactical need to supply its established product range in the most cost-effective and market-responsive way possible. Secondly, a complementary need to address forward-looking issues of strategic competitiveness (Pearce 1999), in the sense of securing the new sources of firm-level distinctiveness that can help sustain its position in an inevitably dynamic market environment. We can then suggest that these needs provide the TNC with three levels of competitive priority in the areas of technology application and generation, which are increasingly being pursued through global networks.

As suggested, the immediate short-term priority for TNCs is to achieve the optimally effective and competitive use of their existing technologies, as embodied in successful established goods and services. Crucially this involves being responsive to differences in supply conditions in particular locations in the global economy (i.e. the input heterogeneity noted earlier). Thus, over perhaps the past four decades, the increasing freedom of trade, along with the adoption of export-oriented development strategies in many of the countries that were earlier oriented to import substitution has made it both necessary and feasible for TNCs to implement integrated global supply strategies (Papanastassiou and Pearce 1999, Pearce 2001) and, separate where goods are produced from where they are sold (generating intra-group trade).

In this process, a careful categorization of the different factor needs of different goods can lead to each being allocated to a supply affiliate in the location able to provide the required input mix in the most cost-effective manner. Once a particular affiliate has been allocated supply responsibility for a product, in reflection of the host economy's input potentials, the TNC will then make available all the technical specifications (product characteristics, manufacturing process details, etc) needed to activate its role. Thus, the generation of such a supply network in TNCs places a high priority on effective intra-group mechanisms for technology transfer, assimilation and adaptation.

Nevertheless, however proficient a TNC may be in securing optimal supply and maximized profitability from its current products, it will know that this range will not sustain its competitive position very far into the future. Therefore, it must be continually targeting the medium-term priority of innovation, seeking to add new technological and/or market insights to existing competences in order to secure very significant developments to its competitive scope. Some of the most important insights into the strategic evolution of TNCs in recent years have then related to their increasing acceptance of the decentralization of innovation into globalized operations. Implicit in this is the acceptance of technological and market heterogeneity, indicating that new scientific or customer-driven initiatives towards significant product development can emerge anywhere in a TNC's global operations.

Vital to the decentralization of innovation in TNCs has been the emergence of a new type of affiliate, often designated as a product mandate, which acquires permission from its group parent to take full responsibility for the development of a new good. To accede effectively to this degree of individualized creativity, a product mandate must assemble, from strengths available in its host-country economy, a rich range of functional capabilities. These need to include R&D (to generate, or mediate the acquisition and application of new technologies), market research (to detect unmet market needs and/or to formulate the means of projecting new goods to initial customers), inventive engineering (to establish a prototype production process) and crucially, entrepreneurial affiliate-level management (to drive the integrated creative processes and to provide persistent advocation of the affiliate's status in the group network). By allowing such localized initiatives in product mandates the modern heterarchical (Hedlund 1986) TNCs provide themselves with a means of tapping into the globally dispersed technological and market heterogeneities that drive competitive progress. Here, by contrast with the cost-based supply affiliates, product mandates go through a creative transition (Papanastassiou and Pearce 1999) such that (rather than being allocated existing group technology to play an externally-determined role) it is their own internalized and individualized technology and competences that earn them their position.

Looking into a longer-term future, TNCs should also foresee a need for much more radical changes in competitive scope, based on much more fundamental restructuring of the types of services supplied and the technologies used. In anticipation that such changes are most likely to derive from new science-based possibilities and, in the hope of securing a highly profitable leadership advantage in these discoveries, TNCs may commit resources now to speculative pure-science research in disciplines considered likely to generate relevant breakthroughs. However, to cover a number of potentially relevant areas of science, bearing in mind the narrow national specialisms resulting in the technological heterogeneity observed earlier, ambitious TNCs may need to be involved with basic research programmes in several countries. Covering this aspect of forward-looking competitiveness may again involve internationalized perspectives.

2. Global R&D programmes of TNCs

In order to organize an understanding of the complex strategic positioning of R&D in contemporary TNCs two types of classificatory system have been developed. Firstly, typologies have been derived (Behrman and Fischer 1980, von Zedtwitz and Gassmann 2002) to distinguish different emphases in overall global R&D programmes of TNCs. Secondly, typologies (Ronstadt 1977, Haug, Hood and Young 1983, Medcof, 1997) have been generated to distinguish the different roles played by individual R&D laboratories in TNC networks. Here we use a particular three-part typology (Papanastassiou and Pearce 1999, Pearce 1999 and 2002, Pearce and Singh 1992, Pearce and Papanastassiou 1999).

a. Support laboratories

Support laboratories help achieve the short-run aims of TNCs by securing the effective transfer and application of the group’s already successful technologies as embodied in the current product range. As efficiency-seeking TNCs reconfigure global-supply networks and reallocate production responsibility for particular goods to new affiliates, in potentially lower-cost locations, support laboratories facilitate this transfer process by helping these affiliates to assimilate, apply and, where relevant adapt these technologies. This is essentially a static optimization role in that its aim is to allow the TNC to make the most effective use of its current sources of competitiveness and, similarly, secures the greatest value from the activation of the country's sources of static comparative advantage (notably labour). For neither the TNC nor the country does the support laboratory possess any real dynamic potentials, in the sense of providing additional forward-looking dimensions to their sources of competitiveness. Nevertheless, by putting into an affiliate a source of potential individualization (albeit only in terms of improving local ability to play a predetermined role using externally-provided technology) support laboratories may still suggest a creative route forward to a more significant deepening of a localized element in the affiliate's competitiveness.

b. Locally integrated laboratories

The *locally integrated laboratory* becomes a key component of a localized innovation process that is encompassed within a particular affiliate of the product mandate type and, therefore contributes to the way the TNC is pursuing its medium-term objective (i.e. of effective product-range renewal). Whether the innovation is science-driven or demand-driven, the assumption is that it will usually involve either the initial operationalization of completely new technologies, derived from recent scientific breakthroughs or, a substantial reconfiguration of existing ones. The locally integrated laboratory then plays the role of mediating the application of these technologies in closely integrated collaboration with the other key innovation-supporting functions (marketing, engineering, management). A successful nexus between the product mandate and the locally integrated laboratory, through its own distinctive contribution to the TNC's product range, asserts a powerful middle-level position in the group; subject to the continued approval of higher-level decision makers, (validating the mandate) but also possessed of scope for dynamic initiative and capacity to commit resources to speculative creative work.

Though the broad product mandate/locally integrated laboratory position in TNCs plays a demand-side role (in the sense of seeking to fill perceived gaps in the group's current competitive scope) the location of a particular unit of this type also reflects supply-side influences (in the sense that its ability to play the role derives from specific creative inputs-personnel, technologies, etc. – available in its host economy). For the product-mandate/locally-integrated laboratory to then contribute positively to host-country development, two conditions ought to be fulfilled. Firstly, that the local creative inputs co-opted by the TNC are, in the short-run, used more effectively than they would otherwise have been. Secondly, that the product mandate/locally integrated laboratory contributes to further improvements in the capacities and capabilities of these local resources.

With regard to the former it can be suggested that very often when TNC product mandate/locally integrated laboratory operations make use of local skill/technology inputs they combine them with strong group-level attributes (e.g. established technologies, global market perspectives and access) to develop strongly original and competitive new goods (beyond the compass of a purely local enterprise). This then immediately endows the local economy with a new high-employment export-oriented supply capability. However, this may be temporary since, once the product becomes mature and its market more price-competitive, the TNC may reallocate its production to a lower-cost location. This emphasis on the dynamic intra-group competition within TNCs then points toward the second issue. Thus, due to the vulnerability of their dynamic developmental role, product mandate/locally integrated laboratory affiliates need to be looking towards further innovation and improving the creative assets at their disposal to do this. This, in turn, indicates that these TNC operations expect to benefit from progress in the scientific and technological capacity of their host-country and, therefore, will provide support (including R&D collaboration, scientific and other training) for local upgrading in these areas.

c. Internationally interdependent laboratories

In pursuing the longer-term strategic need of TNCs, the internationally independent laboratories are immediately differentiated from support laboratories and locally integrated laboratories by having no concern or connexion whatsoever with the group's currently-operationalized technologies or, with any of its current commercial issues. Instead, an internationally independent laboratory is entirely oriented to pure/basic research in one or more of the scientific disciplines that are considered likely to provide results that can become part of the technological inputs to very radical new product breakthroughs (perhaps reformulating the very nature of the services offered by an industry). Given the narrow focus of the outstanding areas of research leadership of individual countries (technological heterogeneity) and, the often wide range of disciplines that can potentially fuel the technological progress of an industrial sector, a TNC seeking access to top quality investigation in all the relevant areas of science will need to set up internationally independent laboratories in a quite extensive selection of locations. This leads to a network of internationally independent laboratories, each of which follows its own distinctive research agenda, reflecting a specialized area of expertise. But since the expectation is that any new breakthroughs may ultimately derive from synergistic combinations of results from different parts of the network, TNCs will propagate interdependencies between internationally independent laboratories. Thus these laboratories, whilst focusing on clearly defined research of their own, will also share their new insights with, and be prepared to ask questions of, other such units.

Internationally independent laboratories certainly have the potential to reinforce a country's developing strength at the phase of basic research and pure science. They can do this both by providing extra funding and by adding further dimensions to the research by positioning it in the wider technological perspectives of the TNC. However, there is no mechanism by which internationally independent laboratories necessarily strengthen the competitive scope of the host economy. Thus, important results of an internationally independent laboratory feed into the internal technology programmes of parent TNCs and are likely therefore, to contribute to competitiveness generation for the group that need not be activated in the internationally independent laboratory's host country (Pearce 2002).

3. TNC R&D and national development

From an understanding of how TNCs at a point in time build global technological and supply strategies around different roles for laboratories and affiliates, we can also suggest how this can support processes of economic change (development or transition) over time. The various roles taken by laboratories and affiliates reflect different host-country resource potentials, and development (in its very nature) comprises changes in the resource characteristics of economies. Thus, the form of TNCs' involvement with economies can change over time in mutually beneficial and supportive ways.

At the very early stages of a country's development, cost-based TNC operations (perhaps including a support laboratory) can provide a strong impetus to growth by drawing unemployed resources (notably labour) into export-oriented industrial activity. A danger here is that once full-employment is reached labour and other costs will rise, providing a potential for footloose closure (relocation) of the cost-oriented TNC affiliates. A positive possibility here, however, would be for an affiliate to firstly move towards the supply of higher-value parts of the TNC product range (involving inward transfer of more advanced group technologies, again perhaps mediated by a support laboratory) and, eventually accede to product mandate/locally integrated laboratory status (Pearce 2001). This option would clearly be more viable where, in the manner of the newly industrialized Asian economies (Lall 1996), host governments reinvested revenues from early development in improved training, education (including higher education) and commitment to scientific research (ultimately the generation of an NIS). As countries' sources of growth and competitiveness move towards science and technology, the global R&D and innovation strategies of TNCs have the potential to become sustainable embedded components of such knowledge-based development.

Finally, we can note a variant of this scenario that is potentially available to some of the countries in transition from centrally planned economies (Manea and Pearce 2004). During the earlier socialist periods, many of these countries built up strong science bases and quite well trained industrial labour forces. That this had not led to competitive industries, based around local technology and creative capacities, reflected a lack of entrepreneurial risk taking in the absence of market forces. The availability of a stock of creative potentials (technology and human capital) in important emerging market spaces could lead TNCs to very quickly adopt the product mandate/locally integrated laboratory, and even internationally independent laboratory research, in these countries. Here TNC R&D and innovation could provide a short cut through some stages of industrialization-oriented development.

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Knowledge creation and why it matters for development: the role of TNCs

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TNCs are one of the key features of globalization and important sources of capital and technology. Perhaps even more importantly, TNCs account for a significant share of global business expenditures in R&D and, present an important *potential* opportunity to promote knowledge creation (of which formal R&D is a subset) in the countries in which they locate. They also represent an alternative to traditional technology transfer approaches to promote the competitiveness of domestic firms in the developing world. The failure of protected industries in developing countries to become competitive in global markets has highlighted the limitations of the arms-length technology transfer approach. At the same time, the need to build strong local capabilities has not diminished. On the contrary, it has risen as increasingly mobile TNCs seek strong complementary factors at sites where they locate.

Hence, in recent years, both governments and supranational organizations have increasingly come to focus on the role TNCs and FDI can play in innovation and knowledge creation. This has been accompanied by a lifting of many types of regulations that previously limited the role of FDI and TNCs in many developing countries, and a reassessment among donors of the role of public versus private actors in development aid.

This paper will focus on improving our understanding of the role of innovation and knowledge creation in the process

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of economic development. TNCs play a pivotal role in global knowledge creation and, although they represent a small component of the learning or innovation system, which furthers knowledge creation, they are important catalysts. It is necessary to define and explain some important underlying concepts and trends regarding knowledge creation in general, before proceeding to place these concepts in a developing country context and, to highlight the issues and opportunities that TNC-assisted knowledge creation presents.

1. Globalization, innovation and technology

Globalization is an ongoing *process*, rather than an *event*. Economic globalization implies *the growing interdependence of locations and economic units across countries and regions* (Narula 2003). The term interdependence is used very deliberately here. Cross-border linkages between economic entities do not imply globalization, merely internationalization. Trading activities do not necessarily result in interdependence. The new element of international business is the growth of FDI and the TNC. When we distinguish between trade, long-term capital flows, portfolio investment and FDI, we come to an important differentiation. Historically, international business activity used to be dominated by the development of vertical linkages, with a flow of goods between locations, in response to varying elasticities of supply and demand. Raw materials were transported from one location to another, manufactured, and transported to a third location for sale. Factors of production were immobile, and although capital did in fact get relocated, these were capital flows rather than capital embodied in physical assets or personnel and, there was no significant integration of operations in disparate locations within the control and management of the same individuals. Firms were *international*, but neither *multinational* nor *transnational*. International business and economic activity were *extensive* in the sense that the value of goods and capital exchanged were considerable, and involved numerous countries and actors, who were all dependent upon each others' patronage. But it was not *intensive*, in that activities were largely not integrated across borders.

Technological change and innovation are acknowledged almost universally as determinants of globalization. Technology implies the application of scientific knowledge for practical aims. Technology is the application of scientific concepts that help us to understand our environment, and allow us to convert this knowledge to develop and fabricate artefacts. Technology and science are *cumulative*, and build upon previous science and technology. The *practical* dividing line between science and technology is not always clear. Science and technology advance through *innovation*, which represents change in the stock of knowledge. Technology and science are subsets of knowledge. The difference is sometimes considered to be in the intent of the work, in that science is conducted in the altruistic thirst for information, while firms increase their knowledge base in order to create a product or a service. But this difference has also been blurred.

In a very general sense, innovation may mean the introduction of *any* novelty, but in economic and technology literature it has come to have a more precise meaning. An invention is an idea, sketch or model of any new or improved device, product, process or system. Innovations only occur when the new product, device or process is involved in a commercial transaction. Multiple inventions may be involved in achieving an innovation. In the Schumpeterian sense, scientific discoveries and inventions would not be termed innovation although they might fall within a second, broader, type of definition, which is concerned with the entire *process* of innovation, including antecedent work not necessarily undertaken by the entrepreneur. The broad definition of innovation as used here implies *changes in the knowledge, ability and techniques required to produce goods and services of higher or better quality per unit price,* while technology represents the cumulative stock of these innovations. It is to be emphasized that although knowledge creation and innovation are often associated with manufacture and design of new, high-technology products such as aircraft, computer components and large industrial projects, this is not always the case. Innovations can also be the discovery of a better or cheaper way to affix labels to beer bottles, a more appropriate technology to extract palm oil from palm kernels, a modified feed to improve the milk production of cows, or a superior management information system. Technology therefore – for the purposes of this paper – includes all activities that provide assets with which an economic unit can generate products or services. Science provides us with more generic knowledge, which may or may not generate products and services. As will be discussed in this paper, the challenge for many developing countries is to improve the process by which science and invention lead to innovation, thus providing a tangible economic return.

2. Knowledge creation in developing countries

Knowledge creation is often associated with formal activities within R&D that is undertaken in a systematic manner within universities and specialized public and private R&D facilities. However, these formal means represent only a small proportion of knowledge creation. Knowledge creation is a much larger and more systemic phenomenon, although formal facilities account for a large percentage of output. There are two points to be emphasized here.

- First, measuring the informal aspect of knowledge creation is immensely difficult, since its benefits and value cannot always be identified before it is used or sold. These informal aspects are also hard to benchmark, because a large proportion of them are qualitative in nature, in the form of managerial or service innovations and improvements in processes. Finding novel means to reduce the costs of pesticide use on a farm may provide cost savings of a few pennies per kilo to a small farmer, and represents the creation of new knowledge. However, it is often not possible to measure its exact value or, to determine whether this innovation is superior to a similar technique developed by another farmer in another location.

- Second, in developing countries, the informal sector tends to be very large. Developing countries undertake less than 8% of the formal R&D activities globally, and much of these tend to be undertaken by public, state-supported organizations such as universities and research institutes. It is within the domain of R&D expenditures of private enterprise in developing countries, that TNCs can play an important role, although this varies considerably by country.

In general, despite the large amounts of FDI in terms of capital values, TNCs still tend to largely concentrate their more strategic and core activities close to home. In other words, they remain more deeply embedded in their home country than elsewhere. A large proportion of even the most internationalized TNCs tend to exhibit significant inertia regarding their more strategic activities, such as R&D and headquarters functions that tend to stay at home. General Electric for instance has approximately 1,600 researchers in its United States facility, and about 400 in its two international corporate research laboratories. One point that derives indirectly from these data is that if FDI by developed country firms in other developed countries tends to have such low levels of embeddedness in locations where they have been present for many years, it is not surprising that TNCs in developing countries have an even lower level of embeddedness.

3. Foreign affiliates within host-country systems

It has been pointed out that public-sector knowledge creation is often the mainstay of R&D in developing countries, and that within the private sector, TNCs play a leading role.

However, despite the relatively large share of investment (relative to the size of the overall economy) in knowledge creation, this does not always prove to be beneficial to economic development. For developmental benefits to derive from innovation, it is essential that knowledge flows efficiently between different groups within an economy, and this is unfortunately not always the case.

Innovation involves complex interactions between a firm and its environment. The environment is not confined to the firms' networks of direct customers and suppliers only; it stretches much further. It also includes the broader factors shaping their behaviour and activities: the social and cultural context; the institutional and organizational framework; infrastructure; knowledge creating and diffusing institutions, and so on. Within a system, there exists a broad knowledge base outside industrial enterprises and, this base is central to technological accumulation by industries. Learning and innovation involve complex interactions between firms and their environment. This is the essence of the systems approach to technology.

A system, does not necessarily mean that the influences on industrial innovation are systematically organized (Narula 2003). To put it simply, a system means a regularly interacting or interdependent group forming a unified whole. A system is in most cases the serendipitous intertwining of economic actors that defines the stock of knowledge in a given location (Etzkowitz and Leydesdorff 2000). For instance, changes in the educational policies of the government are likely to affect other actors and institutions, and influence the process and extent of technological learning in the future.

Economic actors refer to two groups: The *first* group consists of firms – private and public – engaged in innovatory activity, and the *second* consists of non-firms that determine the knowledge infrastructure that supplements and supports firm-specific innovation. Knowledge infrastructure is defined in the sense proposed by Smith (1997) as being "generic, multi-user and indivisible" and consisting of public research institutes, universities, organizations for standards, intellectual property protection etc, that enables and promotes science and technology development.

In a system, the efficiency of economic actors – firm or non-firm – depends on how much and how efficiently they interact. The means by which interactions take place are referred to as institutions in the economics literature, though sociologists prefer to speak of social capital. Institutions are the "sets of common habits, routines, established practices, rules, or laws that regulate the interaction between individuals and groups" (Edquist and Johnson 1997). Institutions create the milieu within which innovation is undertaken; they establish the ground rules for interaction between economic actors and represent a sort of "culture". Institutions are associated with public sector organizations, but are not exclusively so. It is not only the creation of new knowledge but also the diffusion of extant knowledge that determine the national knowledge stock and the accumulation of national absorptive capacity.

The role of formal institutions has traditionally been considered under the rubric of political economy and has been the focus of debate on the role of the state in establishing, promoting and sustaining learning. Conventional wisdom now argues that governments are essential to promoting inter-linkages between the elements of absorptive capacity and to creating the opportunities for economic actors to absorb and internalize spillovers.

The importance of building institutions cannot be overstated: efficient institutions can contribute more to economic growth than location or trade (Rodrik et al. 2002). Institutions can be formal or informal. Formal institutions include the intellectual property regime, competition policy, technical standards, taxation, incentives for innovation, and education. Informal institutions are more difficult to define, but are associated with creating and promoting links between the various actors. For example, the government may play a role in encouraging firms to collaborate with universities or in promoting entrepreneurship.

Developing countries have switched reluctantly from inward-looking strategies with a large role for the government to market-friendly strategies that force them to face a new multilateral milieu, one in which they have little experience and with which they are often poorly prepared to cope. Institutions continue to remain largely independent and national. While formal institutions can be legislated, modifying and developing informal institutions is a complex and slow process, since they cannot be created simply by government fiat. Developed countries have taken 50 years to liberalize and adjust, but even they have faced considerable inertia. For instance, they have yet to reform their agricultural industries.

Innovation systems are built upon a relationship of trust, iteration and interaction between firms and the knowledge infrastructure, within the framework of institutions based on experience and familiarity of each other over relatively long periods of time. It is certainly true that institutions are often associated with spatial proximity (Freeman 1992). This is not unusual, given the concentration of most firms' production and R&D activities close to, or in their home location over long periods. Besides, knowledge diffuses more rapidly when actors are geographically concentrated (Ehrnberg and Jacobson 1997). This partly accounts for the tendency of firms to locate R&D (or at least the most strategically significant elements) closer to headquarters.

Nonetheless, as firms respond to demand conditions and, because there is increasing need to seek complementary assets in multi-technology, knowledge based industries, firms have spread out spatially and sought to relocate some of their activities in host locations. In engaging in foreign operation in new locations, these operations have gradually become embedded in the host environment. It is germane to this discussion to note that the routines and institutions associated with systems of production in a particular location are related but not identical to systems of innovation. That is, networks associated with production in a location are not quite the same for R&D.

In a purely domestic innovation system, comprised of purely domestic or local sources of primary knowledge (excluding the international and cross-border elements), the path of technological development is determined primarily by domestic factors. The technological development trajectory is driven largely by the changing demand of local customers. Likewise, domestic governmental organizations determine domestic industrial policy, which in turn determines domestic industrial structure. National non-firm sources of knowledge and national universities also determine the kinds of skills that engineers and scientists possess, and the kinds of technologies that these individuals have appropriate expertise in, the kinds of technologies in which basic and applied research is conducted in and thereby, the industrial specialization and competitive advantages of the firm sector.

However, few (if any) such purely national systems exist. In reality, the sources of knowledge available in a typical national system are a complex blend of domestic and foreign ones. In most countries, it is increasingly difficult to separate foreign knowledge sources from domestic ones. Although this is partly the result of globalization, it is also the result of changes in policy orientation. Some countries have voluntarily accepted the limitations of an isolationist industrial development model based on import-substitution and an inward-looking orientation, others more reluctantly, as part of World Bank instituted structural adjustment programmes.

Policies in most developing countries are oriented towards export-led growth and increased cross-border specialization and competition, and most countries are now trying to promote economic growth through FDI and international trade. This wave of liberalization is part of the new, received wisdom that is focused on tackling the deep-rooted causes that underlie market distortions.

Liberalization is an important force in economic globalization since it requires a multilateral view on hitherto domestic issues and promotes interdependence of economies. It is implicit within this view that FDI and TNC activity can be undertaken with much greater ease than previously. This view is enforced because countries have explicitly sought to encourage TNC activity as a source of much-needed capital and technology. In addition to financial crises, the general warming of attitudes towards FDI emanates from an accelerating pace of technical change and the emergence of integrated production networks of TNCs (Lall 2000).

There is a clear link between the geographical spread of the TNC and the process of technological change. Firms (of which TNCs are a subset) expand their (international) activities depending upon the strength (or weakness) of their competitive assets. These are not only confined to technological assets in the sense of ownership of plant, equipment and technical knowledge embodied in their engineers and scientists. Firms of all sizes also possess competitive advantages that derive from (a) the ability (i.e. knowledge) to create efficient internal hierarchies (or internal markets) within the boundaries of the firm and (b) from being able to efficiently utilize external markets. These ownership-specific assets are unique to each individual firm, because firms themselves consist of uniquely individual human beings. Even where two firms have the same product, one may be more profitable than the other because its managers are more efficient in utilizing its resources. Some of these are associated with the efficiency with which hierarchies are organized, and referred to as organizational innovations. Improvements in the quality of these assets leads to a greater quality per unit price. Thus they can be regarded as innovations and as part of the firm's core assets. Such assets form a necessary (and sometimes sufficient) basis for a firm to remain competitive. Such assets include *inter alia* knowledge of overseas locations, capabilities associated with organizing multi-location operations, marketing and logistics, transfer pricing, etc. The point here is that ownership-specific assets – be they technological in the narrow sense, or organizational – all share the common characteristics that they are cumulative, and evolve over time. That is, firms seek to maintain a stock of these assets, and *learn*.

4. The challenges of promoting knowledge creation in developing countries

It is relatively uncontroversial to argue that economic growth occurs due to the ability of a nation's industries to develop and sustain their competitive position, and that this requires growth of capital and labour productivity. We may further postulate that economic growth concerns not just the development of knowledge through innovation, but also the diffusion of knowledge such that it may be utilized and exploited in an efficient manner. In other words, accumulated technology is an engine of growth *only* if it can be harnessed to make the best use of available resources and therefore, must also consist of the knowledge to organize transactions efficiently, whether intra-firm, intra-industry or intra-market.

Developing countries tend to be constrained in terms of resources, at several different levels. This also limits their ability to promote knowledge creation. Some of these resource constraints are associated with attitudes and the absence of stability, trust, and transparent institutions. Others have to do with capital scarcity, the limited availability of natural or created assets, and the normal limitations that derive from a weak economy. This severely limits the opportunities to promote knowledge creation in developing countries using the policy tools that are otherwise available to developed countries. This is why TNCs provide a viable alternative that many developing countries pursue. Nonetheless, simply attracting FDI does not lead to knowledge creation. Market forces cannot substitute for the role of governments in developing and promoting a proactive industrial policy. TNCs and FDI may well lead to an increase in productivity and exports, but they do not necessarily result in increased competitiveness of the domestic sector or increased industrial capacity, which ultimately determines economic growth in the long run. FDI *per se* does not provide growth opportunities unless a domestic industrial sector exists which has the necessary technological capacity to profit from the externalities from TNC activity. This is well illustrated by the inability of many Asian countries that have relied on a passive FDI-dependent strategy to upgrade their industrial development (Lall and Narula 2004).

In many cases, foreign affiliates are so well embedded that they are regarded as part of the domestic environment. This reflects not just the length of time that these affiliates have been present (e.g. ABB in Norway), or that the affiliate is jointly owned (e.g. Hindustan Lever in India) or has been acquired (e.g. Nycomed-Amersham, Unilever, Reed Elsevier), but also the nature of the industry, and the growing trend towards consolidation in industries with low growth and opportunities of global rationalization (e.g. metals, banking, automobiles). Nonetheless, the interaction between domestic firms and foreign affiliates varies considerably, either because domestic firms are largely present in different industries or, because the two have evolved separately.

In the case of developing countries, such knowledge dependencies are often more pronounced in the case of the non-firm sector, in that universities and research organizations tend to be linked with international agencies, universities and organizations in other countries, sometimes through supranational organizations. Nonetheless, the role of TNCs remains important even in developing countries, as foreign affiliates tend to be linked with their parent corporations, as well as other affiliates in other countries. The high cost of maintaining a wide network of affiliates and the high cost of innovating, means that TNCs are always on the look-out for domestic firms in their host countries with whom they can either collaborate or from whom they can acquire important inputs for their operations. Domestic firms also seek (and are sought as) partners in international R&D consortia because there is a convergence in technological trajectories across countries, as firms seek the best partners in a given industry regardless of their national origin (Narula and Hagedoorn 1999, Narula 2003). This creates considerable potential – which may initially be modest – for smaller domestic firms and public sector organizations to benefit from the presence of TNCs, and to acquire and transfer knowledge assets. When TNCs establish affiliates in a particular location they need to build linkages with domestic agents in order to carry out their operations, and these linkages constitute one of the ways in which skills and technological transfer is thought to disseminate to the rest of the economy. Thus TNCs can promote domestic enterprise and technological learning in the entire national system, as they seek cheaper local alternatives to inputs, and can act as catalysts for system-wide learning.

It is worth pointing out that many developing countries seem prone to technological learning and attracting TNCs in “white elephant” projects, which neither fit their comparative advantage nor are the capabilities of the systems able to supply the needs of such projects. A typical example is Nigeria’s investment in satellite technology. TNCs are unlikely to respond to investment opportunities that provide little or no opportunity for their own growth. *Ceteris paribus*, TNCs prefer to use technologies that are suited to their own needs, and the purposes for which they have made the investment. TNCs generally do not make available their proprietary assets available at the whims of governments; rather they tailor their investment decisions to the existing market needs and locational advantages, especially skills and capabilities in which the domestic economy has a comparative advantage (Lall 2000).

The TNC investment motive and its overall strategy are important factors to consider. For example, domestic market oriented affiliates generally purchase more locally than do export oriented firms because of lower quality requirements and technical specifications (Reuber et al 1973, Altenburg 2000). As a result, foreign affiliates are more likely to be integrated backward in the host country when they source relatively simple inputs. For example, in the case of FDI in agro-based industries, there is a greater likelihood for affiliates to be integrated backward, especially given the early stage of development of the host country. Rodriguez-Clare (1996) argues that more linkages are created when production by TNCs uses intermediate goods intensively, when communication costs between parent and affiliate are large and when the home and host markets are not too different in terms of intermediate goods produced.

Affiliates established through mergers and acquisitions are likely to have stronger links with domestic suppliers than those established through greenfield investment (UNCTAD 2000, Scott-Kennel and Enderwick 2001), since such FDI can find established linkages upon acquisition that are likely to be retained if they are efficient. Most importantly, linkages vary by industry. In the primary sector, the scope for location-specific vertical linkages is often limited, due to the production processes and capital intensity of such operations. In manufacturing, the potential for vertical linkages is broader, depending on the extent of intermediate inputs to total production and the type of production processes (Lall 1980). Blomström and Kokko (1997) suggest that "some of the host country characteristics that may influence the extent of linkages

– and thereby in the longer term the extent of spillovers – are market size, local content regulations and the size and technological capability of local firms". They argue that there is a propensity for linkages to increase over time, as the skill level of local entrepreneurs grows, new suppliers emerge and local content increases. The time factor is highlighted also by Rasiah (1994) and is related to the experience and integration of a foreign affiliate in the host country through greater indigenization of operations in terms of management, knowledge about their location and operations. The embeddedness of firms is often (but not always) a function of how long the TNCs have been present in the host country, since firms tend to build incrementally.

Technology diffusion through backward linkages presupposes that first, domestic firms in the industry exist, and second, they possess the capacity to usefully internalize the knowledge being made available by the TNC. Diffusion to the rest of the economy may not occur because of deficiencies in the institutional capability systems of the host country or other deficiencies in the absorptive capacity of domestic economic agents in the host country. Wider technology gaps between domestic firms and foreign affiliates are more likely to result in fewer backward linkages as well as the type of technological content of inputs sourced locally (Narula and Portelli forthcoming).

It is obvious that national governments have a strong interest in the ability of firms in a given location to conduct competitiveness-enhancing activities, and particularly those associated with the creation and deployment of knowledge capital. These reasons can be qualified under two main headings, *viz.* the promotion of the wealth creating assets of its firms and, maintaining and improving indigenous resources and capabilities. By doing so, it can help to maintain and improve its own locational attractiveness to mobile and footloose investors (of whatever nationality) to conduct high value adding activities. These two issues are strongly related, since the presence of highly competitive firms at a given location acts as a location advantage, often prompting a virtuous circle. Conversely, strong location advantages, such as the presence of support institutions and firms, infrastructure and skilled manpower will enhance the ownership advantages of firms located there.

The role of governments in improving the quality of human capital cannot be over-emphasized. One of the primary determinants behind technological accumulation and absorptive capacity is human capital. Qualified human resources are essential in monitoring the evolution of external knowledge and in evaluating their relevance and, for the integration of these technologies into productive activities. Human capital represents an important subset of absorptive capabilities, and this is well acknowledged by policy makers everywhere. However, the presence of a highly skilled labour force is a necessary condition. Simply providing tertiary level education and skilled manpower does not lead to increased R&D, nor is there a direct connexion between education and technological competence. The availability of a large stock of suitably qualified workers does not in itself result in efficient absorption of knowledge, as is well illustrated by the former centrally planned economies of Eastern Europe. But the quality of the training and the ability of industry to exploit available skills in R&D or other technical effort matter a great deal.

5. Conclusion

The failure of most countries to successfully promote knowledge creation and take advantage of TNC-assisted knowledge creation reflects two difficulties. The first is the difficulty to integrate various policies in a systemic way; the second is the difficulty of transforming institutions associated with the old order of import substitution. Policies, administrators and policy-makers have largely attempted to graft the new model onto the remnants of the old model, partly because political and social interest groups are resistant to change, and partly because rapid and sweeping policy shifts require considerable time for the informal institutions to adjust (Lall and Narula 2004).

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The complexity and internationalization of innovation: the root causes

Dieter Ernst[1]

The internationalization of innovation continues to lag behind the internationalization of finance, distribution and manufacturing but, it is now experiencing a rapid proliferation. The main drivers are TNCs who are increasing their overseas investment in R&D, while seeking to integrate geographically dispersed innovation clusters into global networks of production, engineering, development and research. This adds an important new dimension to the evolution of cross-border corporate networks. Global innovation networks are now being crafted, in addition to the existing global production networks.

Since the late 1990s, this process has no longer been restricted to the industrial heartlands of the OECD. The internationalization of innovation is now expanding into new locations in emerging economies, primarily in South, East and South-East Asia. Going beyond adaptation, R&D in the new locations now also encompasses the creation of new products and processes. TNCs are at the forefront of these developments, experimenting with new approaches to the management of global innovation networks. However, local firms are playing an increasingly active role as sources of innovation and in shaping relevant standards.

As R&D and innovation are critical for economic growth, competitiveness and welfare, the internationalization of innovation creates new challenges and opportunities for a wide range of public policies that affect FDI and economic development. In the home countries of TNCs that are internationalizing R&D and innovation, there are concerns that

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[1] The views expressed in this study are those of the author and do not necessarily reflect the views of the United Nations, its Member States, or the Institutions to which the author is affiliated.

this may extend the "hollowing-out" of their economies well beyond manufacturing to research and development, the most fundamental sources of their economic growth.[2] These fears may feed into protectionism (Granstrand and Sjölander 1990). On the other hand, emerging economies (the host countries of international R&D and innovation) are all searching for strategies that would enable them to benefit from integration into global R&D and innovation networks. Prominent examples are attempts by governments and domestic firms in East and South-East Asia's leading electronics exporting economies (China, the Republic of Korea, Taiwan Province of China, Singapore and Malaysia) to build innovative capabilities within the above global networks.

Research on the internationalization of innovation has recently received a boost, but it is still at a very early stage. There are few robust data on the drivers and especially the impacts of these processes. There are now concerted efforts to close this research gap for the internationalization of innovation among industrialized countries. However, there is limited research on what precisely is driving the more recent extension of R&D and innovation into new locations outside the established centres of excellence in the United States, Japan and Europe. Even less is known about possible impacts, and effective policy responses.

This paper addresses a particularly important unresolved question: *What explains the internationalization of innovative activities that involve highly complex technological knowledge?* In innovation theory, it is assumed that complexity constrains the internationalization of innovation. This is based on the proposition that physical proximity is advantageous for innovative activities that involve highly complex technological knowledge. In a frequently quoted article, the late Keith Pavitt and his co-author Pari Patel (Pavitt and Patel 1991) used patent

[2] See for instance, Friedman 2005.

data to demonstrate that innovative activities of the world's largest TNCs were among the least internationalized of their functions. They argued that firms tended to concentrate innovation in their home countries, in order to facilitate the exchange of complex knowledge. Hence, complexity explained why innovation remained an important case of "non-globalization".

However, chip design, a process that creates the high value in the IT industry and that requires complex knowledge, does not confirm this proposition. Over the past few years, a heavy concentration in a few centres of excellence (mainly in the United States, but also in Europe and Japan), has given way to growing organizational and geographical mobility. Vertical specialization within global design networks represents an important test case for the study of global innovation networks. Global design networks are shaped by the progressive *dis-integration* of the design value chain and to its *geographical dispersion*. Vertical specialization within global design networks thus combines the "outsourcing" of stages of chip design to specialized suppliers and its "offshoring" across national boundaries. Of particular importance has been a rapid expansion of chip design in leading Asian electronics exporting countries that has been accompanied by substantial progress in the complexity of design.

1. Spatial stickiness of innovation

For decades, the dominant position of researchers has been that innovation, in contrast to most other stages of the value chain, is highly immobile. Cognitive complexity is the main reason for such spatial stickiness of innovation. It is assumed in innovation theory that to cope with the demanding requirements of cognitive complexity, firms have a strong incentive to concentrate innovation in their home countries. However, recent empirical research on globalization has clearly established that the centre of gravity has shifted beyond the national economy. International linkages proliferate, as markets for capital, goods, services, knowledge and labour are integrated across borders. While integration is far from perfect in markets for technology (Arora et al. 2001), it is nevertheless transforming the geography of innovation (Ernst 2002a). This process is well captured in Cantwell's important observation that instead of a few pre-eminent centres of innovation, there are now "multiple locations for innovation, and even lower-order or less developed centres can still be sources of innovation." (Cantwell 1995: 172).[3]

2. Root causes of organizational and geographical mobility

To explain the internationalization of innovation, this section highlights the following four general root causes that are gradually reducing the constraints imposed by knowledge complexity on the organizational and geographical mobility of innovation (Ernst 2003a):

- institutional change through liberalization;
- the impact of general-purpose technologies (such as ICT);
- transformations in markets, competition and industrial organization (especially vertical specialization through network arrangements);

[3] A particularly intriguing example is China's pioneering role in the development of the world's first commercially operated nuclear "pebble bed" reactor that offers the hope of cheap, safe and easily expandable nuclear power stations (China in drive for nuclear reactors, *Financial Times*, 8 February 2005: 4). Within Asia, new innovation clusters have also emerged for broadband technology and applications in the Republic of Korea and Singapore, for digital consumer devices in the Republic of Korea, China, Hong Kong (China) and Taiwan Province of China, and for software engineering and project management in India. Other examples are Europe's newly emerging innovation clusters for microelectronics technology in Crolles (near Grenoble), at the Inter-University Microelectronics Center (IMEC) at Leuven, Belgium and in Dresden, Germany.

- adjustments in corporate strategy and business models.

a. Liberalization

Liberalization has four main elements: trade liberalization; liberalization of capital flows; liberalization of FDI policies; and privatization. While each of these has generated separate debates in the literature, they hang together. Earlier success in trade liberalization has sparked an expansion of trade and FDI, increasing the demand for cross-border capital flows. This has increased the pressure for liberalization of capital markets, forcing more and more countries to open their capital accounts. In turn this has led to a liberalization of FDI policies, and to "privatization tournaments".

The overall effect of liberalization has been a considerable reduction in the cost and risks of international transactions and a massive increase in international liquidity. TNCs have been the primary beneficiaries: liberalization provides them with a greater range of choices for market entry between trade, licensing, subcontracting, and franchising (*locational specialization*); it provides better access to external resources and capabilities that a TNC needs to complement its core competencies (*outsourcing*); and it has reduced the constraints for a geographic dispersion of the value chain (*spatial mobility*). During the last part of the 20th century, this has given rise to the spread of global production networks. Since the turn of the century, TNC-cantered network arrangements are now also encompassing innovation, giving rise to global innovation networks.

b. Information and communication technology

The second important root cause of the increasing mobility of innovation is the rapid development and diffusion of ICT. ICT has had a dual impact: it has increased the need for, and has created, new opportunities for globalization. The *cost* and *risk* of developing ICT has been a primary cause for *market* globalization: international markets are required to amortize fully the enormous R&D expenses associated with rapidly evolving process and product ICT (Kobrin 1997: 149). Of equal importance are the huge expenses for ICT-based information management (Brynjolfsson and Hitt 2000). As the extent of a company's R&D effort is determined by the nature of its technology and competition rather than its size, this rapid growth of R&D spending requires a corresponding expansion of sales, if profitability is to be maintained. No national market, not even the United States market, is large enough to amortize such huge expenses.

ICT-based information management also creates new opportunities for globalization, enabling international production rather than exports to become the main vehicle for international market share expansion. Over time, the expansion of global production networks requires the parallel extension of engineering support services. This implies that knowledge diffusion among different network nodes becomes the necessary glue that enables global production networks to grow. At some stage, once an individual global production network node has reached a critical threshold, TNCs may need to upgrade these activities to include product development and design. Much depends of course on the development of local innovation capabilities and systems (Ernst and Kim 2002).

Of critical importance has been the enabling role played by ICT: these general-purpose technologies (Lipsey and Carlaw forthcoming) have substantially increased the mobility, i.e. *dispersion* of firm-specific resources and capabilities across national boundaries; they also provide much greater scope for cross-border linkages, i.e. the *integration* of dispersed specialized clusters. This has substantially reduced the friction of time and space, not only for sales and production, but also for R&D and other innovative activities. A TNC can now serve distant markets equally as well as local producers; it can also now disperse more and more stages of its value chain across national borders in order to select the most cost-effective location.

In addition, ICT and related organizational innovations provide effective mechanisms for constructing flexible infrastructures that can link together and coordinate economic transactions at distant locations (Antonelli 1992, Hagstrøm 2000). This has important implications for organizational choices and locational strategies of firms. In essence, ICT fosters the development of leaner, meaner and more agile production and innovation systems that cut across firm boundaries and national borders. The underlying vision is that of a network of firms that enable a TNC to respond quickly to changing circumstances, even if much of its value chain has been dispersed.

c. Transformations in markets, competition and industrial organization

The third root cause of the increasing organizational and geographical mobility of innovation is found in the transformations in markets, competition and industrial organization that result from the interplay of liberalization and ICT. "Globalization" is a widely used shorthand for transformations in markets, defined as the integration, across borders, of markets for capital, goods, services, knowledge, and labour (Ernst 2005b). Barriers to integration continue to exist in each of these different markets (especially for low-wage labour), so integration is far from perfect but, there is no doubt that a massive integration of markets has taken place across borders that, only a short while ago, seemed to be impenetrable.

This has drastically changed the dynamics of competition. The geographic scope of competition has broadened and competitive requirements are now much more complex. Competition now cuts across national borders - a firm's position in one country is no longer independent from its position in other countries (Porter 1990). The firm must be present in all major growth markets (*dispersion*). It must also integrate its activities on a worldwide scale, in order to exploit and coordinate linkages between these different locations (*integration*). Competition also cuts across industry boundaries and market segments: mutual raiding of established market segment fiefdoms has become the norm, making it more difficult for firms to identify market niches and to grow with them.

This growing complexity of competition has changed the determinants of location, as well as industrial and firm organization. In the case of location decisions, while both market access and cost reductions remain important, it has become clear that they have to be reconciled with a number of equally important requirements that encompass:

- the exploitation of uncertainty through improved operational flexibility (Kogut 1985, Kogut and Kulatilaka 1994);
- a compression of speed-to-market through reduced product development and product life cycles (Flaherty 1986);
- learning and the acquisition of specialized external capabilities through asset-augmenting R&D (Hedlund 1986, Kogut 1989, Kogut and Zander 1993, Dunning 1998, Zander and Kogut 1995, Kuemmerle 1996, Patel and Vega, 1999, Le Bas and Sierra 2002);
- the need to access the evolving global talent pool (D'Costa 2004, Ernst, 2005a) and, a shift of market penetration strategies from established to new and unknown markets (Christensen 1997).

As TNCs seek to cope with the increasingly demanding determinants of location, this induces them to consider the offshoring of gradually more knowledge-intensive activities, including some aspects of product development. In this sense, it is possible to argue that the transition from the offshoring of manufacturing to the "outsourcing of innovation" (*Business Week* 21 March 2005) is an evolutionary process and, that TNCs are gradually building global innovation networks onto their existing global production networks.

Changes in industrial organization are equally important. No firm, not even a dominant market leader, can generate internally all the different capabilities that are necessary to cope with the requirements of global competition. Thus, competitive success critically depends on "vertical specialization": TNCs selectively "outsource" certain capabilities from specialized suppliers, and they "offshore" them to new, lower-cost locations. While vertical specialization initially was focused on final assembly and lower-end component manufacturing, it is increasingly being pushed into higher-end value chain stages, including product development and design capabilities. To make this happen, TNCs had to shift from individual to increasingly collective forms of organization, from the multidivisional (M-form) functional hierarchy (Williamson 1975 and 1985, Chandler 1977) to the networked global flagship model (Ernst, 2002b).

The electronics industry has become an important breeding ground for this new industrial organization model. A massive process of vertical specialization has segmented an erstwhile vertically integrated industry into closely interacting horizontal layers (Grove 1996). Until the early 1980s, IBM personified 'vertical integration': almost all ingredients necessary to design, produce and commercialize computers remained internal to the firm. This was true for semiconductors, hardware, operating systems, application software, and sales and distribution.

Since then, vertical specialization became the industry's defining feature (Ernst 2003a). Most activities that used to characterize a computer company are now being farmed out to multiple layers of specialized suppliers, giving rise to rapid market segmentation and, an ever finer specialization within each of the above value chain stages. Over time, as firms have accumulated experience in managing global distribution and production networks and, as they are learning from successes and failures in inter-firm collaboration, this has given rise to new and increasingly sophisticated forms of corporate network arrangements. It is on the basis of such learning processes that TNCs are now pushing vertical specialization deeper into the innovation value chain, gradually constructing global innovation networks.

d. Adjustments in corporate strategy and business models

Vertical specialization went hand in hand with adjustments in corporate strategy and business models that further enhanced the organizational and geographical mobility of innovation. In the IT industry for instance, these adjustments were especially important in the choice of product and process specialization, in investment funding and, in human resources management. Feeding into each other, these adjustments are "systemic" in that small changes in any of them require adjustments in all the other aspects of the business model.

The spread of venture capital and related regulatory changes in the financial industry[4] have drastically changed corporate strategies of investment funding. United States venture capital firms provide access to a massive infusion of capital from United States pension funds as well as hands-on industrial expertise. As a result, start-up companies in the IT

[4] Important complementary changes in United States financial institutions include the launching of NASDAQ in 1971 (making it much easier for start-up firms to go public), the reduction of the capital gains tax by the United States Congress in 1978, from 49% to 28%, and, the Department of Labor decree in 1979 that pension fund money can be invested not only in listed stocks and high-grade bonds but also in more speculative assets, including new ventures (Lazonick 2005: 23).

industry now were able to raise capital for high-risk innovation projects. At the same time, global IT industry leaders have increasingly used stock to attract and retain global talent and to acquire innovative start-up companies (Lazonick 2003). Both changes in investment funding have led to far-reaching changes in corporate governance, with the result that investment decisions are now primarily oriented towards servicing shareholder requirements. This has drastically changed the parameters for innovation management. As IT firms can rely more and more on stock and venture capital, they are under increasing pressure to raise the productivity of their innovation efforts and, to commercialize as fast as possible the resulting IPRs.

As for the management of labour, the IT industry has seen a dramatically diminished commitment to long-term employment "on both sides of the employment relation" (Lazonick 2005:2), giving rise to a substantial increase in the inter-firm and geographical mobility of labour, especially for highly skilled engineers, scientists and managers. In the United States, the emergence of a "high-velocity labour market" (Hyde 2003) for IT skills is driven by the proliferation of start-up companies; a drastic increase in the recruitment of highly educated foreigners; and the spread of lavish incentives (such as stock options) to induce job-hopping.

This has raised the cost of employing IT workers in the United States. For instance, between 1993 and 1999, computer scientists and mathematicians experienced the highest salary growth (37%) of all United States occupations (NSF 2004, chapter 3, page 14). Average real annual earnings of full-time employees in California's software industry rose from $80,000 in 1994 to $180,000 in 2000, only to fall drastically to below $100,000 in 2002, after the bursting of the "New Economy" bubble. However, even in the midst of the IT industry recession, employees in the United States IT industry continued to earn, on average, much more than in most other industries of the economy and, between five and ten times more than their counterparts in Asia (outside of Japan). In 2002, the average annual wage in the United States IT industry was $67,440 (with a high of $99,440 in the software industry), compared with $36,250 in all private-sector industries (United States, Department of Commerce 2003, appendix table 2.3). This has created a powerful catalyst for IT firms in the United States to increase their overseas investment in R&D, in order to tap into the growing pool of educated and experienced IT talent that is available in Asia at much lower wages.

3. Changes in innovation management

The above transformations in markets, technology, competition and strategy have provoked fundamental changes in innovation management, further enhancing the mobility of innovation. A transition is under way towards gradually more open corporate innovation systems, based on an increasing vertical specialization of innovation. What explains the dynamics of these changes, and how do they shape the internationalization of innovation? This section highlights a gradual opening and networking of corporate innovation systems; examines the role played by evolving global markets for technology and for knowledge workers in the transition to global corporate innovation networks; and finally, discusses possible strategic benefits for TNCs.

a. Opening and networking of corporate innovation systems

Corporate innovation management needs to address four tasks simultaneously: to develop innovative capabilities (including R&D);[5] to recruit and retain educated and

[5] "Innovative capabilities" are defined as the skills, knowledge and management techniques needed to design, produce, improve and commercialize "artefacts", i.e. products, services, machinery and processes (Ernst 2005c).

experienced knowledge workers; to develop and adjust innovation process management (methodologies, organization and routines) in order to improve efficiency and time-to-market; and to match all three tasks with the corporation's business model, which determines customers, market segments, pricing, the degree of in-sourcing and outsourcing and, which defines the structure of required distribution, production and innovation networks. All four tasks are intrinsically interdependent but, of greatest importance is compliance with the firm's business model. In fact, if a firm pursues the first three tasks without a clear definition of the business model, this is likely to produce commercial failure.

The growing organizational and geographical mobility of innovation creates new challenges, but also provides new opportunities for innovation management. The challenge is that no firm, not even a global market leader like IBM, can mobilize all the diverse resources, capabilities and bodies of knowledge internally. Instead, both the sources and the use of knowledge become increasingly externalized. Now, firms must supplement the in-house creation of new knowledge and capabilities with external knowledge sourcing strategies. There are strong pressures to reduce in-house basic and applied research and, to focus primarily on product development and the absorption of external knowledge (e.g. Chesbrough 2003, Arora et al. 2001). No longer does this externalization of innovation stop at the national border. Firms increasingly need to tap sources of knowledge that are located overseas (Ernst 2002a).

At the same time, corporate innovation management is under increasing pressure to commercialize existing intellectual property rights through aggressive technology licensing. Furthermore, recruitment of knowledge workers now draws on an evolving global labour market, especially for scarce bottleneck skills, in order to keep a cap on rising costs of R&D and engineering. Finally, a corporation's business model is no longer exclusively shaped by peculiar characteristics of home country markets, but needs to adjust to diverse idiosyncratic overseas markets.

The result has been a gradual opening and networking of corporate innovation systems (Arora et al. 2001, Chesbrough 2003, Ernst, 2005b). For instance, the *Science and Engineering Indicators 2004* report by the United States NSF highlights the increasing importance of innovation networks that cut across industries and national borders. The report argues that "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, page IV-36).

Chesbrough's concept of "open innovation" provides a useful stylized model of this gradual opening of corporate innovation systems. However, the model does not address explicitly the international dimension, i.e. the development of global innovation networks. In Chesbrough's model, a corporation has a "closed" innovation system, when it seeks to discover new breakthroughs, to develop them into products, to build the products in its factories and, to distribute, finance and service those products; "all within the four walls of the company" (Chesbrough 2003: 4).[6] An "open" innovation system, on the other hand, requires that the corporation redefine its business model to commercialize technologies that it has at

[6] Naturally, hardly any company has ever relied on a completely closed, self-contained innovation system, except in times of war or in dictatorial societies. Chesbrough's concept of a "closed innovation system" highlights two stylized organizational routines that over time constrain the economic benefits from innovation: First, the firm creates ideas for the sole purpose of using them, and second, the firm only uses ideas that have been created internally, the so-called NIH ("not invented here") syndrome (Chesbrough 2003: 29).

its disposal, both from external sources and through in-house development.

b. Global markets for technology

In an open innovation system, both the source and the use of knowledge can be external for the TNC. The firm can create ideas for external and internal use, and it can access ideas from the outside as well as from within. Firms are able to move to an open innovation system, because an increasing mobility of knowledge has created an abundance of knowledge outside the firm. "The proliferation of public scientific databases and online journals and articles, combined with low-cost internet access and high transmission rates…[provide]…access to a wealth of knowledge that was far more expensive and time-consuming to reach as recently as the early 1990s" (Chesbrough 2003: 44).

Arora et al. (2001) demonstrate that the gradual opening of corporate innovation systems is driven by the increasing division of labour in innovation.[7] This gives rise to the growth of "markets for technology", which is further enhancing the mobility of innovation. Markets for technology affect corporate innovation strategy in multiple ways, creating more space for a gradual opening and networking of corporate innovation systems. TNCs can now outsource knowledge that they need to complement their internally generated knowledge and, they can choose to license their technology, and hence enhance the rents from innovation.

The idea of knowledge outsourcing runs counter to established wisdom in innovation theory. Barney (1991) for

[7] The argument that technology and innovation can be the subject of a division of labour goes back to Stigler (1951). That widely quoted article argues that as the extent of the market is increasing, the division of labour would also embrace innovation, leading to the rise of stand-alone R&D laboratories that would sell their research results to other parties.

instance, argues that for a firm to grow, it must control resources that are valuable, rare and imperfectly mobile. The underlying assumption is that technological assets cannot be directly bought and sold, and the services of such assets cannot be rented. Teece (1986) demonstrates that in the absence of technology markets, firms must invest in creating "co-specialized assets" (such as the production of core components and accumulated knowledge of customer requirements) to maximize their returns from innovation. And Edith Penrose, in her pioneering study ("The theory of the growth of the firm"), concludes that "... a firm's rate of growth is limited by the growth of knowledge within it" (Penrose [1959] 1995: XVI-XVII), emphasizing the capacity for knowledge integration.

However, markets for technology broaden the choices available to a firm. There is now much greater scope for external technology sourcing. Markets for technology actually increase the penalty for the NIH ("not invented here") syndrome, i.e. a reluctance to use external technologies. As the mobility of knowledge increases, a firm's competitive success critically depends on its ability to monitor and quickly seize external sources of knowledge (Iansiti 1997). As demonstrated by Iansiti and West (1997), a company can leverage basic or generic technologies developed elsewhere, which allows it to focus on developing unique applications that better suit the needs of specific overseas markets. Industry leaders can now attempt to balance in-house innovation and external knowledge sourcing. However, external knowledge sourcing can also provide a short cut for late entrants from developing countries. For instance, companies that trail behind industry leaders in their in-house technological capabilities can now use external technology sourcing to enhance their in-house innovative capabilities (Ernst 1997 and 2000).

Markets for technology also create new opportunities for appropriating innovation rents through technology licensing. The underlying assumption is that once markets for technology exist, knowledge will be sufficiently codified and IPRs will be well defined and protected (Kogut and Zander 1993) but, theory also shows that an excessive reliance on technology licensing may be risky, as it cuts the company off from vital system integration knowledge that is necessary for continuous innovation (Grindley and Teece 1997).

c. Evolving global markets for knowledge workers[8]

Equally important for the gradual opening of corporate innovation systems has been the increasing availability of knowledge workers outside the dominant corporations and their rapidly increasing geographical mobility, first within the United States (e.g. the GI bill after World War II), then in Europe (Marshall aid for reconstruction and later various rounds of EU enlargement) and Japan and, after 1970, in the newly industrializing economies of East and South-East Asia. In all of these regions, as well as in China, India, Brazil and the Russian Federation, government policies to improve education and training, and to enhance their interaction with business needs, have helped to increase the supply of knowledge workers.

The result is an evolving global market for knowledge workers. According to the United States NSF (2004, Volume 1, chapter 3), more and more governments are implementing aggressive policies designed to attract highly trained and experienced engineers, scientists and R&D managers from abroad. TNCs are responding to the intensifying competition for scarce global talent, "by opening high-technology operations in foreign locations, developing strategic international alliances, and consummating cross-national spinoffs and mergers" (*ibid*: 0-3). For some bottleneck skills, like experienced design engineers for analogue integrated circuits, this may lead to global "auction markets" for knowledge workers, enabling them to sell their talents to the highest bidder. Overall however, the

[8] This section draws on Ernst 2005a.

emergence of a global market for knowledge workers seems to have kept a tight cap on increases in remuneration (Lazonick 2005). In summary, the leading TNCs can tap into global markets for knowledge workers who are readily available for hire and need not require extensive internal training or the inducement of lifelong employment.

Until the turn of the century, the United States was the main beneficiary of the globalization of knowledge workers, as the main recipient of a global brain drain. A 1998 NSF study showed that over 50% of the post-doctoral students at MIT and Stanford were not United States citizens, and that more than 30% of computer professionals in Silicon Valley were born outside the United States (United States NSF 2004). Data from the most recent 2000 United States Census show that in science and engineering occupations approximately 17% of bachelor’s degree holders, 29% of master’s degree holders, and 38% of doctorate holders were foreign born. This has enabled start-up companies to pursue “learning-by hiring away” strategies. They could rapidly ramp up complex innovation projects with highly experienced personnel that were trained by other corporations or countries. However, the main beneficiaries were major TNCs who were able to reduce the cost of research, product development and engineering by shifting from national to global recruitment strategies.

It is important to emphasize that over the last few years, the privileged position of the United States in global markets for knowledge workers, has faced new challenges. In fact, the two main concerns of the most recent Nation Science Board report on “Science & Engineering Indicators”, are competing recruitment practices of foreign governments and TNCs and whether “post 9/11” visa restrictions to foreign students, scholars and engineers will dry up the erstwhile readily available supply of top talent for United States firms.

d. Strategic benefits for TNCs

An important strategic benefit that TNCs can draw from the opening and networking of corporate innovation systems is that this may facilitate the matching of business models and technology road maps. For instance, external and international knowledge sourcing can help to fill the gaps between both, at least temporarily. It can also help to identify and address "blind spots" that have gone undetected within a closed innovation system. This is of critical importance, as the increasing complexity of technology road maps poses a serious challenge to corporate innovation management.

The *International Roadmap for Semiconductors,* was co-published by the semiconductor industry associations of the United States and other leading semiconductor exporting countries (ITRS 2004). Until the mid-1990s, its primary concern was to coordinate requirements *within* fabrication that needed to be fulfilled to extend Moore's Law.[9] The road map thus focused on defining interfaces between a variety of complementary semiconductor manufacturing technologies, including photolithography (the process of using light to etch a circuit pattern on a chip), the mask (the device that contains the circuit pattern), the chemical agents used to impart the pattern, the physical size of the wafers used to hold the etched pattern and, the equipment used to measure these tiny distances reliably and accurately. For each of these different innovation agents, the road map defined the sequencing of complementary innovations, so that these technologies are produced right at the time when other required technologies will also be available, instead of being delivered too early or too late. Today, the semiconductor road map is substantially more complex, and needs to coordinate multiple interfaces between the design, fabrication and application of semiconductor devices that

[9] In 1965, Gordon Moore, one of the co-founders of Intel, predicted that economical integrated circuit density would double roughly every one to two years (Moore 1965).

increasingly integrate systems on a chip. Hence, it becomes much more difficult to match technology road maps and business plans. This has given rise to a progressive vertical specialization of innovation within global design networks.

Furthermore, an open corporate innovation system can help the company to hedge against failures of internal R&D projects or against slippage in capacity expansion. It also helps TNCs to multiply opportunities for technology diversification. In other words, there is a choice between “build-or-buy” new business lines. It may also accelerate the speed of the innovation cycle and reduce the very high fixed cost of investing in internal R&D capabilities.

In essence, the transition to more open innovation systems through global innovation networks reflects the recognition by incumbent market leaders that there is simply no way to prevent knowledge diffusion. Even the most aggressive attempts to slow down such diffusion (such as “black-boxing” of technology)[10] are unlikely to succeed (Ernst 2004). This explains why incumbent market leaders now prefer to exploit the diffusion of knowledge, rather than fighting rearguard battles to protect themselves against knowledge leakage.

Finally, it is important to emphasize that once a TNC relies on global innovation networks, internal R&D becomes even more important than it used to be in a “closed” innovation system. However, the internal research team now needs to develop extensive linkages with outside and especially international knowledge sources. This explains the drastic changes in the organization, routines and incentives of

[10] “Black box” technologies are defined as technologies “that cannot be easily imitated by competitors because they are: (1) protected under intellectual property rights, such as patents, (2) made of complex materials, processes, and know-how that cannot be copied, or (3) made using unique production methods, systems or control technologies” (Ernst 2005c).

corporate innovation management that this section has documented.

In sum, “vertical specialization” is no longer restricted to the production of goods and services, but now extends to all stages of the value chain, including research and new product development. Over the years, this process has taken on an increasingly international dimension, with the result that corporate innovation management can now “integrate distinctive knowledge from around the world as effectively as global supply chains integrate far-flung sources of raw materials, labour, components and services” (Santos, Doz and Williamson 2004: 31). Most importantly, TNCs now can proceed to construct international innovation networks that improve the productivity of R&D “by accessing knowledge from non-traditional cheaper locations” (*ibid*).

As the number of specialized suppliers of innovation modules increases, this provides a powerful boost to the organizational and geographical mobility of innovation. TNCs are now seeking to integrate geographically dispersed innovation clusters into global networks of production, engineering, development and research. Since the turn of the century, these networks have been extended to emerging new innovation clusters, especially in Asia. This is expected to provide TNCs with a new source of competitive advantage: more higher-value innovation at lower cost.

4. Conclusion

An important lesson from this analysis is that the internationalization of innovation, and its vertical specialization within global innovation networks, is driven by a combination of pull, push and enabling factors that are systemic. For host country policies, this implies that a narrow focus on demand- or supply-oriented forces can attract foreign R&D only if these policies are based on a profound understanding of the underlying changes in the methodology and organization of the relevant innovation processes in the particular industry. Only when pull, push and enabling factors are coming together, creating a virtuous circle, will host country policies attract R&D by TNCs and produce the expected results.

Another corollary of the analysis above is the critical importance of the absorptive capacity of local firms, i.e. their resources, capabilities and motivations. To stay on the global innovation networks, local firms need to invest constantly in their skills and knowledge bases. Policies to strengthen the innovative capabilities of local firms are equally important. To reap the benefits of integration into global innovation networks requires an active involvement of local, regional, and central government agencies, as well as a variety of intermediate institutions. This involvement has to take on a very different form from earlier top-down "command economy" type industrial policies.

As an immediate policy instrument, it may be necessary to import missing critical skills from overseas. This could help to catalyze necessary reforms in the domestic innovation system. But most important are support policies for local firms through local supplier development, (co-funded) skill development, standards setting, policies on IPRs and the provision of investment and innovation finance through a variety of sources, including venture capital, and initial public offerings.[11]

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[11] An initial public offering is the first sale of stock by a private company to the public. Smaller, younger companies seeking capital to expand their businesses are the most frequent users of initial public offerings.

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R&D-related FDI in developing countries: implications for host countries

Prasada Reddy[1]

The internationalization of R&D is not a recent phenomenon. Since the 1960s, companies have been performing some kind of R&D activities outside their home countries for various reasons but, the magnitude, nature and scope of the overseas R&D performed in the past were limited. Much of such R&D was undertaken either to facilitate technology transfer by adapting parent firms' technology to local operating conditions or, to gain a greater share of the local markets by developing products that met the preferences of the local customers better.

In the 1990s, the globalization of corporate R&D attracted greater attention of economists and policy makers, mainly due to its changing features and its potential implications. The scope of work in overseas R&D units of TNCs has gone beyond adaptation tasks to encompass innovatory product development for global markets or even the performance of basic research to develop generic technologies.

The objective of this paper is to analyze the driving forces behind R&D-related FDI in developing countries by TNCs and its implications for the developing host countries, particularly for building up innovation capability.

1. Patterns and motives of the globalization of R&D

There are wide differences in the degree of globalization of corporate R&D between different industries. In

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[1] The views expressed in this study are those of the author and do not necessarily reflect the views of the United Nations, its Member States, or the Institutions to which the author is affiliated.

general, it is observed that technology-intensive industries, such as electronics, biotechnology, chemicals and pharmaceuticals tend to internationalize their strategic R&D to a greater degree than other industries (Reddy 1997). Globally, the pharmaceutical industry, followed by food and beverages, machinery, and transportation equipment manufacturing, show the highest levels of internationalization of R&D (Niosi 1999). In the case of Japanese TNCs, most of their R&D units abroad are in the electronic equipment, pharmaceutical and automotive industries (Odagiri and Yasuda 1996).

The significant increase in the overseas R&D activities of TNCs in recent years was motivated mainly by TNCs' aims to attain global competitiveness. Their new strategic approach involves recasting the roles of individual affiliates and their intra-group interdependencies. In the traditional approach, the scope of R&D performed by an affiliate had to fit within the framework of the bilateral relationship between the parent and the individual affiliate. However, the new approach involves performance of distinctive operations in a framework of interdependent networks of mutually supportive facilities (Pearce 1999: 160).

The growing trend of international technological alliances is another important element in the globalization of R&D. The traditional approach, using transaction costs as the basis, viewed that TNCs tend to develop technology in-house and internalize within their corporate networks by transferring technology to their own affiliates, rather than selling it to other companies. However, since the late 1980s, TNCs have been entering into technological alliances with foreign companies and research institutes in an effort to develop new technologies and products. This new strategy runs contrary to the strategy of internalization. Such alliances are viewed as evolving strategies of the TNCs, designed to successfully compete in a turbulent business environment.

According to Pearce (1999: 157) the growing importance of overseas R&D units in TNCs' strategies reflects:

- an increasing involvement in product development, at the expense of adaptation;
- an interdependent, rather than dependent, position of overseas laboratories in TNCs' technology programmes;
- increased relevance of supply-side influences (host country technology competencies, capacities and heritage); and,
- a decline of centralizing forces on R&D (e.g. economies of scale, communication and co-ordination problems, concerns of knowledge security).

The selection of locations for R&D by TNCs depends on several criteria. These include: proximity to a manufacturing site; the availability of local universities and professionals; the ability to build up a critical mass of local researchers (critical for global technological research); the attractiveness of sources of technical excellence, e.g. universities, customers or suppliers etc. and, the availability of excellent communication systems (de Meyer and Mizushima 1989). The choice of location of R&D also depends on the type of technology to be developed and the advantages of national scientific capacity. For instance, the United Kingdom has been attracting significant foreign R&D investments in the pharmaceutical industry, because of its high quality skills in the life sciences and in chemistry. Similarly, Germany has been a centre for foreign R&D activities in the electrical engineering and electronics industries, reflecting German excellence in these areas (Wortmann 1990).

The scope and level of technological activities carried out abroad by TNCs are determined by the national capabilities of both home and host countries. Cantwell and Janne (1999) suggest that when TNCs based in countries with more advanced technological capabilities in a given industry invest in less advanced countries in the same industry, they tend to differentiate their technological activities. Conversely, when TNCs based in less advanced countries move R&D abroad, they tend to specialize within the same areas as the parent company at home. They also suggest that the TNCs located in leading centres of excellence of a particular industry tend to build up specialization on the basis of the local technological capabilities in host countries. At the same time, TNCs located in less advanced centres tend to draw more on their home-country capabilities, by replicating their home specialization abroad.

The globalization of corporate R&D has been mainly limited to location of R&D units between developed countries but, globalization of corporate R&D continues to evolve as a phenomenon. In recent years, the globalization processes have been encompassing more industries, as well as more geographical areas. Hitherto uncommon locations are attracting R&D-related FDI by TNCs (Reddy 1993).

Since the mid-1980s, as an offshoot of the globalization of corporate R&D, TNCs have started performing some of their strategic R&D in some developing countries. TNCs involved in this new trend seem to be mostly those dealing with new technologies. This strategic move by TNCs is facilitated by the availability of large pools of trained manpower, at substantially lower wages compared to their counterparts in developed countries and, an adequate infrastructure.

The primary driving forces behind the new trends are:

- technology-related motives, i.e. to gain access to foreign science and technology (S&T) resources;
- cost-related motives, i.e. to exploit the cost differentials between different countries and,
- organization-related motives, i.e. rationalization of TNCs' internal operations, where an affiliate in a developing country is assigned a regional or a global product mandate.

The performance of strategic R&D, aimed at developing products for global/regional markets or mission-oriented basic research by TNCs, has implications for the innovatory capabilities of developing host countries (Reddy 1993).

2. Types of R&D units

The different types of R&D activities carried out by foreign affiliates of TNCs can be categorized into:

- Technology-transfer units, which facilitate the transfer of parents' technology to affiliates and, provide local technical services.
- Indigenous technology units, which develop new products for the local market, drawing on local technology.
- Global technology units, which develop new products and processes for main world markets.
- Corporate technology units, which generate basic technology of a long-term or exploratory nature for use by the parent company (Ronstadt 1977).
- Regional technology units, which develop products for regional markets. While markets worldwide are integrating in terms of standards and technologies, some regional clusters are also emerging. National markets in these regional clusters share some common features and needs for specialized products. Examples of this can be found in biotechnology, food processing (special types of food, taste, etc.), pharmaceuticals (drugs for regional diseases) or, in software development (Reddy and Sigurdson 1994).

3. Waves of R&D globalization

The evolution of the globalization of R&D can be analyzed in terms of waves (phases). Such a framework helps in a comprehensive understanding of globalization as a broader process, by analysing the driving forces in each time period, the type of R&D located abroad and, the potential impact on the host countries. Each wave represents a set of distinctive characteristic features, yet reveals the continuation from one wave to the other (Reddy 2000: 52-56). The division of time periods should be taken as approximate indications and not as precise cut-off dates.

a. The beginnings of the internationalization of R&D – the first wave in the 1960s

The number of firms performing R&D abroad in the 1960s and earlier was extremely small. Most of the R&D performed abroad was that of technology-transfer units. The driving force during this *first wave* was to gain entry into a market abroad. This required the adaptation of the product and process technologies to local conditions and the need for the continuous support of technical services. The establishment of technology-transfer units was considered a more cost-effective way of dealing with technical problems than sending R&D missions from headquarters. The categories of industries involved in this process were mostly mechanical, electrical and engineering, including automobile industries.

b. The growth of international corporate R&D –the second wave in the 1970s

By the 1970s, firms had started performing R&D abroad in a significant way. The main driving force was to increase the local market share abroad. This required increased sensitivity to local market differences to enhance competitiveness and TNCs' general move towards serving world markets. This was reflected in the fact that most of the R&D units abroad had been established through acquisitions of companies abroad (Behrman and Fischer 1980). Moreover, host-country governments, using industrial policies stipulating local-content, re-export or plant-location requirements, started pressurizing TNCs to increase technology transfer. These circumstances triggered what can be considered the *second wave* of the internationalization of R&D, which differed from the earlier wave in that an increasing number of indigenous technology units were set up to develop new and improved products for local markets. This type of activity was predominant in branded and packaged consumer goods, chemicals and allied products, etc.

c. From internationalization to globalization of R&D –the third wave in the 1980s

A number of major changes have been taking place since the 1980s in the nature and scope of R&D undertaken abroad by TNCs. Increasingly higher-order R&D, such as regional technology units, global technology units and corporate technology units, had been located abroad in what can be regarded as the *third wave* of globalization of R&D. Such R&D abroad is carried out as part of long-term corporate strategy and is often carried out through inter-organizational collaboration. Hence, the change in the term from internationalization to globalization, reflecting the characteristic differences from the earlier waves. The main driving forces for this phenomenon had been:

- first, the increasingly globalized basis of competition, aided by the convergence of consumer preferences worldwide, creating a need for learning;
- second, the increasing science-base of new technologies, necessitating multi-sourcing of technologies;
- third, the rationalization of TNCs' operations, assigning specific global roles to their affiliates abroad.

These trends are visible mainly in microelectronics, pharmaceuticals, biotechnology and new materials. The improvement of information and communication technologies and the flexibility of new science-based technologies, that allow de-linking of R&D and manufacturing activities, vastly facilitated this globalization process.

d. The evolving patterns of globalization of R&D -the fourth wave in the 1990s

The key driving forces for globalization of R&D since the 1990s have been the increasing demand for skilled scientists and rising R&D costs. These forces are triggering the *fourth wave* of globalization of R&D, encompassing some developing economies and countries in transition. The mismatch between the outputs of universities and the needs of industry is giving rise to shortages of research personnel throughout the developed world, especially in engineering fields related to electronics, automation and computer-aided development/manufacturing (OECD 1988), compelling companies to widen their research networks in order to tap more geographically dispersed scientific talent. The existence of an international market for investments in research, education and scientific and engineering personnel and the necessity of scientific knowledge for competitiveness are leading corporations to direct their investments to those geographical areas which can best meet their research needs, including developing countries. TNCs are also sensitive to variations in the cost of R&D inputs from country to country (Mansfield et al. 1979). This move by TNCs is facilitated by the availability of large pools of scientifically and technically trained manpower in these countries at substantially lower wages *vis-à-vis* the developed countries. The categories of industries involved are microelectronics, biotechnology, pharmaceuticals, chemicals and software.

4. Implications for developing host countries

A few studies have been done on the impact of TNCs' R&D activities on the host country. Whatever the implications suggested by these studies, they tend to be postulated as hypotheses. Whether the performance of R&D by TNCs contributes to the enhancement or retardation of independent technological capability of the host country is a complicated issue.

In general, there are now two opposing views regarding the impact of TNCs' R&D on the host countries. One view considers inward R&D-related FDI to be beneficial to economic growth, by providing technology and managerial skills, which in turn create indirect positive effects for the host country at a lower cost. These positive effects include technical support to local suppliers and customers and contract jobs from foreign R&D units to local R&D organizations, etc. The counter view argues that R&D activities by foreign firms tend to tap into unique local R&D resources with little or no benefit to the host country. Concentrating on problems of little relevance to the local economy, they may be a little more than disguised "brain-drain", diverting scarce technical resources from more useful purposes (Dunning 1992).

In the context of developing countries, where the scientific and technical resources are underutilized, the counterview may lose strength. The benefits are larger, while the costs involved may be smaller. In the case of developing host countries, the cost factor may be that such R&D activities may create islands of high-technology enclaves with little diffusion of knowledge into the economy. However, over the long term knowledge and skills cannot be isolated. The mobility of researchers, the need for local procurement of persons and materials etc. are bound to diffuse technologies throughout the economy (Reddy 1993).

In general an R&D affiliate is expected to benefit the host country in three ways (Pearce 1989).

- By adapting products and processes to local conditions, it improves the efficiency of the local manufacturing facilities. This, in turn, may benefit the host country by increasing the size of output, employment and tax revenue and, the consumers would have access to products better suited to their requirements, at perhaps a lower price.
- By assisting the local production affiliate to introduce a new product, R&D may help to improve the export performance of the affiliate.
- Through its linkages with the local S&T community, an R&D unit derives benefit as well as contributing to the widening of the scope of capabilities of local S&T resources.

While analysing the implications for the host countries, it is important to consider the type of R&D being performed and its direct and indirect effects. Depending on the type of R&D being carried out, the impact on the host country varies. Each type of R&D unit displays distinctive linkages with the local affiliate, the corporate headquarters and, with the local science and technology system. The stronger the ties with the local organizations, be it the firms or research institutes, the greater will be the diffusion of technology/knowledge into the host country.

The ties are virtually non-existent for a technology-transfer unit, whose main technology links are with the parent; somewhat strong for an indigenous technology unit, which may (but not always) to some extent draw on the local science and technology system to develop products particularly designed for the local market. In this type of R&D unit, its linkages with the local marketing function assume greater importance than linkages with the local S&T system; stronger for a global technology unit and strongest for a corporate technology unit. In these two types of R&D units, the primary motive being that of exploiting local sources of S&T that cannot be accessed easily from outside the country, strong local linkages are established (Westney 1988).

The quantity and quality of R&D performed abroad by a TNC, i.e. the degree of globalization depends on the type and cost of knowledge available abroad that is complementary to the TNC's operations, i.e. the degree of complementarity. The larger the degree of complementarity available abroad, the larger the degree of globalization. Similarly, the degree of integration of TNCs' activities in a host country depends on the degree of complementarity provided by that country. The larger the degree of complementary knowledge or skills available in a host country, the larger is the degree of integration. TNCs tend to locate R&D in countries that offer a knowledge base that is complementary to their home country's knowledge base. This is mainly because the home country still remains the base for the largest proportion of R&D activities and, a TNC by globalizing R&D either seeks to overcome shortages of specific inputs in the home country or, expand its knowledge base into related activities. So the larger the degree of complementarity between the home country and host country, the larger is the degree of globalization from the home country and the larger is the degree of integration with the host country.

On one hand, the location of R&D facilities by TNCs would increase the size of the technology-base of the host country, through the employment of local research personnel but, on the other hand, the recruitment of these resources by TNCs, may pre-empt their availability to domestic firms. The final impact depends on the type of R&D performed by the TNCs, the type of local resources used by them and, the supply conditions for such resources in the host economy (UNCTAD 1995).

The potential impact of R&D-related FDI on a developing host country can be classified into direct effects, spin-off effects and spillover effects.

a. Direct effects

- *Transfer of technology.* R&D-related FDI brings into the host country new equipment (e.g. laboratory machinery and testing equipment), transfer of application knowledge and new research methodologies to local scientists and engineers, and know-how relating to R&D management etc. While scientists and engineers in developing countries do possess the basic scientific and engineering knowledge, they often lack the skills to convert this knowledge into tangible products and processes. An inflow of R&D-related FDI helps the host country personnel in acquiring such application knowledge.

- *Subcontracting R&D to local research institutes and firms.* Depending on the type of R&D being conducted by an affiliate, it may sponsor research projects in local universities, by providing finances, equipment and training. For instance, the pharmaceutical TNC GlaxoSmithKline established a trust fund (S$31 million) for a drug-screening centre and another (S$30 million) for a neurobiology laboratory focusing on the brain in the Institute of Molecular and Cell Biology in Singapore.

b. Spin-off effects

- *Transfer of technology to local firms.* R&D affiliates of TNCs may transfer some technologies developed by them to local firms. During the course of R&D, an affiliate may develop some by-products that the TNC may not want to keep for itself. In such cases an affiliate may transfer such technologies to local firms for commercialization. For instance, AstraZeneca’s Research Centre India spent its initial two years of its establishment in developing reagents (the basic tools of recombinant DNA research) and transferred these technologies to two local scientists in India, who established a new company called GENEI (Gene

India) to commercialize these products. Prior to the establishment of GENEI, these products were being imported in refrigerated containers, which added costs and delays to biotechnology research in India. Now GENEI exports these products to several countries, including the United States. From being a net importer of these products, India has now become a net exporter. In addition, other organizations in India involved in biotechnology research benefit from low costs supplies and also avoid delays associated with imports. AstraZeneca gains by securing regular supplies at low costs.

- *Emergence of spin-off firms set up by former employees.* There are several cases of scientists working in an R&D affiliate leaving the TNC to set up their own subcontract R&D firms. The technical, commercial and managerial knowledge gained through work in the affiliate helps these scientists in setting up such new firms. Affiliates often support such former employees through awarding R&D contracts to them. For instance, Parallax Research of Singapore was established by a former research engineer of Hewlett Packard. Parallax now carries out subcontracted R&D for several TNCs, including Hewlett Packard, in the areas of mechanical and electromechanical systems design and development. For example, under such a subcontract Parallax designed and developed an integrated chip for infrared communications exclusively for Hewlett Packard.

- *Acquisition of new skills and knowledge by supplier firms.* TNCs' R&D activities are placing demands on their suppliers in host countries for new products and services. Consequently, these suppliers in the host countries are acquiring new skills and knowledge necessary to meet such demand either from other organizations located within the country and abroad or developing such products and services on their own. For instance, the inflow of R&D-related FDI placed demands on Indian architect firms to acquire new skills. The construction of R&D laboratories requires high technologies and skills (e.g. laboratories need to have rooms with highly sterile environments and/or rooms that can withstand earthquakes and fire and, are also aesthetically inspiring to researchers). Faced with this challenge, Indian architect firms have acquired these new skills/knowledge and are now competing for such contracts abroad.

c. Spillover effects

- *The emergence of a new class of entrepreneur*. One of the most important benefits is that international corporate R&D activities are infusing the scientific community in developing countries with commercial culture. R&D-related FDI opened up new opportunities for scientists and engineers in developing countries by training them in converting their theoretical knowledge into tangible products and processes and, by providing them with opportunities to become entrepreneurs by helping them set up subcontract R&D firms. The examples of GENEI and Parallax reflect this trend.

- *The emergence of an R&D culture in developing host countries*. Inflows of R&D-related FDI reinforce the R&D culture of the host economies. Local firms in host countries also tend to take up or increase innovation activities due to the demonstration effect of TNCs' R&D affiliates. For instance, although precise figures are not available, the R&D spending by Indian companies has gone up significantly since the 1990s, when the R&D-related FDI by TNCs started flowing into India. This is reflected in the increasing number of national and international patents granted to Indian companies and research institutes. India's spending on R&D as a proportion of GDP has also gone up to more than one per cent mainly because of private sector spending on R&D.

- *Competition for R&D personnel.* R&D affiliates of TNCs tend to attract the cream of the scientists and engineers in developing host countries through higher pay, better career prospects and challenging tasks. This leaves only the relatively less talented people for recruitment by host countries' firms and research institutes. This may affect the quality and quantity of R&D focused on national social and economic objectives. However, this negative effect is mitigated to a large extent through the mobility of people from TNCs' affiliates to set up their own firms or join other large local firms at a more senior level.

5. Conclusion

The emergence of R&D-related FDI seems to offer some fresh opportunities for developing host countries. R&D investments can bring international prestige as well as employment opportunities for the highly educated. Potentially, international R&D would be also an impetus to the R&D being performed by the indigenous industry. Moreover, by creating a proper framework, developing host countries could persuade the TNCs to commercialize the research results in the country, making the benefits larger and quicker. However, for the host economy to show substantial improvements, the capabilities of the majority of the population must be enhanced.

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