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Carriers of Cross-Border Knowledge Diffusion: Information Technology and Global Production Networks

Dieter Ernst

Dieter Ernst is a Senior Fellow at the East-West Center. Previous affiliations include the OECD, Paris (as Senior Advisor); the Berkeley Roundtable on the International Economy (BRIE), at the University of California at Berkeley (Senior Fellow); and the Copenhagen Business School (SSF-Research Professor).

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INTRODUCTION

The study of innovation as a source of economic growth and development has reached a certain level of maturity. Basic principles are now well established within the economics profession: a focus on learning and innovation as major sources of economic growth is no longer a minority position. Some key concepts are beginning to shape policy debates in the OECD, the World Bank, and the European Commission (e.g., OECD, 1999). Yet, along with recognition comes the danger of misrepresentation. An example are currently fashionable writings on the *New Economy* or *Network Society* (e.g., Castells, 1996) that use innovation as an abstract metaphor for a revitalized capitalism with a human face. It is time to address some of these misconceptions that frustrate an effective policy implementation.

This paper suggests that more work is needed on the economic geography of innovation. An important weakness of this literature is a neglect of the *international dimension*[1]. Very little empirical and theoretical research has been done on the way globalization increases the mobility of innovation across national borders, and how such international knowledge linkages affect innovation management and innovation policies[2]. Equally important is a neglect of the role played by disruptive technological change, especially information technology (IT), as a driver of such processes. Both weaknesses are the subject of the paper[3].

We argue that IT and globalization have a *puzzling spatial* impact on innovation: Both reduce its spatial stickiness, enhancing the geographic dispersion of knowledge, while at the same time increasing the scope for agglomeration economies. This proposition runs counter to much of the established wisdom of the economic geography of innovation (e.g., Davelar and Nijkamp, 1997). A central proposition of the latter literature is that innovation, in contrast to most other stages of the value chain, is highly immobile: it remains tied to specific locations, despite a rapid geographic dispersion of markets, finance and production (e.g., Archibugi and Michie, 1995). The main reason for such *spatial stickiness* is the inter-active nature of innovation (e.g., Lundvall, 1988): it requires dense knowledge exchange between users and producers, much of it being tacit knowledge. Such *information-rich* transactions necessitate *localized clusters* within a nation, or even better, an industrial district, or micro- region (e.g., Porter, 1990; Lundvall, 1992; Saxenian, 1994; Markusen, 1998; Swann et al, 1998). This reflects the importance

[1] This constitutes a common weakness of economic theories of innovation and the firm: "…most of the work of scholars from these disciplines has not generally embraced an international dimension and, as a result, our understanding of the way resources are organized and distributed across national boundaries has been constricted." (Dunning, 1998, p.291)

[2] There are of course exceptions, like Patel and Pavitt, 1991; Chesnais, 1992; Pearce and Singh, 1992; Granstrand et al, 1993; Harrison, 1994; Storper, 1997; and, especially, Patel and Pavitt, 1999. Much of this literature however focuses on R&D within leading multinational corporations and neglects important other vehicles of knowledge diffusion. In a review of the spatial evolution of innovation systems, Chris Freeman (1997: p.50) for instance highlights the importance of international production and marketing networks. And Lundvall and Borras (1998: p.115) explicitly acknowledge that *national innovation systems* (NIS) can benefit from participating in "global networks". This issue however has remained at the margin of innovation studies.

[3] For a related paper that addresses these weaknesses from a developing countries` perspective, see Ernst, 2000c.

of *dynamic agglomeration economies*: co-location facilitates a continuous, intense and rapid exchange of new ideas about technical, organizational and production improvements.

This implies that knowledge and innovation do not easily migrate across borders: they do not automatically follow, once production moves. Even while globalization extends its reach beyond trade and finance, giving rise to an extensive relocation of production, this may not help to reduce the huge international gaps in knowledge and innovation. For industrial countries, the spatial stickiness of innovation may foster attempts to sustain their technological superiority. For developing countries however, spatial stickiness of innovation may fundamentally constrain their sources of growth, and hence perpetuate global inequality.

The paper sets out to qualify this argument. IT and globalization can act as powerful forces behind growing inequality. But the root cause may not necessarily be that knowledge is immobile. The real challenge is different: an increased mobility of firm-specific resources and capabilities across national boundaries may erode established patterns of *specialization* in certain locations, and the strengths of existing knowledge bases and capabilities. This may cause a loss of competitiveness, and hence a decline in growth and welfare. Yet, IT and globalization can also create new *opportunities* for weaker and smaller actors (whether firms, industrial districts and countries). To the degree that they enhance cross-border knowledge diffusion, these *international knowledge linkages* may help to *recharge domestic knowledge creation* and *industrial upgrading*, *provided* appropriate policies and support institutions are in place. We use this proposition as a focusing device for our analysis.

We first introduce a stylized model of globalization *drivers*, focusing on liberalization, information technology, and competition (part 1). We then concentrate on two spatial globalization impacts that reshape the geography of innovation: *concentrated dispersion* and *systemic integration*. In part 2, we highlight the puzzle of *concentrated dispersion*: agglomeration economies continue to matter, yet their spatial stickiness has been reduced. And in part 3, we argue that globalization has culminated in an important organizational innovation: the spread of global production networks (GPN) combines concentrated dispersion with systemic integration, creating *new opportunities* for international knowledge diffusion. We then use this framework to assess conflicting claims on how placing these networks on the Internet is likely to affect their geographic dispersion and international knowledge diffusion (part 4).

1. GLOBALIZATION DRIVERS

In order to explain how IT and globalization reshape the geography of innovation, we need a theory of globalization *drivers*. Our analysis focuses on *firm behavior*: Why is it that, despite the advantages of co-location, there has been a massive geographic dispersion of production and other stages of the value chain? What explains that agglomeration economies have to compete with conflicting determinants of location?

For instance, a substantial rise of labor costs in the home country and the existence of alternative lower-cost overseas locations may well result in a decision that

values such cost savings higher than possible proximity advantages at home. This is however only part of the story. The determinants of international production are more complex than is assumed by conventional economic theory. The need to reduce costs to offset an erosion of the home country comparative advantages is an important catalyst, but no more. More fundamental forces are at work.

We first review the debate on conflicting determinants of location (1.1.), highlight the importance of circular causation (1.2.), and introduce a stylized model of globalization drivers (1.3.). We then discuss the role of institutional change, focusing on liberalization (1.4.); demonstrate how IT has shaped globalization, both as a driver and as an enabling force (1.5.); and demonstrate how this affects competitive dynamics and firm behavior (1.6.).

1.1. Conflicting Determinants of Location

A *firm*-level perspective can help to explain why agglomeration economies have to compete with conflicting determinants of location. There is a rich body of literature that describes what benefits a firm can reap from a shift to international production[4]. For quite some time, the focus has been on two aspects: the penetration of protected markets through tariff-hopping investments and the exploitation of international factor cost differentials, primarily for labor. This has given rise to a peculiar pattern of international production where offshore production sites in low-cost locations are linked through triangular trade with the major markets in North America and Europe. The hallmark of this pattern of international production was that it led to a clear-cut division of labor and that locational decisions were shaped by fairly straightforward criteria.

Over time, it became clear that, while both market access and cost reduction remain important, they are no longer an exclusive concern. Today, international production involves a much more complex agenda. Market penetration and cost reduction have to be reconciled with a number of equally important requirements that encompass: the exploitation of uncertainty through improved operational flexibility (e.g., Kogut 1985; and Kogut and Kulatilaka, 1994); a compression of speed-to-market through reduced product development and product life cycles (e.g., Flaherty, 1986; Stalk and Hout, 1990; and Clark and Fujimoto, 1991); learning and the acquisition of specialized external capabilities (e.g., Antonelli, 1992; Kogut and Zander, 1993; Zander and Kogut, 1995; Coombs and Metcalfe, 1998; and Patel and Pavitt, 1999); and a shift of market penetration strategies from established to new and unknown markets (e.g., Christensen, 1997).

It is necessary to move beyond mono-causal and static explanations. Firms make investment decisions on the basis of several factors. Not only are these factors frequently interdependent, but they also differ across products and market segments, and their relative weight keeps changing over time[5]. For instance, labor costs and experience

[4] Good overviews are John et al, 1997, Dicken, 1992, and Dunning,1993.

[5] This is in line with evolutionary theories of firm behavior. Coriat and Dosi (1998: pages 105 and 110) for instance argue that the complexity of competitive requirements renders firm behavior "opaque". Equilibrium theory is unable to capture this essential feature: "most often, elegant equilibrium rationalizations have assumed away" the complex problem-solving tasks of management. "Remarkably, most breeds of economic theories focus primarily upon one single function, often trying to ´explain´ it on

matter for price-sensitive products with demanding production requirements. On the other hand, certain components and sub-assemblies require close interaction with customers, with the result that proximity is critical.

Of equal importance are changes over time: For instance, while low labor costs and the general business climate may be a primary concern at the point of entry, they are likely to give way to access to skills and an experienced labor force, and to close links with clients and suppliers. Finally, international labor cost differentials are not cast in iron. As the Asian crisis amply demonstrates, abrupt and drastic changes in exchange rates can produce quite dramatic reversals (e.g., Ernst, 2000d, and 2000e).

1.2. Circular Causation

We obviously need a theory that can take into account complex trade-offs between multiple explanatory variables. The concept of *circular causation*[6] makes it possible to capture possible trade-offs between conflicting determinants of locational behavior. The critical issue is under what conditions their interaction generates a *virtuous* rather than a *vicious circle*. While the former is necessary for learning and innovation, the latter is bound to *truncate* such attempts.

At the most fundamental level, we are looking at possible trade-offs between static efficiency requirements in resource allocation (the topic of neo-classical economics) and the dynamic requirements of learning and innovation (the topic of innovation theory). Current decisions on resource allocation influence future opportunities for innovation, while current decisions on innovation constrain future resource allocation. For instance, an exclusive focus on static efficiency considerations is likely to hinder innovation: as the latter requires large investment over long periods of time with highly uncertain outcomes, such investments would simply not materialize, if static efficiency considerations prevail. Vice versa, an exclusive focus on the dynamic requirements of learning and innovation could gravely threaten static allocation efficiency, and may give rise to monetary instability.

The concept of *circular causation* implies that learning and resource allocation could either be linked by *virtuous circles*, or conversely, they could be trapped in *vicious circles*. In the latter case, the system generates low rates of innovation and thus also low productivity improvements, irrespective of how efficient available resources are currently used. In other words, if a vicious circle exists, fulfilling the static efficiency requirements may well lead to persistent low growth.

1.3. A Stylized Model

We distinguish three factors that determine a firm´s exposure to globalization: institutions, technology, and competition. These factors we call *globalization drivers*[7].

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the grounds of the usual maximization cum equilibrium assumptions".

[6] This concept goes back to the work of a Swedish economist, Gunnar Myrdal, who received the Nobel price for his path-breaking work on development economics. This concept was later formalized by Nicolas Kaldor at Cambridge University.

[7] Each of these drivers obviously serves as a proxy for a bundle of factors that, in reality, are quite complex. We also need to emphasize that, in reality, these drivers closely interact.

The established procedure is to model technical change as providing the "original impetus" (Freeman, 1997: p.47), while institutions are largely treated as the dependent variable. This reflects a research agenda that attempts to highlight the importance of social and institutional change in the emergence and diffusion of major new technologies. Our model proceeds in a *reverse* order, taking *institutional change* as the starting-point. This reflects our different research agenda, which is to highlight drivers of globalization and their impact on locational behavior.

We also distinguish a third globalization driver, *competition*, which provides the missing link to firm behavior. Technical change, combined with liberalization have drastically changed the dynamics of competition; the latter reflect the combined impact of technology and institutions. Changes in competition, in turn, impinge directly on firm behavior, in terms of its *growth and diversification*, and, more specifically, in terms of *location* and *innovation*.

Our starting-point is *institutional change*. Douglas North (1996: p.12) defines *institutions* as "the rules of the game of a society that structure human interaction". They are composed of *formal rules* (statute law, common law, regulations), *informal constraints* (conventions, norms of behavior, and self-imposed codes of conduct), and the *enforcement characteristics* of both. Institutions shape the *allocation of resources,* the *rules of competition* and *firm behavior*[8]. Important economic institutions include, for instance, capital markets, labor markets, and corporate governance. Our primary concern are changes in such institutions that affect globalization.

1.4. Institutional Change: Liberalization

For our model, we take *liberalization* as a convenient short-hand for such changes: a progressive liberalization and deregulation of international trade and factor markets, especially related to finance, has acted as a powerful catalyst for globalization. Liberalization dates back to the early 1970s: it thrived in response to the breakdown of fixed exchange rate regimes and the failure of *Keynesianism* to cope with pervasive stagflation. To a large degree, it has been initiated by government policies. But there are also other actors that have played an important role: financial institutions; rating agencies; supra-national institutions like bi-lateral or multi-lateral investment treaties and regional integration schemes, like the EU or NAFTA[9]. In some countries with decentralized devolution of political power, regional governments can also play an important role.

Four main elements can be distinguished: trade liberalization; liberalization of capital flows; liberalization of FDI policies; and privatization. In the literature, each of them has been treated in isolation, giving rise to neatly separated debates. It is important

[8] Nelson and Winter`s concept of *organizational routines* (1982) is an attempt to trace the impact on the latter. Coriat and Dosi (1998) model firm behavior as embedded in a set of social relationships, rules and institutional constraints.

[9] For instance, financial institutions shape the "rules of the game", by constantly lobbying for *progressive liberalization*. By assigning market values through their "strong buy/buy/hold/sell" recommendations, financial institutions also intensify competition: they accelerate entry and exit, and contribute to a constant re-shuffling of assets and market positions.

however for our purposes to emphasize that they hang together. For instance 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 a 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. The rapid expansion of international capital flows has opened a Pandora box of *incentive tournaments*: "… many countries have increased their incentives with the intention of diverting investment away from competing host countries. Competition for FDI with incentives is pervasive not only among national governments, but also among sub-national authorities." (UNCTAD, 1998, p.103).

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. Large MNEs have been the primary beneficiaries: liberalization provides them with a greater range of choices for market entry between trade, licensing, subcontracting, franchising, etc (*locational specialization*); it provides better access to external resources and capabilities[10] that a firm needs to complement its core competencies (*outsourcing*); and it has reduced the constraints for a geographic dispersion of the value chain.

We also need to emphasize a perplexing result: as liberalization has been adopted as an almost universal policy doctrine, it has lost much of its earlier power to influence locational decisions. As their FDI policies become indistinguishable, host countries are forced to differentiate themselves by other means, and to implement much more aggressive policies. The result has been a rapid proliferation of *complementary* policies geared to *business facilitation* and the development of *created assets*. This explains why a replication of clustering effects at multiple locations is now a realistic option.

1.5. The Dual Impact of Information Technology

It is now time to introduce *technology*, especially changes in *enabling technologies*[11]. Our model highlights the dual impact of information technology (IT): it both increases the need and creates new opportunities for globalization. This argument is based on two *propositions*. First, the *cost* and *risk* of developing IT 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 information technologies (Kobrin, 1997, p.149). Of equal importance are the huge expenses for IT-based organizational innovations. (Ernst and O`Connor, 1992: chapter 1). 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 US market is large enough to amortize such huge expenses.

[10] *Resources* refer to *factor endowments* (natural resources and unskilled labor), while *capabilities* refer to *created assets* (e.g., skills, localized marketing intelligence and lower-cost support services).

[11] *Enabling technologies* are defined as "technologies that are widely used in various forms throughout the whole economy" and that require deep structural adjustments (Lipsey,1997:76). They include technologies for information, communication, materials, energy, and transportation.

A second proposition explains why international production rather than exports have become the main vehicle for international market share expansion. Partly this reflects the pace of liberalization: while originally international production was driven by the need to overcome protective barriers ("tariff-hopping"), over time liberalization has become a major pull factor. Of critical importance however has been the enabling role played by IT: it has substantially increased the *mobility*, i.e. *dispersion* of firm-specific resources and capabilities across national boundaries; it also provides greater scope for *cross-border linkages*, i.e. *integration*. This has substantially reduced the *friction of time* and *space*, both with regard to markets and production: a firm can now serve distant markets equally well as local producers; it can also now disperse its value chain across national borders, in order to select the most cost-effective location.

In addition, IT and related organizational innovations provide effective mechanisms for the international diffusion of knowledge that is required to establish, operate and continuously upgrade spatially dispersed locations. It is now possible to construct an infrastructure that can *link* together and *coordinate* economic transactions at distant locations. This has important implications for organizational choices and locational strategies of firms. In essence, IT fosters the development of leaner, meaner and more agile production systems that cut across firm boundaries and national borders. The underlying vision is that of a *network* of firms that is able to respond quickly to changing circumstances, even if much of its value chain has been dispersed (see part 3).

1.6. Competitive Dynamics and Firm Behavior

Technology together with liberalization have drastically changed the dynamics of competition. Again, we reduce the complexity of these changes and concentrate on two impacts: a broader geographic *scope* of competition; and a growing *complexity* of competitive requirements. Both change considerably the determinants of firm organization and location: firms are under growing pressure to outsource from foreign suppliers lower-cost, specialized capabilities that are complementary to their own competencies (e.g. Prahalad and Hamel, 1990).

Globalization has drastically expanded the *geographic scope*: Competition now cuts across national borders - a firm´s position in one country is no longer independent from its position in other countries. This has two implications. 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. Furthermore, competition is no longer restricted to very large European, American and Japanese firms: new firms from countries like Korea and Taiwan have entered the game that differ substantially in their approaches to competitive strategy. Finally, competition now also cuts across sector 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 has forced firms to engage in complex strategic games to pre-empt a competitor`s move. Intense price competition needs to be combined with product differentiation, in a situation where continuous price wars erode profit margins. Of critical importance however is speed-to-market: getting the right product to the highest volume segment of the market right on time can provide huge profits. Being late is a

disaster, which quite frequently may force a company out of business (Richardson, 1996; Ernst, 1998).

The result has been an increasing uncertainty and volatility, and a destabilization of established market leadership positions. This growing *complexity* of competition has changed the determinants of firm organization and location. The most important prerequisite for competitive survival now is *flexibility*, i.e. a capacity to adjust strategy and organization at short notice to often unexpected changes in markets, technology and competitors` strategies. As a result, competition today centers on a firm´s ability to build capabilities quicker and at less cost than its competitors (Kogut and Zander, 1993). The director of the Rank Xerox Research Centre at Cambridge/UK provides a concise description of this challenge: "..Both the pace and the acceleration of innovation are startling; nay terrifying....No-one can predict the ... range of skills which will need to be amassed to create and take advantage of the next revolution but one (and thinking about the next but one is what everyone is doing. The game is already over for the next)." (Anderson, 1997: pages 2 and 3).

No firm, not even a dominant market leader, can generate all the different capabilities internally that are necessary to cope with the requirements of global competition. Competitive success thus critically depends on a capacity to selectively source specialized capabilities *outside* the firm that can range from simple contract assembly to quite sophisticated design capabilities. This requires *a shift from individual to increasingly collective forms of organization*, "... from the legal entity known as the firm to the contractual network of firms tied together by mutual long-term interest." (Stopford, 1994, p.21) We now turn to the perplexing spatial impacts of globalization, and ask how they reshape the geography of innovation.

2. CHANGING AGGLOMERATION ECONOMIES: CONCENTRATED DISPERSION

2.1. The Agglomeration Economies Argument

Proximity exerts a powerful constraining effect on the location of economic activities: industries tend to agglomerate and cluster in particular geographic locations, giving rise to persistent patterns of national and regional specialization. Alfred Marshall´s pioneering concept of *externalities* (1890/1916, p.271) helps to identify both static and dynamic economies of agglomeration. In Marshall´s view, the latter is clearly the decisive advantage[12]. While *static* agglomeration economies focus on *efficiency* gains resulting from scale economies, transaction and transport costs, and input-output linkages, *dynamic* agglomeration economies highlight the central role of learning and knowledge creation.

[12] Marshall emphasizes three advantages of an *industrial district*: i) it provides a pool of skilled workers with industry-specific capabilities; ii) intermediate inputs, especially non-tradable ones, are provided by local suppliers; and iii) there is a continuous, intense and rapid exchange of new ideas about technical, organizational and production improvements.

Marshall´s important observations have been forgotten for a long time: neo-classical economists have neglected until recently the agglomeration or clustering of related activities. Since Krugman (1991a, 1991b, 1995), economic geography has been re-established as a respectable topic for mainstream economists. This has brought back into economic theory *increasing returns* and other anomalies like the *path dependency* of spatial location. Unfortunately, these debates have remained trapped in the static efficiency paradigm and miss the importance of knowledge and learning[13].

There is however now a growing literature that analyzes the *dynamics* of spatial agglomeration. It is argued that clustering effects are particularly important for *knowledge externalities* and *spill-overs* (Lundvall, 1988; Porter, 1990; Enright, 1998; Spender, 1998; and Porter and Sølvell, 1998). Concentrations of companies succeed when they cooperate as well as compete; the focus of cooperation is on the sharing of knowledge, skills and technologies among the companies and with public agencies.

2.2. The Puzzle of Concentrated Dispersion

Attempts to construct a neo-Marshallian agglomeration theory are a positive development, as long as we remain conscious of some inherent limitations. It is not possible to use this concept today without substantial changes[14]. We need an explicit analysis of the impact of globalization on agglomeration economies and on international knowledge diffusion. Research on globalization has clearly established that, despite the advantages of co-location, geographic dispersion has occurred on a massive scale. This reflects a shift in the carriers of globalization: while intra-industry trade dominated till the mid-1980s, since then, international production has grown considerably faster than international trade[15]. By the 1990s, sales of foreign affiliates of multinational enterprises (MNEs) far outpaced exports as the principal vehicle to deliver goods and services to foreign markets.

It is important to emphasize that globalization should not be reduced to geographic dispersion. In contrast to the assumptions of convergence theory, globalization does not lead to the wonderland of a "borderless world" (Ohmae, 1991) where capital, knowledge and other resources move freely around the globe, acting as a

[13] For Krugman (1991a and b), agglomeration in essence results from three factors: i) substantial *increasing* returns to scale - both at the level of the single firm (*internal* economies) and the industry (*external* economies). ii) Sufficiently low transport costs; and iii) large local demand. Proximity matters, resulting in agglomeration, once these three factors interact. For an excellent critique of the "New `Geographical` Turn in Economics", see Martin, 1999.

[14] After all, Marshall´s analysis was shaped by value judgments which reflect a peculiar historical concern of late 19th century Britain: Will Britain be able to survive the new and aggressive competition from emerging nations such as the US and Germany, with their highly concentrated industries? Marshall believed that "a proliferation of small-scale proprietary enterprises was both a morally superior form of industrial organization and more favorable to economic development. … The implication was that economic development did not require concentrations of power within industry " (Lazonick, 1999, p. 10), like in the US and Germany.

[15] During the 1980s, FDI flows quadrupled, growing three times faster than trade flows, and almost four times faster than GDP. Growth has been less impressive though for FDI outward stock, which constitutes the capital base for MNE operations: it was 21% between 1986-1990, (in current prices), fell to 10.3 % between 1991 -1995, and increased again to 11.5% (1996) and 13.7% (1997) (UNCTAD 1998, table I.1.)

powerful force of equalization[16]. Globalization does not rescind the gravitational forces of geography. It has given rise to "ever more finely grained patterns of locational differentiation and specialization" (Scott, 1998: 399). Inequality and diversity prevail. A breath-taking speed of geographic dispersion has been combined with *spatial concentration*: much of the recent cross-border extension of manufacturing and services has been concentrated on a handful of *specialized local clusters*, both within the Triad and some so-called emerging economies, especially in East Asia.

Globalization thus poses some important *puzzles* that need to be addressed in a revised agglomeration theory: What factors explain that some value chain activities are more prone to geographic dispersion, while others are more sticky? Why is it that agglomeration economies are no longer restricted to the home country basis? What makes it possible to reproduce certain co-location effects at overseas locations? And what explains the creation of dense cross-border linkages between these locations that facilitate cross-border knowledge diffusion?

2.3. Empirical Evidence

Concentrated dispersion can be found in all globalized industries, such as cars (e.g., Florida and Sturgeon, 1999, and Noble, 1999), textiles (e.g., Gereffi, 1999), food**,** financial services, and most sectors of the electronics industry (e.g., Ernst, 1997b and 2000a). Take for instance the *hard disk drive (HDD)* industry which provides an example both for the breath-taking speed of geographic dispersion, as well as for its spatial concentration (Ernst, 1997b) Until the early 1980s, almost all HDD production was concentrated in the U.S., with limited additional production facilities in Japan and Europe. Today, only 1 percent of the final assembly of HDDs has remained in the US, while Southeast Asia dominates with almost 70% of world production, based on units shipped. Slightly less than half of the world´s disk drives come from Singapore, with most of the rest of the region´s production being concentrated in Malaysia, Thailand, and the Philippines.

Let us take a closer look at firm-level developments. Seagate, the current industry leader provides a good example of *concentrated dispersion* (Ernst, 1998). Today, Seagate operates 22 plants worldwide: 14 of these plants, i.e. 64% of the total, are located in Asia. Asia's share in Seagate's worldwide production capacity has increased from roughly 35% in 1990 to slightly more than 61% in 1995 - an incredible speed of expansion. Concentrated dispersion is also reflected in the regional breakdown of Seagate's employment. Asia's share increased from around 70% in 1990 to more than 85% in 1995.

The fact that Asia's share in employment is substantially higher than its share in capacity, while the opposite is true for the US, indicates a clear-cut division of labor: volume manufacturing and the production of low- and mid-range components has been shifted to Asia, while the US retains the high-end, knowledge-intensive stages of the value chain, especially hardcore R&D. We need to add a further aspect: an extreme spatial concentration *within* East Asia. Slightly more than 92% of Seagate's capacity in Asia is concentrated in three locations: in Bangkok (almost 32%), Penang (more than

[16] For a critique, see Boyer, 1996; and Ernst and Ravenhill, 1999

30%) and Singapore (a bit less than 30%). And almost 50% (26,000 out of 55,000) of Seagate's Asian employment is concentrated in its plant in the outskirts of Bangkok. This indicates that Bangkok is the centre for low labor cost volume manufacturing. Next comes Singapore with more than 27% (15,000), substantially more than Malaysia's 16% (9,000 people). For both Singapore and Malaysia, the low ratio of employment relative to its share in Seagate's production capacity indicates that production facilities have been rapidly automated and include now higher-end manufacturing activities such as component manufacturing.

Over time, Seagate has developed a quite articulate regional division of labor in East Asia. Bottom-end work is done in Indonesia and China. Malaysian and Thai plants make components and specialize in partial assembly. Singapore is the centre of gravity of this regional production network: its focus is on higher-end products and some important coordination and support functions. It completes the regional production network, by adding testing, which requires precision.

In short, rapid cross-border *dispersion* coexists with *agglomeration*. Globalization often occurs as an *extension* of national clusters across national borders. This implies two things: First, some stages of the value chain are internationally dispersed, while others remain concentrated. And second, the internationally dispersed activities typically congregate in a limited number of overseas clusters. This clearly indicates that agglomeration economies continue to matter. What needs to be explained however is *how they have changed under the impact of globalization*. There is a growing literature that explains the *bifurcation* of geographic location patterns along functional activities (Audretsch and Feldman, 1996, McKendrick, 1998) or value-chain stages (Dicken, 1992; Ernst, 1997b). The essential point is that such distinctions should be made not on the basis of different industries, but rather for different value chain stages[17].

Concentrated dispersion thus raises an important question: What factors explain that some value-chain activities are more prone to geographic dispersion, while others are more prone to proximity constraints? The usual suspects of course are differences in labor costs and knowledge-intensity. There is a strong presumption that high-wage and more knowledge-intensive activities are more prone to agglomeration effects, and hence resistant to geographic dispersion. By the same token, geographic dispersion can be expected to be most prominent for low-wage, and low-skill value chain activities.

2.4. Diverse Agglomeration Propensities

There is nothing surprising about these propositions - this is precisely what one would expect from an agglomeration economies perspective. This would seem to imply that a clear-cut separation is possible between low-end activities that are highly

[17] Much research on *industrial restructuring* has been based on a distinction between low-wage, low-skill *sun-set* industries and high-wage, high-skill *sunrise* industries. Such simple dichotomies have failed to produce convincing results, for two reasons: First, there are low-wage, low-skill value stages in even the most high-tech industry, and high-wage, high-skill activities exist even in so-called traditional industries like textiles (Ernst, Ganiatsos and Mytelka, 1998). Second, both the capability requirements and the boundaries of a particular "*industry"* keep changing over time, which makes an analytical focus on the industry level even more problematic.

dispersed, and knowledge-intensive ones that require localized clusters. Yet, reality is considerably more messy. An important complication results from the *diversity* of agglomeration propensities: co-location requirements differ across industries and product markets; they also differ across firms. Take first industry-specific features: co-location becomes more important, the greater an industry`s volatility, i.e. the shorter its product-life cycle (PLC), the quicker the required speed-to-market, and the greater the number of design changes. Yet, such co-location can occur at different places.

This is borne out by the example of the hard disk drive industry. Due to its high volatility, HDD assemblers cannot afford to have a geographically extended supply chain. Hence the importance for suppliers to locate close to the main drive assemblers (Ernst, 1997b; McKendrick, 1998). During the early stages of this industry, this implied *co-location at home* (primarily around IBM´s San José facility in California). We have seen that globalization has given rise to the concentrated international dispersion of such clusters.

Agglomeration propensities also differ by type of supplier[18]. There is no need for close interaction with suppliers of standard equipment and components. Intense interaction is essential however for the client´s relation with high-end suppliers (*technology setters*). Suppose the client has established an overseas affiliate. Here again, globalization has broadened the co-location options. Interaction does not need to be localized, i.e. it does not need to occur on the spot, at the client´s overseas facility. It frequently takes place at the client`s or the supplier`s home facility.

Intense *localized* interaction (i.e. interaction on the spot) is necessary only for newly established and still relatively weak suppliers (*technology takers)* who need to be nurtured till they can stand on their own feet. In information industries, *technology takers* are frequently used as second sources. Their main purpose is to provide the client with a price leverage against suppliers who are *technology setters* and who are inclined to charge premium prices. *Technology takers* are also used as capacity buffers, especially when the technology setters resist client requests for price cuts.

Probably the most important caveat to the agglomeration economies argument is that dispersion is no longer restricted to lower-end activities. This becomes clear when we look at an important organizational innovation, GPN, and its role as a carrier of cross-border knowledge diffusion.

3. GLOBAL PRODUCTION NETWORKS: KNOWLEDGE DIFFUSION THROUGH SYSTEMIC INTEGRATION

[18] Williamson´s concept of site specificity, a particular form of physical asset specificity, provides a formal treatment of this issue. A fundamental weakness however is the theory´s inherent incapacity to address the issue of innovation. As Williamson himself explains:" The introduction of innovation plainly complicates the earlier-described assignment of transactions to markets and hierarchies based entirely on an examination of their asset specificity qualities. Indeed, the study of economic organization in a regime of rapid innovation poses much more difficult issues than those addressed here." (1985: 143). In the final analysis, Williamson`s theory explains the firm as a response to market failure: "The cause of this market failure is "asset specificity" - a technological condition that is given to the firm." (Lazonick, 1999: 22)

Concentrated dispersion goes hand in hand with increasingly complex and *systemic forms of integration* through global production networks (GPN). These networks are a response to the demanding coordination requirements of geographic dispersion: they *integrate* the dispersed supply and customer bases of a large, multi-divisional MNE (the *network flagship*), i.e. its subsidiaries, affiliates and joint ventures, its suppliers and subcontractors, its distribution channels and value-added resellers, as well as its R&D alliances and a variety of cooperative agreements, such as standards consortia[19].

A global *network flagship company* breaks down the value chain into a variety of discrete functions and locates them wherever they can be carried out most effectively, where they improve the firm's access to resources and capabilities, and where they are needed to facilitate the penetration of important growth markets. The main purpose is to *gain quick access to lower-cost foreign capabilities that are complementary to the firm´s own competencies*. This reflects increasing pressures to exploit *complementarities* that result from the *systemic* nature of knowledge (Antonelli, 1999).

Under certain conditions, these networks may enhance the *migration* of *knowledge across firm boundaries* and *national borders*; they may also improve the opportunities for knowledge sharing and interactive learning *without* co-location. We describe key features of *systemic integration*: an increasing *scope* of international *linkages* (3.1.), and a growing *intensity* of such linkages (3.2.), and highlight how global production networks (GPN) enhance international knowledge diffusion (3.3.)

3.1. Scope of Linkages

One reason to talk about systemic integration is a substantially broadened *scope* for international linkages: a GPN encompasses both *intra*-firm and *inter*-firm linkages; creates a diversity of network participants; links together *multiple* locations; and covers a variety of value chain stages, including higher-end, and more *knowledge-intensive* ones.

This raises a number of important issues that are highly contested in the literature. For instance, GPN do not necessarily give rise to less hierarchical forms of firm organization (as predicted for instance in Bartlett and Ghoshal, 1989). Firms also differ in their access to and in their position within such networks, and hence face very different challenges. We use a *taxonomy* of network participants that distinguishes various hierarchical layers that range from *flagship companies* that dominate such networks, down to a variety of usually smaller, local network participants. The flagship is at the heart of a network: it "… provides … strategic and organizational leadership…beyond the resources that, from an accounting perspective, lie directly under… (its)…management control." (Rugman, 1997: 182)

The strategy of the flagship company thus directly affects the growth, the strategic direction and network position of lower-end participants, like specialized

[19] The concept of a *global production network* (GPN) captures the spread of the value chain across firm boundaries and national borders. It may, or may not, involve ownership of equity stakes. For details, see e.g., Ernst, 1994b, 1997a, 1997b, 1998, and 2000a. For empirical case studies on diverse GPN, see Ernst and Ravenhill, 1999, and various chapters in Borrus, Ernst and Haggard (eds.), 2000.

suppliers and subcontractors. The *flagship* derives its strength from its *control* over critical resources and capabilities, and from its capacity to *coordinate* transactions between the different network nodes. Both are the sources of its superior capacity for generating economic rents[20]. This taxonomy helps us to distinguish the different capacities of these firms to reap potential network benefits, and the institutions and policies required to support weaker network participants.

One critical capability for instance is the intellectual property and knowledge associated with setting, maintaining and continuously upgrading a de facto market standard. This requires perpetual improvements in product features, functionality, performance, cost and quality. It is such "complementary assets" (Teece, 1986) that the flagship increasingly *outsources*. This has given rise to a number of organizational innovations that culminate in the spread of GPN. Take recent developments in the electronics industry, which has become the most important breeding ground for a *New Industrial Organization* model (e.g., Chandler, et al, 1998). For instance, for a typical flagship in the PC business, the cost of components, software and services purchased from outside, has increased from less than 60 percent to more than 80 percent of total (ex factory) production costs (Ernst and O´Connor, 1992, chapter I). As external sourcing relations become geographically dispersed and increasingly complex, they are fraught with very high coordination costs: some firms report that the cost of coordinating such outside relations can exceed in-house manufacturing costs[21]. As a result, the focus of *cost reduction* strategies is shifting from scale economies in manufacturing to a reduction of the cost of global sourcing.

In the electronics industry, this has given rise to a proliferation of specialized suppliers, segmenting the industry into separate, yet closely interacting horizontal layers (Grove, 1996). The initial catalyst was the availability of standard components, which allows for a change in computer design away from centralized (IBM mainframe) to decentralized architectures (PC, and PC-related networks). As a result, new options emerged for outsourcing, transforming an erstwhile vertically integrated industry into horizontally disintegrated, yet closely interacting market segments, e.g., integrated circuits, board assembly, disk drives, operating systems, applications software, and networking equipment (Sturgeon, forthcoming, and Luethje, 1999).

The network flagship outsources not only manufacturing, but also a variety of high-end, knowledge-intensive support services. Most research on the location of knowledge-intensive activities has focused on the role of R&D, but this may be a too narrow focus (for details, see Ernst, 2000b). It is necessary to cast the net wider and to analyze the geographic dispersion of *cross-functional*, *knowledge-intensive support services* that are intrinsically linked with production. Even if these activities do not

[20] We refer of course to Penrose-type rents. Spender (1998, p.433) demonstrates that "… each type of knowledge can, in principle, be associated with a different kind of rent and competitive advantage." Tacit social knowledge (which Spender calls collective) is of critical importance: "The collective knowledge which develops as key players interact under conditions of uncertainty leads to Penrose rents, so labelled because such activity-based learning lies at the core of her theory of the growth of the firm."

[21] Such costs are typically defined as "... all incremental cost associated with dealing with suppliers remote from the initial design site and/or the final assembly site", with communication costs and administrative overheads absorbing the largest share (Ernst and O'Connor, 1992, ibid.)

involve formal R&D, they may still give rise to considerable learning and innovation. The latter include for instance trial production (prototyping and ramping-up), tooling and equipment, benchmarking of productivity, testing, process adaptation, product customization and supply chain coordination.

The result is that an increasing share of the value-added shifts across the boundaries of the firm as well as across national borders. This necessitates dense linkages between geographically dispersed, yet concentrated and locally specialized clusters, and their integration into GPN.

3.2. Intensity of Linkages

Systemic integration also implies that linkages between any two countries A and B are no longer secondary, quasi optional to their domestic linkages. Instead, existing clusters in both countries *supplement* each other and may experience mutual inter-penetration[22]. Systemic integration implies that *international linkages are essential for the continuous growth of a localized cluster*.

This is self-evident for the *suppliers*, whose growth and strategic direction is heavily determined by the *network flagship*. Dependence however also works the other way round. To the degree that the flagship has moved to *global sourcing*, it may no longer have any credible domestic suppliers. This implies an *erosion* of the *collective knowledge*, which used to be a characteristic feature of the lead firm´s home location. In some cases, that collective knowledge may have migrated for good to the supplier`s overseas cluster(s).

The semiconductor industry provides a typical example (Ernst, 1983 and 1997b, chapter IV). Since the 1970s, the leading American producers had moved much of their final assembly and testing to Asia, with the result that knowledge had to follow suit. Take the case of Texas Instruments: "As far as assembly and testing are concerned we have more expertise here [i.e. in Malaysia] than we have in the U.S. We sometimes have to send our Malaysian engineers to the States to solve their problems."[23] In the case of Intel's Penang subsidiary, such expertise became particularly strong for the design and production of specialized automated assembly equipment. When Intel, in 1983, set up highly automated assembly plants in Chandler/Arizona and in Ireland, the company had to rely on senior Malaysian engineers from its Penang affiliate for plant lay-out, equipment design, as well as for sorting out technical teething problems[24]. Intel Penang even claims that the first manager of its Mechanisation and Automation group has been seconded to automate Intel's wafer fabrication lines in the United States and that its automation team makes substantial contributions to upgrade the level of automation in Intel's worldwide operations.

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[22] *Partial* integration is characterized by a loose patchwork of arms´-length trade and stand-alone, unrelated investment projects. Most of these focus either on access to domestic markets or on exploiting particular resources (cheap labor). They are *footloose*, in the sense that they are prone to rapid closure and redeployment. Partial integration implies a limited scope for international specialization. This is due to an absence of interactions across functions and locations, and to a lack of coordination.

[23] Author's interview at Texas Instruments Malaysia, May 1984

[24] Author´s interview at Intel Penang (April 1992).

Over time, much of this knowledge has moved out of inidividual subsidiaries and has become widely diffused across different network nodes, especially in East Asia. The irony is that, today, chip assembly is no longer the uninspiring "back-end" of the semiconductor industry. Assembly and packaging technologies in this industry have become highly complex and play an important role for yields and performance features of leading-edge devices. Much of the knowledge required for designing innovative new IC packaging technologies has migrated to companies in Korea (Anam Industrial, the world's largest IC contract assembler being a prime example), Taiwan, and Singapore that now are among the leaders in IC packaging design.

The evolution of "Silicon Valley" provides another example of the growing density of international knowledge linkages. This region has gone through various *incarnations*. Originally, its main function was to churn out "chips and computers", i.e. to provide the basic inputs for the global electronics industry. Its economic *structure* was defined by a narrow product specialization, the incessant proliferation of new start-up companies, and *disintegrated* forms of firm organization: limited interaction within the firm between product development and production was compensated by a heavy reliance on the region`s sophisticated knowledge base. Saxenian (1994:5) for instances argues that, while the region´s *market* orientation is *global*, its production and innovation system remains primarily local.

This distinction may have made sense during the early stages of development of the region. It is no longer valid. Today, Silicon Valley is a highly diversified industrial region with a focus on two main functions: to connect and coordinate a variety of international linkages, both tangible and intangible ones. This region now critically depends on its position as the source and control centre of a dense web of GPN that provide access to lower-cost overseas supply bases, global labor markets for engineering talent, and (potential) growth markets. Such international linkages can recharge local linkages. They provide important opportunities for international knowledge sourcing - a possible explanation for Silicon Valley´s apparently inexhaustible upgrading capacity[25].

3.3. New Opportunities for International Knowledge Diffusion

We have seen that the main purpose of GPN is to gain quick access to lower-cost foreign capabilities that are complementary to the flagship´s own competencies. To mobilize and harness these external capabilities, flagships are forced to accept a certain *dispersion* of the value chain. They also must broaden their capability transfer to individual nodes of their GPN. The (often unintended) result is a creeping *migration of knowledge* to external actors abroad. This opens *new opportunities* for international knowledge linkages that change the geography of innovation.

[25] A good example of such a research agenda is provided by AnnoLee Saxenian whose earlier work on informal peer group networks in Silicon Valley (Saxenian, 1994) has made an important contribution to the debate on *localized* agglomeration economies. She has now moved on to study *international* linkages: the dense links between the Valley and Taiwan, the source of a large number of Silicon Valley`s circuit designer and computer engineers (Saxenian, 1999). For a case study of how Taiwan`s computer industry has benefited from such international knowledge linkages, see Ernst , 2000f.

A GPN can create a *virtuous circle* of international knowledge diffusion for two reasons. *First*, it increases the length of a firm's value chain, as well as its logistical complexity. This creates new gaps and interstices that can be addressed by small, specialized suppliers. While in some cases (like for instance "screw-driver" contract assembly), such entry may be short-lived, this is not necessarily so. Outsourcing requirements have become more demanding and have forced specialized suppliers to develop their capabilities. Over time, they may be able to upgrade their position from simple contract manufacturers to providers of integrated service packages, and hence increase the benefits that they can reap from network participation.

A typical example is Solectron, the world´s largest electronics manufacturing services company that we mentioned before. Founded in 1977 as a tiny contract manufacturer of electronic controllers for solar energy equipment, it only began to grow once it moved into circuit board assembly for the PC industry, acting as a low-cost buffer for the periodic capacity deficits of large electronics equipment producers. Given the low entry barriers of this business, this market was soon inundated with lower-cost competitors. Competitive survival required a focus on quality and speed, necessitating substantial investments in assembly automation (surface-mount-technology), leading-edge process technology, and training. This high-risk strategy paid off, as it allowed Solectron to move up the ladder in the contractor hierarchy and to a become a preferred supplier of leading electronics companies. This in turn required investments in overseas facilities (geographic dispersion) to provide manufacturing and design services where required. Since the late 1990s, the company has further upgraded its capabilities. It defines itself now as a global supply chain facilitator: "…customers can turn to Solectron at any stage of the supply chain, anywhere in the world, and get the highest-quality, most flexible solutions to optimize their existing supply chains (Solectron, 2000: 1).

Second, once a network supplier successfully upgrades its capabilities, this creates further pressure for a continuous migration of knowledge-intensive, higher value-added support activities to individual network nodes. This may also include engineering, product and process development. This reflects the increasingly demanding competitive requirements. In the electronics industry for instance, product-life-cycles have been cut to six months, and sometimes less (Ernst, 1998). Overseas production thus frequently occurs soon after the launching of new products. This is only possible if key design information is shared more freely between the network flagship and its overseas affiliates and suppliers. Speed-to-market requires that engineers across the different nodes of an GPN are plugged into the lead company´s design debates (both on-line and face-to-face) on a regular basis.

All of this implies that network flagships now have a vested interest in the formation of regional clusters of specialized capabilities that are located within or in close proximity to their main growth markets. Globalization typically has led to the development of regionally integrated GPN in North America, Europe, Japan, East Asia (China, South Korea and Taiwan) and Southeast Asia (the ASEAN region) (Ernst, 1997 a and 1997b). This raises two important questions that we will address in the following section: What changes have occurred in the spatial dispersion of these networks, due to the New Industrial Revolution in information and communication technology, especially the Internet? And how has this affected the capacity of such networks to act as carriers of international knowledge diffusion?

4. PLACING THE NETS ON THE WEB - ASSESSING CONFLICTING CLAIMS ON POSSIBLE IMPACTS

We have seen that global production networks (GPN) have created considerable opportunities for international knowledge diffusion. This can provide smaller and weaker network participants (especially specialized suppliers) with access to state-of-the-art management approaches, as well as product and process technologies (e.g., Wong, 1991; Kim Linsu, 1992 and 1997; Ernst and O`Connor, 1989 and 1992; Ernst, 1994a; Hobday, 1995; Ernst, Ganiatsos and Mytelka, 1998; and Ernst, 2000 c). It is now also well established that *nationality* of ownership of network flagships as well as *sector*-specific features explain why some networks are more conducive than others for knowledge transfer (e.g., Ernst, 1997a; Ernst and Ravenhill, 1999; and Borrus, Ernst and Haggard, 2000).

That research however is no longer sufficient to guide policy debates for two reasons: it is much too narrowly focused on network arrangements that cover relatively low-end manufacturing activities; and the underlying empirical field research covers developments only through the early 1990s. Since then fundamental transformations have occurred in the organization of GPN in response to disruptive changes in technology and markets. There is great uncertainty how these transformations will affect the capacity of these networks to act as carriers of knowledge diffusion. Equally uncertain is how this will affect network access and network position especially for smaller, lower-tier network participants. Let us look at conflicting claims.

4.1. Pessimistic Scenario

A pessimistic scenario emphasizes potential negative implications that may increase the global knowledge divide. This scenario is based on three propositions. First, it is argued that the new "digital markets" created by the Internet will converge globally on a uniform model that comes close to the ideal markets of neo-classical economics and that requires American governance structures (e.g., Gates, 1999; Department of Commerce, 1998). In other words, the Internet may increase the "*marketization"* of network transactions (e.g., Evans, 1999).

A second, related proposition is that this provides new opportunities for a pervasive *rationalization* across the chain. Network flagships as well as first-tier suppliers are under increasing pressure to reduce the high cost of network coordination that results from multiple sourcing, duplication of tasks and excess capacity. Equally important is that suppliers are now confronted with much more demanding performance, efficiency and time-to-market requirements. All of this may have quite negative implications for lower-tier suppliers that do not have proprietary technology (*technology takers*). A third proposition argues that network entry barriers have increased: a shift has occurred from *partial* outsourcing, covering the nuts and bolts of manufacturing, to *systemic* outsourcing that includes knowledge-intensive support services, raising the capability requirements for lower-tier network participants.

Finally, a fourth proposition argues that, by bringing the market back into

network transactions, the Internet may have increased again the role played by agglomeration economies, hence placing a premium on proximity to major Western markets. If true, this would erode the competitiveness of network participants that are far away from these markets, like for instance Asian suppliers.

4.2. Optimistic Scenario

Alternatively, there is also a more optimistic scenario which emphasizes the new opportunities created by the Internet- based infrastructure for new entry and continuous upgrading by smaller players, both firms and districts. This scenario is based on the following propositions: First, the assumption that the Internet will lead to a convergence of network governance structures to the New American model is problematic (e.g., E-conomy, 1999). This assumption denies cross-national and regional variations in the pace of application of these technologies, resulting from differences in economic structures and institutions. It also denies the possibility of unequal access to such markets, and the need for corrective policy interventions. Even within the same industry and market segments, firms may use very different approaches in applying the Internet to GPN (e.g., Dedrick and Kraemer, 1999). Firms also differ in their access to and in their position within such networks, and in their capacity to reap network benefits, and hence face very different challenges.

Second, constraints to convergence translate into a more limited scope for the marketization of network transactions, which may at least slow down the pace of global supply chain rationalization. Third, the more demanding capability requirements that result from the shift to systemic outsourcing, are a real challenge, especially for lower-tier suppliers. Yet, they may as well provide new opportunities for reverse knowledge outsourcing. In line with our analysis in part 3, this may foster the integration of specialized network suppliers into the global knowledge creation circuit of the network flagship.

A fourth, and arguably the most important proposition to which we now turn our attention, addresses the impact of the Internet on knowledge diffusion.

4.3. Possible Impact on Knowledge Diffusion

There are strong expectations that the Internet may further reduce the friction of time and space for the exchange of knowledge, well beyond what has been achieved by earlier generations of IT. How realistic are these expectations?

It has been argued for instance that IT enhances both the incentives and the possibilities to codify knowledge, hence facilitating international knowledge diffusion (e.g, David and Foray, 1995). However, there remain substantial constraints: the very growth in the amount of information which is made accessible to economic agents increases the demand for skills in selecting and using information intelligently, which are mostly tacit in nature. For this reason tacit knowledge may become an even more important bottleneck, constraining the transfer of codified knowledge (Ernst and Lundvall, 2000). This is borne out by empirical research which shows that IT has substantially improved communication flows within MNEs: highly codifiable knowledge

can now be exchanged between different nodes of a GPN that are far away from each other (e.g., Hagstrøm, 1991; Antonelli, 1992). Until recently, this was true primarily for routine tasks at the operational level - cross border exchange remained constrained for decision-making and planning at the strategic level, as well as for control and information processing at the tactical level (Senker and Faulkner, 1996).

But this may now begin to change. More specifically, it is claimed that the Internet and multimedia can substantially reduce the constraints to the diffusion of *tacit* knowledge (e.g., Fransman, 1997; Antonelli, 1997). In principle, closer and smoother interaction can now be established between distant local clusters that are connected through GPN. The Internet may enhance a cluster`s learning and innovation potential by introducing *virtual players* and *processes* (Romano and Passiante, 1999). *Virtual players* are buyers, sellers, intermediaries and public institutions that may be located at multiple locations *outside* the cluster but which can interact on time with cluster participants. *Virtual processes* are interactive and real-time transactions, or other forms of communication that are required for supply chain management, demand management, process and product development.

Within a company, for instance, an *e-mail chain* (Gates, 1999) provides a mechanism that enables a firm to organize *virtual* brain-storming sessions among hundreds and even thousands of people, many of whom would never meet under normal circumstances. These unexpected and non-routine encounters can create unconventional, i.e. innovative approaches to a particular problem, which could not have been identified in the context of formal organizational mechanisms[26]. This facilitates innovation which "… occurs where differences meet" (Nielsen, 1999). It also accelerates knowledge creation, in the specific sense defined by Nonaka and Takeuchi (1995): the transformation of tacit to explicit and then again into tacit knowledge, as well as the spread of knowledge from the individual, to the group, the organization, and across organizational boundaries.

Of critical importance is the *spatial* impact: The e-mail chain makes it possible to quickly set up *virtual teams* that can engage in inter-active learning without necessarily being co-located. As a result of the transition from proprietary EDI to the Internet, *all* network participants can now *interact with each and every other participant*. For each of these different interactions, it is possible to adjust the richness of information, i.e. to *customize* it appropriately. "As new standards are developed and reach `critical mass´, they permit rich interpretation of information across a domain limited only by their universe of adoption" (Evans, 1999).

This gives rise to the familiar effect of *network externalities*: the more people adopt a standard, the more compelling it becomes. Improved connectivity and more open and universal standards may also provide new opportunities for *systemic rationalization*, both within the firm and in relation with other firms. *Within* the firm, functional information "silos" are being supplanted by Intranets. The Internet also provides new techniques to improve information flows and learning efficiency of *inter-firm networks*.

[26] This resembles Utterback`s (1974) concept of *unanticipated and unplanned encounters*, this time however *without* co-location in an industry cluster.

Finally, information flows can now be more easily separated from physical ones, creating new opportunities for global *outsourcing* that covers all stages of the value chain. Based on the Internet, such collaboration also encompasses knowledge-intensive support services, like supply chain management, logistics and engineering. The Internet has created a common platform that enables supply chain participants to cooperate in and integrate their *knowledge management*. Based on a common data base that codifies much of the network participants´ core routines (e.g., prices, materials, engineering data, and customer feedback) it becomes possible to cooperate for instance on product development. A typical example is the Internet-based business model of Cisco, the US networking company (e.g., Borrus, Ernst, Haggard, 2000, chapter 1).

The Internet is a powerful tool for dispersing design knowledge and engineering data throughout an organization and for extending their usefulness. This is particularly true, once this organization spreads across national boundaries: the Internet can help a flagship company to extend and rationalize its GPN. The Internet can facilitate cross-border cooperation in engineering: it becomes possible to circulate digital mock-ups rather than physical prototypes, and hence to increase the scope for interactive engineering without co-location. Even more important is the impact on network *coordination*. The Internet makes it possible to perform *simultaneously* the following major coordination tasks: to control information, to connect people with information, to facilitate cooperation among information users, and to (re-)configure products based on fast, more transparent information-sharing. This helps to speed-up the development cycle, and extends interconnectivity.

4.4. A stylized model

Based on Antonelli (1997), it is possible to sketch a *stylized model* of the perplexing *spatial* impact of IT, of which the Internet is only just the most recent incarnation. The root cause is an increasing *specialization* in the production of knowledge, made possible by IT. The result is that knowledge generation shifts from vertically integrated hierarchies to networks that link together suppliers, system integrators and customers. More specifically, IT has four important impacts. *First*, it enhances the scope, performance features and power of information networks: participants have now access to a much greater variety of linkages (improved *connectivity*); their capacity to receive and absorb information has also been strengthened (improved *receptivity*)[27].

Second, IT has strengthened the position of knowledge-intensive services as "the mediator of increasing interactions between tacit and generic knowledge." (Antonelli, 1997) For any economic system (firm, region, country), the capacity to *coordinate* such interactions is critical for its competitive success. *Third*, IT facilitates and promotes the formation of separate and specialized *knowledge markets*. It provides an opportunity for business services to store and market knowledge, and for firms to access and purchase it.

[27] Of course , access to such information networks does not come free: some countries, regions and firms are better placed than others to participate in and benefit from such networks. Access to low-cost and powerful information network infrastructure is of critical importance, and neccesitates supporting policies.

This, in turn, creates more opportunities to *customize* knowledge: more and more customers make increasingly specific demands on more and more knowledge suppliers. In addition, knowledge becomes on-line, i.e. more rapidly accessible. And finally, *fourth*, the rapid proliferation of the Internet throughout the world economy facilitates the *geographic dispersion* of high-end knowledge-intensive support services. This enables a firm that is located in a particular cluster to source *worldwide* for a variety of *knowledge-intensive support services*.

A *taxonomy of co-location options* can help to clarify this important issue. As a result of IT, a firm can now choose between (or combine) different *sites for co-location*: i) *co-location at home*, i.e. the firm´s original cluster; ii) *localized overseas cluster*, where co-location takes place in a specific overseas site; iii) *macro-regional co-location*, where different elements of a cluster are dispersed at different locations within a macro-region (like the Nordic countries or Southeast Asia); and iv) *virtual co-location* , where close interaction takes place via the Internet, supported by video-conferencing and regular visits.

CONCLUSIONS

The paper has demonstrated a need to reconsider established wisdom on the economic geography of innovation. We have shown that IT and globalization have a puzzling spatial impact on innovation: Both reduce its spatial stickiness, enhancing the geographic dispersion of knowledge, while at the same time increasing the scope for agglomeration economies. There is no doubt that this has created a huge *potential* for international knowledge diffusion. In addition, the Internet may further substantially reduce constraints to the diffusion of tacit knowledge, providing new entry and upgrading possibilities for small players, both firms and industrial districts.

However, these benefits will not come automatically. Information technology consultants now talk of a growing *expectation gap* (Waters, 1999). Euphoric expectations have been generated by telecommunications companies and Internet service providers, promising instant high-bandwidth communications that make the exchange of large volumes of data a routine matter. Many expect the Internet to create a *Brave New Online World*, to paraphrase A. Huxley, where employees can share their ideas or their work in real time, no matter where they are based. Nobody knows what will happen in the long-run. In the short- and medium-term however, there is no doubt that substantial constraints exist to the international diffusion of knowledge that may well produce quite unexpected results.

Future research needs to address a variety of constraints, such as *legal* and *regulatory* issues related to the protection of privacy and intellectual property rights, to pricing, and to the terms and conditions of network access. Equally important constraints reside in organizational routines and national differences in the approach to knowledge creation. For instance, once a firm extends its value chain across national boundaries, it is faced with the risk of disruptions in corporate coherence (Teece, Rumelt, Dosi and Winter, 1994) that may reduce the scope for knowledge exchange. Equally important are constraints to international knowledge diffusion that result peculiar features of national

institutions (Lam, 1998). Understanding these constraints can facilitate the development of countervailing policies and firm strategies.

Of critical importance is the impact of the Internet. We have demonstrated its considerable potential for enhancing international knowledge diffusion. But it may also have destructive effects. In pure technological terms, there are few limits to its further expansion. The real issue is to what degree existing economic structures and institutions can cope with the relentless pace of change, the turmoil, the growing uncertainty, and the social dislocations that may result from this latest stage in the development of information technology.

The severity of the challenge is captured in the following quote from a testimony before US congress by Andy Grove, ex-chairman of Intel, and one of the drivers of these developments. The Internet "is about to wipe out entire sections of the economy". Unless politicians start moving at "Internet rather than Washington speed", America may see a "repeat of the social disaster that followed the mechanization of agriculture." (Economist, 1999). If that statement holds for the richest country in the world, it is obvious that there is indeed an urgent need for public policy response to cope with the so far largely unknown international and national equity implications of placing the Nets on the Web. Very few people have yet understood that the Internet is doing nothing less than "redefining the economic structure of the world"(Eric Schmitt, chairman of Novell, ibid.). Of course, this also affects the geography of innovation. Such far-reaching changes in economic structure require equally far-reaching changes in institutions and policies. Yet, so far very little debate has occurred on the precise nature of such changes and of the necessary policy responses[28].

[28] These issues are addressed in a joint international research project, coordinated at the East-West Center, on "Placing the Nets on the Web - Global Production Networks and Local Capability Formation".

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