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The complex interaction between Global Production Networks, Digital Information Systems and International Knowledge Transfers

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Abstract

Traditionally many studies of knowledge in economics have focused on localized networks and intra-regional collaborations. However, the rising frequency by which firms collaborate within the context of global networks of production and innovation, the increasingly intricate divisions of labor involved and the extensive use of the Internet to facilitate interaction are all relatively novel trends that underline the importance of knowledge creation and flows across different locations. Focusing on this topic, the present chapter examines the complex interactions between global production networks (GPN), digital information systems (DIS) and knowledge transfers in information technology industries. It seeks to disentangle the various conduits through which different kinds of knowledge are transferred within such networks, and investigate how recent generations of DIS are affecting those knowledge transfers. The paper concludes that the dual expansion of GPN and DIS is adding new complexity to the practice of innovation: To access knowledge necessary for sustained creativity firms often have to link up with remote partners in GPN, but to be able to absorb and utilize this knowledge, they also frequently have to engage in local interactive learning processes. These local-global linkages - and the various skills necessary to operate them - are strongly interdependent, mutually reinforcing and critical for the development and maintenance of innovation-based competitiveness.

Introduction

Innovation has traditionally been a complex undertaking, typically involving multiple actors at different organizational levels who combine diverse resources and ideas through repeated cycles of trial and failure (Van de Ven et al. 1999). This complexity has increased in recent decades as the knowledge necessary for innovation has become more geographically dispersed, and as the modes of interaction between innovators have turned more variegated (Consoli and Patrucco, this volume). For instance, in a recent report, The Economist Intelligence Unit (2007) observe a fast growing tendency among large firms to adopt global innovation network models in which R&D is being conducted in multiple globally dispersed sites. In this context, digital information systems (DIS) – meaning electronic systems that integrate software and hardware to enable remote collaborative work (Chandler and Cortada, 2000) – have been attributed a crucial role. Recent generations of DIS are said to be important because they improve people's capacity to collaboratively create, integrate and transfer advanced knowledge across large distances (Foray and Steinmueller, 2003, Ernst, 2003, Foray, 2004, Ernst, 2005c, Gupta et al 2009).

Focusing on these issues, some authors hold that the interplay between local interactive learning and digitally facilitated knowledge sharing is becoming critical for competitive performance in many industries (Bathelt et al. 2004, Bathelt 2005, Asheim and Gertler 2005). For instance, as said by Coenen et al. (2004), regions that are successful in harnessing and balancing both localised and remote forms of collaboration are likely to have a more diversified access to knowledge than other regions, and therefore be more innovative and competitive over time. While linkages to foreign centres of excellence are important for novel inputs and sustained creativity, Coenen et al. argue, well-established local collaborations are often necessary for firms to access global networks and exploit foreign knowledge. This interactive local-global relationship, we propose, is crucial to understanding the complex nature of knowledge in the current economy and for outlining a complexity theory of innovation.

However, while there is by now an extensive body of empirical research on knowledge transfers on the local and regional level, the specific nature of international and digitally mediated knowledge transfers remain much less explored. Only recently has research begun to examine systematically the rising frequency by which firms choose to undertake innovative collaborations within the context of global networks, the increasingly intricate divisions of labour involved and the extensive use of remote interaction in such endeavours (Cantwell, 1995, Borrus, Ernst and Haggard, 2000, Ernst and Kim, 2002, Ernst, 2005a, 2005 b, 2009).As Håkansson has put it: '….the idea has recently been advanced that through the establishment of 'global pipelines' it may be possible to convey (…) knowledge through other means than face-to-face contact. Precisely what sort of mechanisms are at work in such pipelines remains obscure' (Håkansson 2005, 440).

Textbox 1: Concepts and definitions

- **Digital Information Systems (DIS):** DIS are digital systems that integrate software and hardware to enable remote collaborative work (Chandler and Cortada, 2000). Recent generations of DIS uses the Internet as a platform for communication. Important examples are e-mail, videoconferencing, collaborative computer aided design (CoCAD) and remote simulation and training systems.

- **International knowledge transfer:** International knowledge transfer is the process through which the knowledge possessed by one unit in one country (e.g., group, department, division or firm) is affected by the accumulated experience and knowledge of a unit in another country (Argote and Ingram 2002).

- **Information technology (IT) industry:** The global IT industry encompasses all organizations involved in the study, design, development, implementation, service support or management of computer-based information systems. Typical examples, are computer hardware manufacturers like Cisco, software houses like SAP and IT consultancy firms like Accenture.

- **Global Production Network** (GPN): A GPN is an international multi-firm network centred on the value-chain activities of a network flagship company (Ernst 2002b).

- **Network Flagship:** A network flagship is a corporation that depends on a global network of affiliates and independent suppliers to develop, produce and market its products. Flagships are typically either original brand name manufacturers (OBMs) or contract manufacturers that produce for the OBMs (Ernst and Kim 2002). A typical network flagship, such as Cisco or Intel, breaks down their product value chains into a variety of discrete functions and locates them wherever they can be carried out most effectively and where they provide the flagship with necessary competencies (Ernst 2003)

A promising avenue for exploring this topic further is to focus on the recent expansion of global production networks (GPN), meaning global inter-firm networks centred on the value chains of large flagship companies (for definitions of GPN and flagships, see textbox 1). GPN are relevant in this context because they constitute important arenas for knowledge transfers between internationally dispersed firms, and because they depend heavily on recent generations of DIS to facilitate these transfers. Indeed, as Ernst (1997a, 1997b, 1998; 2002b, 2004) has shown in a sequence of studies from the electronics and information technology industries, GPN flagships outsource an increasing proportion of their value chain activities to globally dispersed independent supplier companies. Whereas outsourcing in GPN has traditionally been confined to lower-end stages of manufacturing, more high-end stages such as knowledge-intensive support services, engineering, product development and applied research are now being dispersed through global outsourcing (Ernst, 2005a and 2009).

For these distributed arrangements to function efficiently the flagships need to transfer knowledge more rapidly and more extensively than before, and to facilitate and coordinate these transfers they are making increasing use of recent generations of digital information systems (Ernst 2005c). These arguments are supported by studies demonstrating a strong increase in large firms' investments in digital collaboration technologies (Gartner Group 2007)[1] and by several large-scale surveys showing that large firms increasingly use such technologies to support their knowledge transfer activities (Eppinger and Chitkara 2006, Boutellier et al. 2008).[2]

Taking the above studies as a starting point, one might hypothesize that the combined expansion of GPN and DIS is making it significantly easier and cheaper to transfer knowledge across distances. There are, however, important reasons to be cautious when assessing the consequences

[1] According to a recent Gartner report (2007), a strong demand for information sharing across business function is driving solid growth for internet-based collaboration technologies. Through 2011, the report predicts, web conferencing and team collaboration software markets will grow at a rate of 23% and 15,9 % respectively.

[2] For instance, drawing on a survey of 1000 R&D managers in over 100 large companies in the US, Europe and Asia, Eppinger and Chitkara (2006) document a fast-growing trend to use DIS to support remote knowledge transfers and innovation collaborations. Presenting a comparable study, Boutellier et al (2008) conclude that new ways of using DIS to support knowledge transfer and innovation have come gradually but with a significant impact. Indeed, until the mid 1990s, the primary function of digital information systems was to automate transaction processes and facilitate information sharing. In the last decade and a half, however, the focus shifted to the establishment of Internet-enabled, flexible information infrastructures that can support advanced innovative collaboration and transfer of knowledge across organizational- and geographical borders (Chu et al. 2008).

of DIS and corporate networking for the global mobility of knowledge. While there is much research on the individual topics of global production networks, DIS and international knowledge transfer, their mutual interaction is still largely unexplored territory.

The objective of the present chapter is to explore how recent generations of DIS affects knowledge transfers within GPN. More specifically, we seek to investigate the different conduits through which knowledge is transferred within global production networks, and discuss how recent generations of digital information systems are affecting these knowledge transfers. Through this, we aspire to throw new light on the complexity of internationalized knowledge transfers, and thereby contribute to the present volume's task of delineating a complexity theory of innovation.

We proceed in the following by reviewing past literature about international knowledge transfers and global production networks in the IT industry. Here, we emphasise key operations of current global production networks (GPN), the geographical expansion of those operations in recent years, and the different types of knowledge that network flagship companies need to transfer globally to efficiently carry them out. Next, we focus in on two specific knowledge transfer activities that flagship companies have traditionally relied on in this regard; transfer of technical documentation and expert personnel, and training of employees in best practice locations. At this juncture, we give examples of the ways in which the utilization of two categories of DIS – computer aided design systems and e-learning - and are currently affecting those activities. In the concluding section, we briefly discuss the potential implications of these changes for global knowledge transfers and the complexity of innovation processes.

2. Knowledge and international knowledge transfers

In any discussion of how DIS affects knowledge transfers, it is important to consider how knowledge differs from information. These concepts are often used in the same meaning and this creates a lot of confusion. As Steinmueller (2002, pp. 144-146) has pointed out, 'It is not knowledge that flows through the circuits of a computer network, but bits of data reaching people as information.' (…) What makes knowledge more than 'a body of information' is that it involves the ability to extend, extrapolate and infer new information' This means that the capacity to exchange information is different from the capacity to exchange knowledge (Fransman 1994, p. 715).

According to Argote and Ingram (2000) *knowledge transfer* is the process through which the knowledge possessed by one unit (e.g., group, department, division or firm) is affected by the experience and knowledge of another. By international knowledge transfers, we refer to a process in which a department or firm in one country is affected by the knowledge and accumulated experience of another. Knowledge transfers are usually highly valuable for the recipient firm, but it is important to note that this is not always the case: If the knowledge to be transferred is inappropriate for and cannot be adapted to the new context, negative effects on performance can occur (Argote and Ingram 2000, Greve, 2005). Although knowledge transfer in organizations always involves transfer at the interpersonal level, the topic of knowledge transfer across organizational and national boundaries transcends the interpersonal level to include transfer at higher levels of analysis, such as the group, product line, the firm, the region and the country. In the present chapter, we discuss knowledge transfers that take place both at the inter-personal level in small teams, and knowledge transfers that take place at the inter-firm level in the context of global production networks.

During the past two decades there has been a considerable amount of research on the management of knowledge and knowledge transfers. Early contributions to this literature are characterised by a focus on inherent properties of knowledge such as codification and tacitness, how variations in these properties affect the spatial transferability of knowledge and what firms can do in order to convert knowledge from a non-transferable to a more easily transferable form (Nonaka 1991, Nonaka and Takeuchi 1995, Senker 1995). Prominent in this first wave of knowledge management theories was a focus on technological solutions allowing firms to store and make available information and codified knowledge, such as shared databases and documentation systems. More recently, this research has been complemented by a second wave of knowledge management theories that put less emphasis on inherent characteristics of knowledge- and more attention towards the specific social, organizational, cultural and technological circumstances in which individuals and firms share knowledge (Brown and Duguid 1999, 2001) Indeed, the view of knowledge as embedded in social relationships and interactions has led many researchers to focus on the importance of social capital and the notion of evolving communities of practice (CoP), understood as people bound by informal relationships who share common practices (Brown and Duguid, 1999, 2001). In all types of knowledge activities, even where technology is very helpful, people require local communities of some sort in which they develop the skills and motivations necessary to contribute to those activities (Pan and Leidner 2003, p. 73). Yet a challenge encountered in knowledge transfer initiatives is to bridge these local CoPs in distributed networks (to enable sharing across distances, not just within, local communities). As a consequence, much research attention has lately been directed at DIS that facilitate collaboration and social community formation, such as social media and team collaboration software (Fuh et al. 2005, Gupta et al 2009). The purpose of such systems when implemented in a corporate context is to facilitate a knowledge-intensive culture that encourages behaviours such as knowledge sharing and proactively seeking and offering knowledge across functional and geographical boundaries (Alavi and Leidner 2001, p. 108). A good way to study this further is to focus on knowledge transfers that take place within global production networks in the IT industry.

3. Global Production Networks in information technology industries

To document the growing complexity of global corporate networks of production and innovation, we focus on the information technology (IT) industry, an industry that is unrivaled in its degree of globalization and thus serves as a testing ground for new forms of global corporate networking strategies. What happens here may well signal future transformations in other industries where global production networks have not spread out to an equal extent. Furthermore, emerging economies, especially those in Asia, are playing an increasingly important role as global competitors in this industry.

Competition in the IT industry is driven by rapid changes in technology and markets and by very short product life cycles. A defining characteristic of the industry is “network externalities” (Katz and Shapiro 1985). A company succeeds "when customers expect that the installed base of … [the company's] … technology [will] become larger than any other," with the result that the customers "adopt that technology to the virtual exclusion of others" (Sheremata 2004: 359). However, network externalities are not sufficient to gain and retain a competitive advantage. Equally important is a capacity to combine cost reduction, speed to market, and product differentiation through significant performance improvements (Ernst 2002b). This requires a broad portfolio of intellectual property (IP) rights and explains why innovation in the IT industry is *cumulative* rather than *discrete* (as it is for pharmaceuticals and biotechnology).

A second defining characteristic of innovation in this industry is *fragmentation*, or "modularization," and its dispersion across boundaries (of firms, countries, and sectors) through GPNs. Progress in the division of labor in design (through modular design) has created opportunities for vertical specialization in both manufacturing and innovation, enabling firms to disintegrate the value chain as well as to disperse it geographically. Modular design has also provided ample opportunities for vertical specialization in the production of knowledge-intensive services, such as software, information services, engineering, and research and development (R&D). Innovation is being sliced and diced into modular building blocks of specialized tasks for geographically dispersed R&D teams. Innovation in the IT industry thus requires *interoperability* (or "compatibility") standards that enable independently designed products and components to work together within a technological system (e.g., a laptop, a handset, or a switching system). Increasingly, this process has taken on a global dimension, giving rise to global production networks (Ernst 2005a).

A GPN encompasses both intra-firm and inter-firm linkages and integrates a diversity of network participants who differ in their access to and in their position within such networks. These arrangements may, or may not involve ownership of equity stakes. A network flagship like IBM or Intel 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 of these networks is to provide the flagship with quick and low-cost access to resources, capabilities and knowledge that are complementary to its core competencies.[3] GPNs typically consist of various hierarchical layers that range from network flagships that dominate such networks, down to a variety of usually smaller, local specialized network suppliers.

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). The strategy of the flagship company thus directly affects the growth, the strategic direction and network position of lower-end participants, like specialized suppliers and subcontractors. The latter, in turn, "have no reciprocal influence over the flagship strategy" (Rugman and D´Cruz, 2000, p.84). The flagship derives its strength from its control over critical resources and capabilities that facilitate innovation (e.g., Lazonick, 2000), and from its capacity to coordinate transactions and knowledge exchange between the different network nodes. We distinguish between two types of global flagships: i) "brand leaders" (BL), like Cisco, GE, IBM, Compaq or Dell; and ii) "contract manufacturers" (CM), like for instance Solectron or Flextronics, that establish their own GPN to provide integrated global supply chain services to the "global brand leaders".

Increasing outsourcing and specialization are the fundamental drivers of this flagship model of industrial organization (Ernst 2002a). Flagships retain in-house activities in which they have a particular strategic advantage; they outsource those in which they do not.[4] This includes for instance trial production (prototyping and ramping-up), tooling and equipment, benchmarking of productivity, testing, process adaptation, product-customization and supply chain coordination. It may also include design and product development. More specifically, GPNs typically combine global dispersion of value chain activities with spatial concentration of advanced processes in a limited number of specialized clusters. This combination of spatial dispersion and concentration implies two things: First, that some stages of the value chain are internationally dispersed, while others remain concentrated. The degree of dispersion differs across the value chain: it increases,

[3] GPNs do not necessarily give rise to less hierarchical forms of firm organization as predicted for instance in Bartlett and Ghoshal (1989) and in Nohria and Eccles (1993).
[4] It is important to emphasize the diversity of such outsourcing patterns (Macher et al. 2002; Ernst, 1997b). Some flagships focus on design, product development and marketing, outsourcing volume manufacturing and related support services. Other flagships outsource as well a variety of high-end, knowledge-intensive support services.

the closer one gets to the final product. And second, the internationally dispersed activities typically congregate in a limited number of overseas clusters.

To exemplify these trends, let us look at the computer design and manufacturing (Ernst, 2002b). On one end of the spectrum is final PC assembly that is widely dispersed to major growth markets in the US, Europe and Asia. Dispersion is still quite extended for standard, commodity-type components, but less so than for final assembly. For instance, flagships can source keyboards, computer mouse devices and power switch supplies from many different sources, both in Asia, Mexico and the European periphery, with Taiwanese firms playing a major role as intermediate supply chain coordinators. Concentration increases, however, the more we move toward more complex, capital-intensive precision components. Memory devices and displays are sourced primarily from "centers of excellence" in Japan, Korea, Taiwan and Singapore, and hard disk drives from a Singapore-centered triangle of locations in Southeast Asia. Finally, dispersion becomes most concentrated for high-precision, design-intensive components that pose the most demanding requirements on the mix of capabilities that a firm and its cluster needs to master. Microprocessors for instance are sourced from a few globally dispersed affiliates of Intel, two secondary American suppliers, and one recent entrant from Taiwan, Via Technologies.

From these latter findings, we might draw several propositions: First, the rapid geographical dispersion of value chain activities suggest that firms within global production networks have become more proficient in transferring knowledge in recent years. The above described outsourcing arrangements would simply not work without being accompanied by extensive international knowledge transfers. On a more specific level, we might propose that the combined expansion of DIS is making it significantly easier and cheaper to transfer knowledge across distances. As we pointed out in the introduction, the expansion of GPNs in the IT industry have taken place in parallel with the widespread diffusion of advanced internet-based DIS. Moreover, according to several recent surveys, large firms in this industry make extensive use of DIS to facilitate global knowledge transfers (Eppinger and Chitkara 2006, The Economist Intelligence Unit 2007, Boutellier et al 2008).

Second, the trend of concentrated dispersion indicates that there are presently clear limits to DIS-mediated knowledge transfers within GPN; the most advanced activities are still carried out by specialised clusters of co-located firms. This suggests that advanced firms depend on frequent co-located interaction with other advanced firms in order to tap into the most knowledge-intensive subsets of GPNs. This resonates with the arguments of Coenen et al (2004) and Asheim & Gertler (2005) that well-established local collaborations are often necessary for firms to be able to access and exploit international knowledge flows. While linkages to foreign centres of excellence are important for novel inputs and sustained creativity, these authors suggest, well-established local collaborations are often necessary for firms to be able to absorb and exploit external knowledge. The reason for this is a two sided one. The first is that few single firms have all the capabilities in-house to supply advanced inputs – such as the production of computer hard drives or memory devices– to global production networks. However, by collaborating closely in specialised local clusters firms may collectively develop the competencies necessary to deliver such inputs. Second, single firms are likely to have difficulty developing the skills necessary to operate advanced international collaborations. But once a local cluster of firms has established a critical mass of linkages with (or pipelines to) global production networks, these firms might draw on each other's international experience and thereby collaboratively develop the skills necessary to efficiently manage those linkages (Coenen et al. 2004).

Judging from the pattern of concentrated dispersion and the above studies, we might preliminarily hypothesize that novel DIS has widened the scope for knowledge transfers within GPN, but that firms still require co-location to collectively develop the capability to participate in (and benefit from) the most advanced network activities. To explore these hypotheses further it is necessary to look more closely at the various activities flagship companies carry out to effectuate knowledge transfers within their GPN, and the ways in which recent generations of DIS have affected these activities. In the remainder of the chapter, we direct attention to the impact of two specific categories of DIS – web-based computer aided design (CAD) and e-learning systems. But before we get to this part it is important to disentangle the various conduits through which knowledge is transferred within GPN.

4. Knowledge transfer activities in GPN

The extensive geographical dispersion of value chain activities that are currently taking place in IT industries cannot work without substantial international knowledge transfers. These transfers involve a variety of agents, including flagships' subunits and affiliates, independent component suppliers, contract manufacturers, as well as local technical and business consultancies that market, sell and service the flagship's products (for an elaborate description of these transfer mechanisms, see Ernst and Kim 2002).[5] There are also many different categories of knowledge involved, such as managerial knowledge, technical knowledge about manufacturing equipment, production and product design, as well as knowledge about sales, distribution, installation and various customer-oriented business services.[6] While all these forms of knowledge transfers play important and interdependent roles in GPN, we direct specific focus (in the following) on knowledge transfers from flagship companies to local independent suppliers of components and services. As we pointed out in the introduction, we do this because we deem these latter linkages to be specifically important for local capability upgrading opportunities in emerging economies.

As we pointed out above flagships need to transfer advanced technical and managerial knowledge to their local suppliers to retain the competitiveness of their GPNs. It is necessary to upgrade the suppliers` capabilities, so that they can meet the technical specifications of the flagships and allow for high quality provision of product and services.[7]

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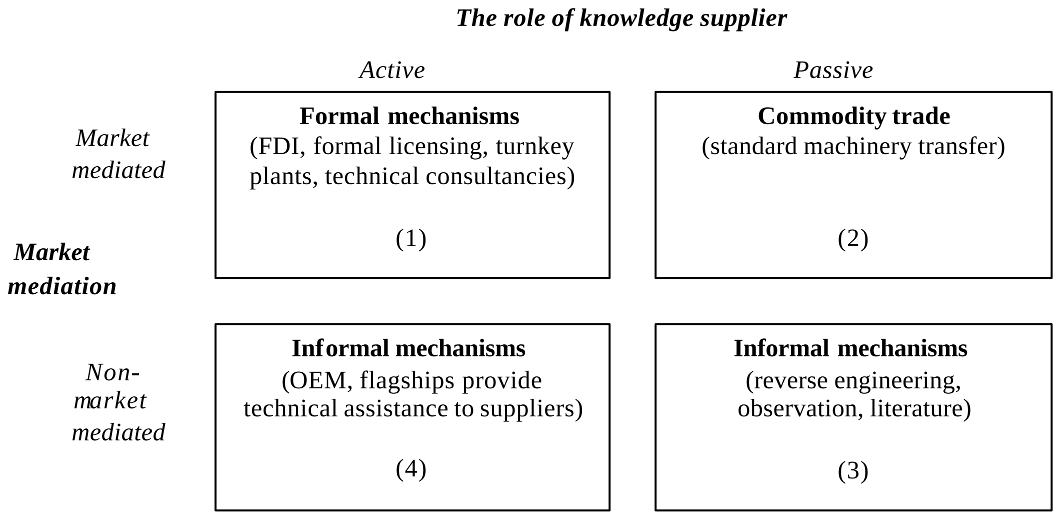
[5] It is important to note that there are important differences between these knowledge transfer mechanisms and the areas in which they are employed. For instance, there is a big difference between knowledge flows from network flagships to smaller suppliers and the flagships sourcing of smaller local knowledge bases (Ernst and Kim, 2002). In any case, recent research suggests that DIS play an increasingly important role in facilitating and coordinating these knowledge-flows (Macher et al. 2002, Ernst 2004, Boutellier et al. 2008).

[6] Finally, each of these different kinds of knowledge can be more or less difficult to transfer across locations due to the nature of the knowledge in question (tacitness, systemicness), the strength of social ties between the agents involved, and the absorptive capacity of the receiving organization.

[7] Once a network supplier successfully upgrades its capabilities, this creates an incentive for flagships to transfer more sophisticated knowledge, including engineering, and even product and process development. This reflects the increasingly demanding competitive requirements that we referred to earlier. In the electronics industry, product-life-cycles have been cut to six months, and sometimes less. Overseas production thus frequently occurs soon after the launching of new products. This is only possible if flagships share key design information more freely with overseas affiliates and suppliers (Ernst 2009).

According to Ernst and Kim (2002), there are two dimensions that are specifically important for analyzing knowledge transfers within GPN; *market mediation* and *the role of the knowledge supplier* (the flagship). Out of these two dimensions, they mark out four distinct categories of knowledge transfer mechanisms (see figure 1.).

Fig.1. Knowledge transfer mechanisms in GPN (adapted from Ernst and Kim 2002, p. 1424)



Quadrant 1 describes a situation where the suppliers are affiliates or formal alliance partners, and the flagship uses formal knowledge-transfer mechanisms such as foreign direct investment (FDI), formal licensing (FL), and independent technical consultancies.[8] In quadrant two, independent local suppliers buy standard machinery to improve their productivity in production operations, thereby gaining new knowledge. Flagships are not necessarily the suppliers of this machinery, but they can play an important indirect role by forcing independent local suppliers to purchase more

[8] For instance, when such flagships as Intel, Motorola and Texas Instruments decided to outsource assembly operations of their semiconductor devices, they took the mechanisms of FDI, FL and technical consultancies to establish their subsidiaries in the Philippines, and other countries in South East Asia. They insisted on majority ownership in the subsidiaries and transferred a complete production system.

sophisticated equipment to improve their production capabilities.[9] In the third quadrant, independent local suppliers use reverse engineering, observations and the hiring of foreign expert engineers to upgrade their knowledge.[10] As in quadrant 2, flagships exert little direct influence over the way independent local suppliers use such mechanisms, but they may exert considerable indirect influence through increased quality and performance requirements.

Finally, quadrant 4 depicts Original Equipment Manufacturing (OEM) arrangements, an increasingly important way for flagships to transfer knowledge and upgrade capabilities within their global production networks. While these arrangements may appear similar to the ones described in quadrant 1, a major difference is that the suppliers under the latter are formally independent and therefore have greater opportunity to use the knowledge to their own competitive ends. While traditional MNCs relied heavily on activities in quadrant 1 in setting up their plants, flagships transfer knowledge also through mechanisms in quadrant 3. Flagships also tend to transfer more knowledge to their suppliers than do vertically integrated MNC. These transfers are necessary to provide the flagship with competitive products and services, in line with the changing requirements of markets and technology. (Ernst and Kim 2002, p. 1424) Under these latter arrangements, flagships transfer knowledge to their suppliers through two basic activities.

First, they actively transfer technical equipment, blueprints, technical specifications and technical assistance to ensure that products and services provided by the latter meet the former's technical specifications. But, in most cases, the acquisition of this equipment and documentation alone is not sufficient for the local suppliers to assimilate new knowledge and use it in production. To tackle this challenge, the flagships also send their own engineers to stay at the local suppliers' sites for extended periods during the establishment of new plants or the introduction of new products, processes or services. During these periods, the foreign experts help local technicians

[9] This is also the case with suppliers of local marketing, sales and technical service. For instance, Cisco gives direct financial rewards and better competitive terms to the local sales and service partners that invest more in technical equipment and technical training (Cisco 2005).

[10] In Korea, for instance, the Small Industry Promotion Corporation and industry-related SME associations frequently organises observation tours of foreign firms as a way to acquire new knowledge. Human mobility in quadrant three includes not only the repatriation of top-rated engineers trained abroad, but also the active use of experienced foreign engineers who are hired for short periods of time.

debug problems in engineering and manufacturing systems, or in carrying out advanced maintenance and service operations. In addition to immediate learning effects associated with demonstration and instruction, such visits might also serve to build bridges between specialised communities of practice across dispersed sites. More specifically, as flagship engineers stay in different local suppliers' sites, they typically engage with local communities of practice (CoP) there, learning about local technical problems and expanding their personal networks. Later, after having returned to their home organizations and their own local CoP these top engineers might maintain regular contact with the supplier companies, giving technical assistance when new technical problems emerge. By virtue of having experiences from several internationally dispersed CoP, they might also take the role as brokers, mediating contact between different supplier companies with similar challenges and complementary knowledge. Such extended visits and business travel might over time lead to the interlinking of related communities of practice at different globally dispersed sites, resulting in the build-up of global networks of practice.

Second, to complement the transfer of technical specifications and expert personnel, network flagships typically invite engineers and managers of the local suppliers to its best practice plants and other centres of excellence so that they can receive a systematic training in how actual production systems and products work. Such visits might include both instructor-led training, observation of production processes and actual hands-on operation of technology and equipment. This can help to translate the knowledge gained from the blueprints into actual operations. It also enables engineers from the local suppliers to understand how the flagship's organization and production systems are actually managed, and acquire knowledge from foreign engineers through hands-on training. Finally, these visits enable engineers from the local suppliers to link up with and engage in communities of practice at the foreign (best practice) plants, thereby establishing contacts and personal relationships that they can capitalise on after they return to their home locations.

Taken together, there are both formal and informal, market and non market knowledge transfer mechanisms. These mechanisms involve exchange of technical equipment and documentation such as blueprints, advanced training in flagships' sites, and most importantly, international mobility of personnel, involving socialization between engineers, on-site practical experience and

– over time - the interlinking of local communities of practice and the construction of global networks of practice. However, the question remains of how recent generations of DIS affecting such knowledge transfer activities. This is the topic to which we turn next

5. The relationship between DIS and knowledge transfers within GPN

The fast-growing tendency of GPN flagships use the DIS to facilitate innovation and knowledge transfers is a relatively recent trend that started to expand rapidly around the turn of the millennium (Friedman 2006, Boutellier et al 2008). Until the mid 1990s, the primary function of digital information systems was to automate transaction processes and facilitate information sharing, but in the last decade and a half, the focus shifted to Internet-enabled collaboration infrastructures that can support remote knowledge transfers (Battin et al. 2001, Gupta and Seshasai 2007, Chu et al. 2008). During the same period, many firms adopted novel organizational forms and collaboration practices which depend on DIS mediated communication (Gupta et al 2009). For instance, digital design and prototyping systems are currently the norm in leading product development firms, and high bandwidth networks have enabled these firms to efficiently share their digital product designs on a global scale (Fuh et al. 2005, Gupta et al. 2009, Eppinger and Chitkara 2009).

At present, there is no single end-to-end system that is able to cover all knowledge transfer needs in a global production network. Rather, GPN flagships and associated network partners utilize a myriad of DIS which support the organizational processes of knowledge creation, storage, retrieval, transfer and application (Alavi and Leidner 2001, p. 114). Important examples are e-mail, web conferencing systems, team collaboration systems, collaborative computer aided design and digital education systems. As we pointed out in the introduction, these technologies have undergone a rapid development in recent years[11] and there is currently a widespread expectation that they will make it cheaper and easier to transfer knowledge within GPN.

[11] Focusing on this issue, Ernst (2004) examines two interdependent paths of DIS development that gained rapid momentum from the mid 1990s and onwards: First, the development and diffusion of open standard internet infrastructure – meaning communication protocols (TCP/IP, HTTP), internet languages (HTML, XML) and web server software (Apache) - allowed for the seamless interconnection of previously detached corporate communication networks, thereby greatly improving opportunities for information exchange. Second, the more

Textbox **1: Cisco Systems - a 'wired' global network flagship**

Cisco Systems, the world leading supplier of Internet technologies, offers an interesting example of a network flagship that makes extensive use of DIS to facilitate global knowledge transfers. Cisco's global production network connects the corporation to 32 manufacturing plants worldwide, as well as a myriad of lower level suppliers, consultancies and sales & service companies. These suppliers are formally independent, but they go through a lengthy process of certification to ensure that they meet Cisco's technical and financial requirements. The core of Cisco's GPN operation is its web site, which encompasses collaboration media and digital training resources associated with all parts of its value chain activities, including design, engineering, production, marketing and sales. Most of the interaction with the suppliers takes place through this web site and only major contracts and highly complex projects are handled in person. Cisco has used the Internet and its own information systems to support its strategy in three main ways: (1) to create a business ecology around its technology standards; (2) to coordinate a virtual GPN that allows it to concentrate on product innovation while outsourcing other functions; (3) to showcase its own use of the Internet as a marketing tool. This strategic use of the Internet has allowed the company to dominate key networking standards and sustain high growth rates throughout the 1990s and until present.

Source: Kraemer, K. L. and J. Dedrick (2002) Strategic use of the Internet and e-commerce: Cisco Systems." The Journal of Strategic Information Systems, Vol 11 (1), pp. 5-29.

However, an important limitation in the research literature is that there are no studies that systematically examine the use and impact of this complex array of DIS in global production networks. Instead, existing studies typically explore how single DIS affects specific functions and value chain activities within GPN, such as the relationship between on-line databases and knowledge sharing among technical maintenance personnel (Brown and Duguid 2001). While these existing studies do not allow us to evaluate the overall impact of DIS on knowledge transfers in GPN, they do allow us to discuss the knowledge transfer potential of these technologies.

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recent emergence of e-business software which capitalise on internet infrastructure to facilitate knowledge work has improved opportunities for knowledge intensive collaboration across distances. At present, these latter technologies are being adopted by a rapidly increasing number of firms. According to a recent report by the Gartner Group (2007), a strong demand for information sharing across business function is currently driving solid growth for internet-based DIS. For instance, the report predicts that web conferencing and team collaboration software markets will grow at a rate of 23% and 16% through 2011.

In the preceding section, we singled out two kinds of activities that flagship companies have traditionally carried out in order to transfer knowledge to their foreign suppliers; 1) transmission of technical documentation accompanied by technical experts, and 2) on-site training of suppliers' employees in best practice locations. In the following, we review research on two important categories of DIS – computer aided design and manufacturing (CAD/CAM) and e-learning – and discuss whether these technologies have changed the need for, and the impact of, the above knowledge-transfer activities.

5.1 Computer aided design (CAD) systems and international knowledge transfers

An important mode of knowledge transfer between flagships and suppliers is the inter-site transmission of technical equipment, specifications and blueprints, but there have traditionally been important limitations associated with this. As we pointed out above, advanced technical knowledge does not lend itself to be transmitted solely through the diffusion of blueprints and texts (Allen 1986, for an overview see Olson and Olson 2003). To compensate for this limitation, flagships have customarily sent expert engineers along with the documentation helping the local suppliers make sense of this information to build-up and improve their manufacturing or service capabilities (Ernst and Kim 2002). According to several studies, the diffusion of recent generations of computer aided design and manufacturing (CAD) systems – understood as combinations of hardware and graphical software that automates the creation, revision and transfer of technology designs – have reduced the need for personnel transfers in this context (Foray and Steinmueller 2003, Fuh et al. 2005). [12]

While CAD systems have been around since the mid 1970s, these technologies have been undergoing a remarkable renaissance during the last few years. This is due to a number of technical improvements such as hardware advances that put 64 bit multi core computers into the mainstream, improvement of 3D graphical designs, new streaming technologies that allow for the

[12] There are several methods available to create the digital CAD model. For example, the model can be created interactively in CATIA a widespread software application, starting from sketches made on the computer by hand or it can be obtained by scanning hand-made clay models into the computer system. CATIA is the leading CAD application in the worldwide automotive and aerospace CAD markets (D' Adderio 2001, 1413-1414)

efficient internet transfer of very large CAD files and finally the interlinking of digital visualization techniques with other information management functions such as e-mail and databases (Fuh et al 2005). In addition, there is by now widespread acceptance among engineers to use recent CAD systems to represent, integrate and share knowledge.[13] As a consequence, complex digital product models can be easily transmitted over the internet and even downloaded into computer controlled manufacturing equipment that later convert these into physical products (Von Hippel 2006). This is an important advance over more traditional ways in which engineers exchanged technical knowledge, typically involving extensive face-to-face meetings and the joint drafting and exchange of blueprints and technical specifications.

For instance, analysing evidence from the global semiconductor industry, Macher et al (2002) shows how CAD and other e-business software have facilitated international knowledge transfers and the development of GPNs in this industry. More specifically, these authors explain, what characterizes the evolution of these GPNs is the so called 'fabless-foundry' model of production: In the first decades of the industry, large integrated producers such as IBM and ATT took care of the design, manufacturing as well as the capital equipment necessary to produce computers. However, from the 1950s and onwards, a group of specialised semiconductor manufacturers emerged, and later - during the 1980s and 1990s - hundreds of 'fabless' semiconductor firms that design and market semiconductor components entered the industry. These design firms rely on independent contract manufacturers or 'foundries' for the production of their designs entered the industry. While the semiconductor design firms are concentrated in the US, Japan and Europe, the foundries are more widely dispersed in manufacturing sites across the globe, particularly South East Asia.

Although shorter product life cycles and requirements for cost cutting, as well as standardization and modularization of semiconductor technology, have facilitated the global dispersion of design and production in the semiconductor industry, new generations of DIS have arguably made this dispersion possible. More specifically, advanced e-business software such as CAD and systems for remote control of manufacturing processes has made it less costly to transmit advanced design

[13] This is for instance evident from the currently fast-growing market for CAD technology. According to Jon Peddie Research (2008), CAD software vendors gained combined revenues of 5235 million dollars in 2007, which represents a 20% increase compared to 2006.

and manufacturing knowledge between computer chip design firms and manufacturers, thereby reducing the need for physical co-location of designers and manufacturers..

Seeking to explain the impact of CAD (and other e-business software) on knowledge transfers in the semiconductor industry, Foray and Steinmueller (2003) claim that it is necessary to distinguish between traditional codification and more recent forms of digital 'inscription'. While the former concept refers to the representation of a particular skill by way of recordings and text symbols, the latter refers to creating a script that not only offers an adequate representation of the relevant skill, but also facilitates adequate execution of the skill by the recipient. By using new and powerful inscription tools, such as 3D engineering diagrams and simulation software, organizations are arguably much more capable than previously of creating scripts that facilitate the efficient transfer and re-enactment of tacit skills (Foray and Steinmueller 2003).

In addition to supporting the transfer of design and manufacturing knowledge, web-based CAD systems are also becoming increasingly widespread as collaboration support in large firms' global product development activities (Fuh et al. 2005, Li et al. 2005, Chu et al 2008). This is relevant in the context of global production networks, because flagship firms often collaborate with their suppliers when developing or modifying their products. Collaborative CAD systems (CoCAD hereafter) extend a single-location CAD system to a multi-location CAD application so that two or more geographically dispersed units can work together on a digital product model (Tay and Roy 2003). In a CoCAD system, designers and engineers can share their work with globally distributed colleagues via the Internet. Furthermore, these collaborative systems allow designers to work closely with suppliers, manufacturing partners and customers to get valuable input into the design chain (Li et al 2005, p. 931).

Like the above described transfers of CAD models for manufacturing purposes, these web-based product development collaborations can also carry with them significant knowledge transfers within global production networks (Fuh et al. 2005). For instance, analysing international product development teams in a global electronics manufacturing corporation, D'Adderio (2001, 2005), demonstrate how virtual prototyping software facilitates the development of on-line networks of practitioners. More specifically, D'Adderio argues, the digital prototype models - which are developed collectively by internationally dispersed teams of engineers - function as collective knowledge-repositories and as “intermediaries” between geographically dispersed communities of practice. These communities, which focus on various technical specializations such as design, manufacturing, capital equipment and user-related issues, contribute distinct and complementary knowledge to the digital prototypes. Through repeated interactions around the prototypes, the communities develop direct interpersonal ties, shared work procedures and trust that might form the basis of what Brown and Duguid (1999, 2001) refer to as a global network of practice (NoP).

In spite of these opportunities, however, there are also important limitations associated with CAD and related DIS-based engineering and production tools. According to Söderquist and Nellore (2002) important drawbacks are lack of motivation of people using the systems, low reliability of the information being transferred, and low willingness to render information transparent. Macher et al. (2002) refer to other types of obstacles, such as standards related issues and data-security concerns. Moreover, they argue, basing inter-organizational collaboration and knowledge – transfers on digital communication platforms require far-reaching internal reorganization of business processes, especially by smaller firms. All of these obstacles, these authors point out, suggest that the realization of productivity benefits associated with CAD technologies are likely to occur slowly.

Similarly, in a study of CAD in large construction firms, Salter and Gann (2003) point out that CAD and other engineering software is not a simple substitution for older forms of communication. Instead, their study shows that these technologies are primarily being used to support older forms of communication and problem solving in engineering design. (Salter and Gann 2003) They also argue that engineers frequently suffer from information overload which is intensified by DIS mediated communication, and that personal contact and interaction in local communities is essential for sifting through the information. Drawing on a study of product development teams, D’Adderio offers a similar conclusion. According to her study, the success of collaborative CAD as a tool for knowledge sharing depends on the strength local technical communities and their capacities to translate and make productive use of the knowledge represented by the CAD models. This latter finding contributes to explaining the pattern of concentrated dispersion of value chain activities in GPN. While web-based CAD systems have made it easier for firms to participate in global knowledge-intensive collaborations, they may require strong local collaborations in order to appropriate and exploit externally developed knowledge.

5.2 E-learning and international knowledge transfers

As we pointed out above, an important way in which flagships transfer knowledge to their local suppliers is to bring the suppliers' employees to visit their headquarters or best-practice production plants where they can observe the actual operation of technical equipment, and get systematic on-site training. While such on-site training is an important way of transposing complex and implicit forms of knowledge, it is time consuming and costly as it requires extensive travelling and the withdrawal of key employees from operative work. In recent years, several studies have examined whether and how e-learning might reduce the need for or even replace on-site presence and co-located interaction among instructors and students (Trondsen at al. 2006, Ray 2006, Hildrum 2009). During the course of the last 10 years e-learning has emerged as an imperative internet-based tool to acquire, impart and share knowledge within and across organizations. Recent estimates predict that the world market for e-learning will exceed 52,6 billion dollars by 2010 (Global Industry Analysts 2007) and research shows that an increasing number of firms – among them technologically leading corporations such as Dow Chemicals and Cisco – presently situate e-learning at the core of their knowledge management strategies (Rosenberg 2001, Trondsen et al. 2006)

During the course of the last 10 years e-learning – understood as digital education and training resources delivered or enabled by the internet (Weller 2003) - has emerged as an imperative tool to acquire, impart and share knowledge within and across organizations. Recent estimates predict that the world market for e-learning will exceed 52,6 billion dollars by 2010 (Global Industry Analysts 2007) and research shows that an increasing number of firms – among them technologically leading corporations such as Dow Chemicals and Cisco – presently situate e-learning at the core of their knowledge management strategies (Rosenberg 2001, Trondsen et al. 2006). While e-learning has traditionally been associated with one-way communication of information mediated through various electronic documents (Rosenberg 2001)[14], present state-of-the art systems involve extensive contact between students and instructors through interactive communication formats such as blogs and live chats, webcams and wikis, live online courses, simulation systems and interactive 3D computer game environments. For instance, Boston College is presently using interactive computer game technology to organise courses in advanced software programming. Logging in via their PCs, professor and student interact and work together as digital avatars using voice-over Internet to talk or ask questions (Newsweek, August 18/25, 2008).

Textbox 3: Remote laboratories in Cisco

During the last decade and a half, Cisco has developed a comprehensive e-learning system to improve internal learning processes, and for the purpose of transferring knowledge to its global web of supplier firms (Trondsen et al 2006). Cisco's e-learning system –which has attracted fame as the state-of-the-art in the industry - consists of a large number of digital training and education resources, including instructional information recorded in various digital formats, on-line classrooms, electronic chat groups and advanced simulation exercises. A central part of the system is a network of remote laboratories, meaning fully equipped physical laboratories which can be accessed and controlled at a distance through a system of telecommunications, control- and robotics technology (Colvell et al 2001). Technicians can access and operate the remote labs alone, but frequently they get on-line assistance from an instructor in the relevant field who monitors the lab exercises and who gives advice and step-by-step instructions of how to solve problems (Hildrum 2009). The students and the instructors, who may be co-located or located in different countries, access the remote lab environment through personal computers with broadband internet connection and communicate by way of a video and voice communication link. In 2005, Cisco had 246 remote labs with 350,000 users worldwide, and was in the process of expanding the network of remote labs further

(Source: Cisco 2005).

In a recent study, Hildrum (2009) examines how Cisco's remote laboratories affect knowledge-transfers to the corporation's local sales and system-integrator service firms. These system integrator companies – which are dispersed across all major markets of the world - specialise in linking together Cisco's internet backbone technologies (routers, switches, network software and wireless technologies) and employ a total of 350000 Cisco-certified network technicians (Waltner

[14] A typical early generation e-learning system included a step-by-step sequence of instructive videos, animations and audio files interspersed with questionnaires that the user had to click his way through.

2006).[15] According to Hildrum, remote laboratory sessions facilitate the exchange of complex and tacit knowledge between technicians who are separated by large distances. While regular on-line information exchange help technicians gain a basic understanding of how advanced products work, Hildrum argues, the remote lab sessions - where students and instructors jointly solve problems – facilitates the sharing of advanced technical troubleshooting- and problem solving skills.[16] This corresponds to previous research on remote laboratories, demonstrating powerful opportunities for remote hands-on learning and training in various fields such as chemical engineering, microelectronics and telecom signal processing (Deniz et al 2003, Ray 2006). Nickerson (2005) studies remote laboratories and conventional physical laboratories in a mechanical engineering course, concluding that students learned lab content equally well form both types of labs. Similarly, Jara et al (2008) presents a study of robotic-controlled remote laboratories in chemical engineering, concluding that these technologies have a significant potential for improving learning in this area. A number of advanced educational institutions – such as MIT - are currently using remote lab technology as a means of extending access to laboratory work for science and engineering students who are unable to attend their physical laboratory classes (MIT 2006, Ray 2006), and these technologies are also becoming increasingly widespread in the corporate sector (Cisco 2005).

However, while e-learning systems such as remote laboratories offer new opportunities for long-distance knowledge transfers, there are also important limitations associated with these technologies. Successful e-learning performance depends critically on the degree to which the users are motivated to use the Internet to acquire new knowledge. Indeed, several studies of e-learning state very high drop-out rates, explaining this by a lack of motivation or the inability to uphold motivation over time (Moshinskie 2001, Bonk 2002). There are many factors underlying different levels of motivation, such as task relevance, authenticity and the availability of meaningful feedback (Bonk 2002) but in the perspective of Hodges (2004), the most important

[15] The day-to-day work of these individuals consists of configuring, installing, troubleshooting and servicing end-to-end communication networks for public and private organizations.

[16] It is important to note here that this study only documents the use of e-learning to support knowledge transfers among sales and service professionals in Cisco's global operations. There is little knowledge about how these technologies might affect knowledge transfer within more advanced operations such as high level manufacturing or R&D.

motivational factor is past learning performance and the feeling of mastering a task or a discipline. Students who have been successful in e-learning in the past are typically more motivated to engage in e-learning in the future.

According to Hardre (2001), it is possible to activate such virtuous circles of motivation and performance through the formation of local and on-line communities centred on the e-learning tasks in question. Communities are useful in the sense that they convene together people with similar skills and interests who engage in informal interaction, support one another and give meaningful advice and feedback regarding e-learning tasks and topics of shared interest. In a study of service technicians in Cisco, Hildrum (2009) suggests that motivation can be facilitated through the formation of on-line networks of practice (NoP) centred on the e-learning activities in question. However, in order to benefit from these networks, Hildrum argues, people require a certain threshold level of technology user-skills and knowledge, which is the most easily generated through interpersonal interaction in local communities of practice. Like the above research on CAD systems, this latter finding supports the argument that firms require good local collaborations in order to benefit knowledge flows in global production networks.

6. Concluding discussion

This chapter has explored various conduits through which advanced knowledge is transferred within global production networks (GPN) in the IT industry, and investigated the ways in which recent generations of digital information systems (DIS) are currently facilitating those transfers. The objective was to throw new light on the complexity of internationalized knowledge transfers, and thereby contribute to the present volume’s task of delineating a complexity theory of innovation.

The global IT industry is characterized by a progressive shortening of product life cycles, fragmentation of products into intricate systems of modules and increasing international dispersion of the knowledge that is necessary for developing those modules. This in turn has created a strong demand for corporate networking practices and remote knowledge transfers. An important proposition of our study is that the combined evolution of GPN and DIS has significantly widened the scope for international knowledge transfers in this industry. The fact that GPN flagships outsource an increasing proportion of their high end activities to globally dispersed supplier companies, suggests that knowledge is being transferred more rapidly and more extensively than before. In addition, several studies have shown that flagship companies are increasingly using DIS to facilitate those knowledge transfers. For instance, while flagship companies have traditionally relied on transferring technical personnel to help their suppliers set up new manufacturing operations and services, there is evidence that web-based CAD systems are making it easier for technicians to share knowledge without being co-located. Similarly, new generations of e-learning systems make possible online technical instruction and hands-on training, thereby reducing the need for on-site technical training in best-practice locations.

At the same time, our study suggests that there are clear limits to DIS-mediated knowledge transfers in GPN. The pattern of concentrated dispersion indicates that there are presently clear limits to DIS-mediated knowledge transfers within GPN; the most advanced activities are still carried out by specialised clusters of co-located firms. This suggests that advanced firms depend on frequent co-located interaction with other advanced firms in order to tap into the most knowledge-intensive subsets of GPNs. As said by Coenen et al (2004), there might be several specific reasons for this. The first is that few single firms have all the capabilities in-house to supply advanced inputs, but by collaborating closely in specialised local clusters they may collectively develop these. Second, single firms might have difficulty developing the skills necessary to operate advanced international collaborations. However, local cluster of internationalized firms, draw on each other's international experience and management skills, thereby collaboratively develop the competencies necessary to efficiently manage linkages to GPN (Coenen et al. 2004). This interpretation resonates with the above cited studies of CAD systems and e-learning. In order to benefit from these technologies, firms require a certain threshold level of technology user-skills and incentives, as well as the capacity to translate and utilise digitally mediated knowledge inputs. To efficiently develop these skills, incentives and translation capacities firms arguably require links to strong local communities and collaborations.

The critical proposition that emerge from this literature review is that there is a complementary relationship between local knowledge creation and DIS-based knowledge transfers. Instead of bringing about the demise of localized clusters, the dual expansion of DIS and GPN appear to make such clusters more relevant. These local-global are particularly important in the context of the present volume, because they point to key complexities involved in current innovation processes, namely the practice of inducing and harnessing virtuous circles of local and non-local knowledge transfers. To understand more about these complexities, there is a need for more comprehensive evidence about the degree to which, and how, flagship companies use DIS to facilitate the diffusion of various categories of knowledge within their global production networks. In this chapter, we have merely discussed how two specific categories of DIS facilitate the transfer of certain types of knowledge within specific sub-sections of global production networks. This evidence is quite limited and has mainly been collected on the level of interpersonal communication in small groups. A key problem in the present study is thus to draw inferences from these specific team-level studies to the overall level of the GPN and the industries in which these networks are prevalent. Future studies should cast the new wider and seek to investigate how recent generations of DIS affect the totality of GPNs.

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