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Geography of Production Linkages in the Irish and Scottish Microcomputer Industry: The Role of Logistics

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Abstract: The economic crisis of the mid-1970s marked the transition from the traditional Fordist mode of industrial organization to one of time-based competition (TBC). It has been postulated that the rise of TBC will lead to an increase in local and regional production linkages. Part of the argument is that the associated search for logistical efficiency and the adoption of the just-in-time (JIT) principles will lead to closer buyer-supplier proximity. In this article, we test the relevance of this idea in a case study of the microcomputer hardware industry in Ireland and Scotland. Most of the data were collected during multiple interviews with subsidiaries of all global microcomputer assemblers with operations in one of the two countries. The study shows that rather than sourcing locally or regionally, the assemblers import the vast majority of their material inputs from regions outside Ireland and Britain, notably from the Far East, and that the inbound logistics pipelines of most components involve inventories, often hubbed in local warehouses. Such supply systems have been interpreted as pseudo-JIT, suboptimal inbound logistics systems that are organized on traditional Fordist principles. We argue that the logistics systems and the geography of the supply linkages should not be interpreted this way. Inbound inventories were tightly managed, leading to modest target buffer levels and high shipment frequencies. Even under JIT supply, the geographic configuration of production linkages and the details of logistics systems remain highly dependent on a range of contextual conditions and component characteristics. The findings of this study suggest that a strategy of building integrated vertical production clusters around subsidiaries of multinational enterprises is no longer suitable for Ireland and Scotland, at least not in the context of the microcomputer industry.

Key words: computer industry, production linkages, logistics.

According to some, the economic crisis of the mid-1970s marked the transition from the traditional Fordist mode of industrial organization to one of time-based competition (TBC) (Schoenberger 1997; Stalk 1988;

Stalk and Hout 1990). As an industrial paradigm, the “old,” ideal-type, Fordism was a system of “assembly-line-based mass production” of standardized goods (Asheim 1992). Production took place in large vertically inte-

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grated plants that were owned and centrally controlled by large, often multinational, corporations. Rising productivity was based on mechanization, the pursuit of internal economies of scale, a detailed division of tasks, and the intensification of work (Amin 1994). Long production runs and dedicated machinery were intended to minimize downtime. Driven by similar considerations, suppliers produced and delivered standardized components in large, infrequent batches. Price competitiveness was the most important criterion in the selection of suppliers (Sayer 1986). Finally, with regard to the geography of production, the narrow focus on the minimization of prices, production costs, and labor costs meant that the Fordist system was often characterized by an extreme spatial division of labor and spaced-out supply chains. Peripheral regions were incorporated in a dependent way through branch-plant investment that contributed little to regional development.

The Fordist methods of work organization had reached their limits in terms of growth in productivity by the 1970s. Furthermore, owing to its inherent rigidities, the Fordist system was unable to cater to modern markets, characterized by the demand for variety, quality, and responsiveness and by shorter product life cycles. For these reasons, among others, the economic crisis of the mid-1970s has been interpreted as a "crisis of Fordism" (Amin 1994; Schoenberger 1997). One idea is that a resolution of this crisis, if such a resolution is possible, would require a return to a more flexible, craft-based mode of production (see, for example, Piore and Sabel 1984 on "flexible specialization" and Storper and Scott 1989 on "flexible accumulation").

Others have pointed to many firms that are successfully competing in the new market environment with new flexible forms of high-volume production that are blurring the distinction between craft and mass production (Jessop 1992; Tomaney 1994). These firms are not producing standardized end products, but instead have succeeded in combining mass production with product

variety and customization. All new high-volume production firms, in one way or another, "combine the benefits of economies of scope and greater flexibility in responding to consumer demand, which are characteristic of small batch production, with those of economies of scale, characteristic of mass production" (Hudson 1997b, 303). These ideas are captured in a number of production concepts, including lean production (Womack, Jones, and Roos 1990), mass customization (Pine 1993), dynamic flexibility (Coriat 1991; Veltz 1991), diversified quality production (Jessop 1992), and TBC (Stalk and Hout 1990; Schoenberger 1997).

The TBC model emphasizes that the new competitive environment and the requirements of modern markets have drastically changed the role of time in competition. According to its proponents, firms now compete primarily on the basis of their ability to compress time in all elements of the value chain and, beyond that, in the firms' relations with upstream and downstream partners. The central focus is on reducing product development times and order-to-delivery cycles. This focus, in theory, results in a highly flexible production system that offers a combination of fast response, increased variety, high value, and low cost (Stalk and Hout 1990).

Schoenberger (1997) postulated that the rise of TBC will have repercussions for the geography of production and regional development. She depicted a stylized scenario of "concentrated deconcentration," in which a multinational firm creates tightly integrated production complexes in each of its primary market regions, including North America, the European Union, East Asia, and Southeast Asia. The regional complexes would include various manufacturing functions, as well as some degree of technical and strategic responsibility that would allow the firm to respond to the particular needs of the individual regional markets.

Schoenberger also postulated that TBC will lead to a greater proximity between buyers and their suppliers and an increase in local and regional production linkages. The argument basically involves two drivers

of buyer-supplier proximity: the efficient exchange of technical information and the efficient flow of products, or logistical efficiency. With regard to the efficient flow of products, one of the central targets of TBC is a reduction of the order-to-delivery cycles or chain-cycle times (Stalk and Hout 1990). Toward this end, TBC envelops the just-in-time (JIT) production and supply principles, which are expected to lead to close buyer-supplier proximity.

We tested the relevance of these ideas in a case study of the microcomputer hardware industry in Ireland and Scotland. The microcomputer industry is here defined as the industry that produces personal computers (including laptops and notebooks), workstations, and entry-level servers that cost less than \$100,000 in 2001. It involves both microcomputer assemblers and the manufacturers of components and parts. Companies in this industry have been portrayed as prime examples of TBC and JIT supply (Hudson 1997a; "Just-In-Time Inventories: Combating Foreign Rivals" 1984; Sayer 1986; Morgan 1991). The microcomputer sector is a good example of an industry that is facing highly volatile markets and irregular and unpredictable demand—characteristics that prove to be central to the analysis we present later in this article. The findings concerning the relevance of the first driver, the efficient exchange of technical information, have been documented elsewhere (van Egeraat and Jacobson 2005; van Egeraat, Jacobson, and Phelps 2002). This article focuses on how the logistical considerations have influenced the geography of production linkages in the industry. Related studies on the industry (e.g., Angel and Engstrom 1995; Dedrick and Kraemer 2002) have tended to focus on the geography of production networks in the United States and the Far East. Our study specifically focused on the production networks of companies that are located in the European semiperiphery. Furthermore, Angel and Engstrom analyzed the role of technical information exchange and paid no attention to logistical considerations.

This article focuses strongly on the relevance of the efficiency argument for buyer-supplier proximity. Less attention is paid to other aspects of buyer-supplier relationships, notably a shift from producer-driven to buyer-driven commodity chains (Gereffi 2001) or from supplier to client markets and the associated shift of relative power among members of the chains. Whether governance mechanisms in the microcomputer hardware industry are really shifting toward buyer-driven chains is a matter for debate (see, e.g., Chen 2002). Nevertheless, power relations, in general, could have a confounding effect on the analysis of logistical arrangements, so their influence receives attention as well.

Most data were collected during interviews with general managers, materials managers, and logistics managers who were employed by the 11 branded microcomputer makers in Ireland (Apple, AST, Dell, Gateway, and Intel) and Scotland (Apricot-Mitsubishi, Compaq, Digital, IBM, Packard Bell-NEC, and Sun Microsystems)—from here on referred to as "the focal companies" or "the focal plants." Three rounds of semistructured and structured interviews were conducted from 1998 to 2001. Unless we state otherwise, all of the data presented here pertain to the situation during the period 1998 to early 1999. Additional data were collected through mailed questionnaires that were completed by staff members at the focal companies and newspaper research. Finally, telephone interviews were conducted with staff at a selection of local supplier firms.

The next section more closely examines the logic underlying the idea that logistical considerations in the context of TBC will drive close buyer-supplier proximity. This section is followed by an outline of the geography of the supply chains of the microcomputer companies in Ireland and Scotland. It shows that the focal companies source the vast majority of material inputs from regions outside Ireland and Britain, notably from the Far East. The next section, which yields insights into the ways in which the focal companies structured their

inbound logistics pipelines, provides the basis for the subsequent analysis of data on inventory levels, shipment frequencies, and modes of transport. We focus on whether the focal companies are still operating suboptimal inbound logistics systems organized on traditional Fordist, mass production principles, or whether, in line with TBC, the focal companies have optimal (or, at least, less suboptimal)¹ inbound logistics systems that take full account of the modern comprehensive logistics management principles underlying TBC. If the latter is the case, then we will have to conclude that these principles do not necessarily lead to buyer-supplier proximity. In the conclusion, we consider the implications of this point for industrial policy.

Comprehensive Logistics Management Principles

One of the central components of TBC is JIT supply. Textbook “true JIT” (Morris 1989, 1992), “full JIT” (Mair 1992), or “pure JIT” (Fawcett and Birou 1992) is a logistics system that is characterized by very low buffer inventories, near-synchronous production, and daily delivery of inputs² directly to the assembly line. The term *sequential JIT* has been used for situations in which suppliers manufacture and deliver components in the same order as they are used on their customers’ assembly lines (Larsson 2000). Such systems are believed to lead to close buyer-supplier proximity (Estall 1985; Kenney and Florida 1992; Mair 1992; Mair, Florida, and Kenney 1988; Sayer 1986; Schoenberger 1997). True JIT is often

¹ We do not prove that the logistical solutions reported in this article are perfectly optimal. However, the data show that the companies have adopted the modern comprehensive logistics management principles and that their systems are at least less suboptimal than the systems that are organized on traditional Fordist principles.

² The criteria are arbitrary. Some authors have reserved the term *true JIT* for cases that involve multiple deliveries a day (Morris 1989, 1992).

presented as the optimal supply system. However, it should really be interpreted as an extreme outcome in a spectrum of possible optimal outcomes that are based on modern comprehensive logistics management principles. The explanation requires a closer look at these principles.

Logistics management systems have always involved calculating the minimum required inventory levels of components and related individual order quantities. In the old system, the individual order quantities, or lot sizes, were typically based on a traditional economic order quantity (EOQ) formulation (Christopher 1992; McCann 1998). The EOQ model is based on the idea that it is possible to calculate order quantities/shipment frequencies involving minimal “total logistics costs” (TLCs). These TLCs are the sum of the ordering/setup costs, the costs of holding inventories, and the costs of transporting goods. The ordering/setup costs include the administration costs that are involved in organizing an individual purchase, plus the labor costs involved in setting up machinery. The inventory holding costs were traditionally reduced to interest costs. The EOQ was derived by balancing these cost components.³

The modern comprehensive logistics management principles that underlie JIT involve a more inclusive interpretation of inventory holding costs. According to

³ The traditional formulation of the EOQ is expressed as $Q^* = \sqrt{\frac{2mS}{Ic}}$, where Q^* is the EOQ, m is the quantity of input per period, S is the ordering/setup costs of conducting each individual shipment, I is the rate of interest, and c is the source price per unit of input (McCann 1998). With his broader logistics costs model, McCann (1996, 1998) showed how total input logistics costs are generally a positive function of transport costs and, thus, of distance. Correspondingly, the EOQ is dependent on transport costs and distance. Integration of this idea, and assuming shipment economies of scale, leads to the following formulation for the EOQ $Q_i^* = \sqrt{\frac{2m(S + ad_i)}{Ic}}$, where a is movement costs per mile and d is delivery distance.

McCann (1998), compared to the traditional models, two extra cost factors are considered and are believed to represent a significant part of the inventory holding costs: space costs and total quality costs (TQCs).

The space costs of inventory are the space and space handling costs of storage and warehouse space, which are made up of the land costs and the labor costs involved in inventory-handling operations. The TQCs are the combined costs of lost market share owing to the poor quality and reliability of the final product and the costs of final-quality control administration, which are the costs of expediting materials, the costs of lost orders, back-orders, scrap, and rejects. The greater the average volume of inventory held, the greater the risk that faults in individual components will go undetected during the production process—the greater the quality costs.

These cost components were not included in traditional Western purchasing techniques, which, as a consequence, underestimated the real costs of holding inventories. In other words, the adoption of the comprehensive logistics management principles creates an incentive to reduce further the average volume of inventories by reducing the shipment size and increasing the shipment frequency. In modern quality-competitive markets, the significance of TQCs and space costs may be so great that the EOQ tends toward zero, that is, lot sizes of one.⁴ However, if shipment sizes go down and shipment frequencies go up, the transport cost and ordering/setup cost components of the TLCs will rise. There are two ways to prevent an increase in transport and ordering/setup costs. First, firms can work to reduce the ordering/setup costs of conducting each individual shipment by streamlining the order-entry system, for

⁴ Taking account of the space costs and TQC, the new formulation of the EOQ becomes

$$Q_i^* = \sqrt{\frac{2m(S + ad_i)}{q + s + Ic_i}}$$

cost coefficient and q expresses the impact of the TQC. Thus, the higher the value of s and q , the closer the EOQ will be to zero (McCann 1998).

example. Second, and more important for the present discussion, firms can attempt to reduce the input delivery distance. This is the basic logic behind the JIT-proximity argument (Mair 1992; McCann 1996, 1998).

The idea that there are forces that drive customer-supplier proximity is obviously not new. Even the traditional logistics models and the traditional way of calculating the EOQ could lead to a situation in which the transport costs and the interest costs of holding inventories would drive customer-supplier co-location. In fact, one could consider buyer-supplier co-location to be the “normal” situation. It is only because of issues such as differences in labor costs between locations, economies of scale in component production, and a whole range of reasons related to history, the technological capabilities of a region’s suppliers, and locational inertia, that customers use suppliers located in other regions. With the modern comprehensive logistics management principles that underlie JIT, the difference is that the forces that tend toward buyer-supplier proximity are stronger because of a greater appreciation of the role of space costs and TQCs.

However, the specifics of the logistical arrangements and the effects on linkage distance remain dependent on a range of component characteristics and contextual conditions. Paraphrasing Christopher (1992), companies still have to make a range of “trade-offs” in working to improve the cost-effectiveness of the total supply chain—the ultimate goal of any logistics system. Here, we briefly consider the four issues that we investigated in the course of the study: differences in labor costs among production locations; the value, volume, and weight of components; the minimum efficient scale (MES) of component production; and component variety. Other issues, notably superior technological capability and locational inertia, are not discussed, since, because they were clearly less relevant for our case, they were not specifically addressed in the study.

Differences in labor costs among regions, as reflected in the price of components,

are very important. More-distant suppliers may be able to compete with lower prices because of cheaper labor costs. If these price advantages outweigh the efficiencies gained by co-location, then a firm may operate JIT supply over longer distances (McCann 1998) or operate logistics systems that diverge substantially from the prototypical true JIT system.

Another often-cited issue is related to the value and bulk or weight of individual components. The incentive for increasing shipment frequency, decreasing order size, and decreasing linkage distance will be greater for high-value components than for low-value components (Christopher 1992), *ceteris paribus*, since components with a high value will incur much-higher interest and insurance costs. Likewise, the incentives for increasing shipment frequency and decreasing linkage distance are greater for physically bulky and heavy components than for small and light components, *ceteris paribus* (Lubben 1988; McKinnon 1997), since bulky components will incur higher space costs, whereas the transport costs are higher for both bulky and heavy components.

The MES of component production also impinges on the logistical arrangements and linkage distance. Production at the MES often means that manufacturers of components need to supply several customers, which can mean that suppliers are located at considerable distances from some of these customers (Bordenave and Lung 1996; Jones and North 1991; McKinnon 1997; Milne 1990; Morris 1992; Schamp 1991).

Finally, the incentives for increasing the shipment frequency and proximity will be stronger for component categories involving a high variety of options (e.g., different colors or styles) than for more-standardized component categories because the greater the variety of options within a component category, the higher the inventory holding costs involved in stockpiling a certain level of finished components in all possible permutations (Christopher 1992; van Hoek 1998; Bordenave and Lung 1996), particularly in situations of highly unpredictable

demand. Therefore, the greater the variety of options, the greater the incentive to delay the final assembly of component materials into finished components. The greater the delay in the final assembly, the greater the frequency of shipments, and the greater the drive for buyer-supplier proximity.

All these component characteristics and the difference in labor costs among regions mean that the adoption of comprehensive logistics management principles can have a variety of outcomes, involving both local and overseas sources and a combination of delivery methods (Lubben 1988). At one end of the spectrum, the pipeline of some components will be organized along the lines of a true JIT system, with suppliers located in close proximity to the customer. Because of technical developments in transport and logistics, even such a true JIT system does not necessarily involve buyer-supplier collocation. Indeed, some companies operate such systems with suppliers located in other countries or even other continents (Clarke and Beany 1993; Glasmeier and McCluskey 1987; Lamming 1993; McCann 1998; Milne 1990). However, these examples are the exceptions. Frequency, distance, speed, reliability, and the cost of transport are inter-related issues that have to be traded off against one another (McKinnon 1997). In general, the literature suggests maximum workable distances for true JIT supply ranging from 30 to 150 miles (Estall 1985; Kenney and Florida 1992; Mair 1992; Mair, Florida, and Kenney 1988; Sayer 1986; Schoenberger 1997).

Alternatively, the adoption of comprehensive logistics management principles may lead to a "JIT-type" supply system (Crowley 1996) involving slightly less-frequent shipments and slightly higher buffer inventories and suppliers that are somewhat farther away. In such instances, "the meaning of JIT delivery starts to change" (Lubben 1988, 192). At the other end of the spectrum of outcomes, the pipelines of components may involve even less frequent shipments, still higher (though tightly managed) buffer inventory levels, and suppliers that are

located at great distances (Fawcett and Birou 1992).

Geography of Production Linkages

This section outlines the sources of the parts and components that are used by the 11 focal companies. Interviewees provided the names of their suppliers as well as the location of manufacturing. The precise detail of the geographic configuration of the supplier networks differed from company to company. However, great commonalities existed, especially with respect to the regional supply situation. The main area of difference was the location of the motherboard/backpanel suppliers. The geographic origin of parts and components is summarized in Table 1. For more detailed data on individual companies, see van Egeraat, Turok, and Jacobson (1999) and van Egeraat (2002).

The vast majority of components and parts were imported from regions outside Ireland and Britain, notably from the Far East and, to a lesser extent, the United States. The only items that were significantly sourced in Ireland and/or Scotland were enclosures, motherboards/backpanels (mainly from Scotland), network cards (from Ireland only), non-English-language keyboards, digital/printed media, accessory kits,⁵ cables/interconnect, and packaging material. Furthermore, England and Wales figured, to a small extent, in the area of monitors, while England also played a role in the supply of motherboards. However, most of these components were imported from other regions as well. Thus, the majority of motherboards/backpanels, network cards, cables, keyboards, and monitors were manufactured in other regions, notably in the Far East. Only enclosures,

packaging, media, kits, and non-English-language keyboards were sourced mainly from suppliers in Ireland or Scotland.

The local supply networks of the 5 microcomputer assemblers in Ireland included 47 (mainly foreign-owned) companies operating 57 component plants. The local supply networks of the 6 focal companies in Scotland included 49 (mainly foreign-owned) companies operating 51 plants. However, the actual production activities in many plants were very limited or added limited value to the product. Apart from limited digital printing activity, 11 kitting plants merely packaged media and other language-specific parts into a box. Similarly, 5 keyboard localization plants merely laser printed (non-English-language) keyboards that were manufactured overseas. Finally, the production activities of the turnkey suppliers that were involved in rework activities added little value.

Ten focal companies provided an estimate of their expenditures on locally (Ireland or Scotland) manufactured components as a percentage of their total expenditures. They also provided figures for the share of components that were sourced in Ireland and Britain together. At the time that the interviews were conducted, on average, 10 percent of the parts and components that were sourced by the focal companies in Ireland were manufactured in Ireland (ranging from 7 percent to 12 percent). The items that were manufactured in Britain accounted for another 4 percent, on average (ranging from 0 to 9 percent). With regard to the focal companies in Scotland, on average, 7 percent of the material inputs was manufactured in Scotland (ranging from 2 percent to 9 percent). The items that were manufactured in the rest of Britain and Ireland made up another 9 percent (ranging from 3 percent to 10 percent).

The figures on local sourcing are substantially lower than those that were presented in other studies that were based on data collected by the industrial development agencies in Ireland and Scotland. Turok (1997) reported that in 1995, the 16 largest foreign-owned electronics companies in

⁵ Items such as media, mice, cables, and connectors were typically packaged in a "country" or "accessory" kit. Some focal companies subcontracted the packaging of these kits to local supply-chain managers that were also responsible for sourcing the items.

Table 1

Summary of Geographic Sources of Material Inputs of Focal Companies, 1998–1999

| Material Input | Main Geographic Sources |
|--|---|
| Enclosures and racks (high-volume models) | Mainly local and, to a lesser extent, the Far East |
| Enclosures and racks (less current models); screws, fasteners, and other c-class items | The United States and, to a lesser extent, local |
| Motherboards, backpanels, and riser cards | For most focal companies: mainly the Far East and, to a lesser extent, the United States; for two focal companies: mainly Scotland and England |
| Microprocessors | Mainly Southeast Asia, small amounts from Ireland; for proprietary technology: the United States |
| Floppy drives, CD-ROM drives, CD-RW drives, DVD drives, low-end technology high-capacity disk and tape drives, batteries and AC adapters (for portables), digital cameras, hard disk drives, speakers and microphones, docking stations, keyboards, mice, joysticks, low-end power supplies, portable computers (contract manufacturing) | Far East |
| High-end high-capacity disk and tape drives, high-end power supply | The United States, the Far East, Europe, and England |
| Heat sinks, cooling fans | Mainly the Far East; to a lesser extent, the United States, England, and Germany |
| Modems and network components | Mainly the Far East and the United States, although four suppliers were manufacturing in Ireland |
| Graphics, video, and sound cards; printers; other semiconductors; capacitors and resistors; memory | Mainly the Far East |
| Cables and interconnect | Mainly the Far East and, to a lesser extent, Ireland and Scotland |
| Displays | Mainly the Far East; Wales and England for a few selected models |
| Media | Printed manuals: mainly Ireland and, to a lesser extent, Scotland; CD replication: Ireland, Scotland, Wales, Germany, and the United States; wrapping of digital and printed media: local |
| Accessory kits, packaging material, subassembly and rework services, printing of non-English-language keyboard models | Local |
| Complete computer systems (contract manufacturing) | Mainly local, England, and Taiwan |
| Etched boards, interconnect, jumpers, and switches | Mainly the Far East and the United States |

Note: For the sake of brevity, many of the details in this table have been omitted. The complete table is available from the first author on request.

Source: Company interviews.

Scotland (including all the main computer assemblers) sourced 21 percent of their total purchases (excluding electronic components, intercompany trading, and services) from Scotland. In Ireland, local sourcing figures are collected by Forfas as part of the annual Irish Economy Expenditure (IEE) survey. Data on four of the five microcomputer focal companies extracted from this survey

provided an average local sourcing figure of 28 percent for 1998 (van Egeraat 2002).

The discrepancy between the figures that are based on the surveys conducted by the industrial development agencies and our figures is partly explained by our less-inclusive definition of local sourcing. Thus, the IEE figures include expenditures for items that were bought from local supply-

chain managers but manufactured in other regions, as well as expenditures for complete systems that were manufactured by contract manufacturers with local operations. We did not consider these items to be vertical production linkages and hence excluded them from the data we collected during the company interviews.

Inbound Pipeline Strategies and Structures

The focal companies had always had a mix of logistical arrangements. Before the mid-1990s, a small part of the inputs was manufactured and supplied on a virtually true JIT basis, involving minimal buffer inventories. In fact, Apple had implemented true JIT supply systems for selected components as early as 1983 ("Just-In-Time Inventories: Combating Foreign Rivals" 1984). However, the supply chains of most other components still involved larger buffer stocks, in most cases stored in customers' warehouses as customer-owned inventory. These components were typically supplied on the basis of a push model, with vendors reacting to relatively inflexible purchase orders, detailing a fixed amount of product and a fixed delivery date on which customers had to accept the material. Supplies could either come direct from the suppliers' manufacturing facilities or be delivered through the suppliers' regional warehouses.

Since the mid-1990s, the strategy of all focal companies has been shifting toward a "hubbing" system. In a hubbing system, suppliers that are not able to supply their customers directly from their manufacturing facilities within a certain lead time are requested to hold an agreed minimum amount of inventory at a location near their customers—the "hub." The customers very frequently pull from these hubs, either their exact material requirements or the amount necessary to replenish minimal on-site buffers. The suppliers are responsible for maintaining sufficient inventories in the hubs and hold title to these inventories. Customers own the material only

from the moment they pull it from the hubs. Suppliers produce and deliver on the basis of very flexible purchase orders, often "blanket purchase orders."

Some of the focal companies pulled material from a multitude of hubs, individually organized by the various suppliers (i.e., vendor hubs). However, there was an increasing trend toward consolidating the hubbed inventories of multiple suppliers into one or two superhubs, which significantly reduced the complexity of the pull system. Some focal companies managed their own superhubs. However, in most cases, these superhubs were owned and managed by third-party-logistics (3PL) providers that offered integrated logistics services. These "3PL hubs" could serve several focal companies.

The delivery lead-time requirements of individual focal companies varied from 24 hours to as low as 1 hour. Most 3PL hubs were therefore located close to the focal companies (see Figure 1), and some focal companies had organized hubbing facilities on-site. Such proximity allowed companies to pull materials multiple times a day, which led to extremely low inbound inventory levels on the customers' books. It is this hubbing system that partly explains the discrepancy between the use of overseas component sources and the high inventory turns published by some of the focal companies (Casey 1997; Oram 1997).

Apart from hubbing, the focal companies still used a range of other pipeline structures, including true JIT. But most structures had one thing in common with the hubbing system: they involved locally stored inventories on the suppliers' books. Thus, focal companies made increasing use of supply-chain-management companies that not only organized the logistics of components, but actually bought and held title to components until they were delivered to the assembly plants. Items that were sourced in this way could include many c-class items, cables and interconnect material, mice, keyboards, and media. From an inbound logistics point of view, there are great parallels between receiving supplies in this way and from a



Figure 1. Location of main third-party logistics hubs in Ireland and Scotland, 1998–1999.

Source: Company interviews.

local hub. In both cases, the customer very frequently pulls from agreed buffers that are located in close proximity and are owned by the supplier/supply-chain manager.

In many cases, local suppliers were requested to hold (at their own premises) minimum buffers of finished goods at levels that were similar to those requested from suppliers delivering through the hubs.

Customers did not have to take the material and did not own it until the moment they pulled it from the local suppliers. Again, in these cases, there was not much difference between a hub and a local supplier.

Through the hubbing system and most of the other pipeline arrangements, focal companies reduced their inbound inventories to a minimum by requesting suppliers

to provide JIT deliveries from finished component inventories, stored in local warehouses. Such supply systems are typically referred to as "apparent JIT" (Lamming 1993; Ryan 1997) or "pseudo JIT" (Hudson 1994). It has been suggested that these systems are suboptimal and hold no benefit for the supply chain as a whole, since the costs of inventory remain in the system (Lamming 1993). Suppliers are allegedly forced to "eat" inventories (Morris, Munday, and Wilkinson 1993; Roper, Prabhu, and van Zwanenberg 1997), and the burden of inventory is simply transferred from the customers to the suppliers. However, the use of hubs, in itself, does not necessarily mean that the supply system is suboptimal. The fact that the supply system diverges from the prototypical true JIT picture does not mean that the modern comprehensive logistics management principles are not appreciated. To determine the optimality of the supply chain, one requires data on the actual size of the inventories, the shipment frequencies, and the mode of transport. These data are presented in the next section. However, additional information on the details of the hubbing arrangements/contracts can cast some light on the issue.

With regard to the idea of suppliers being forced to eat inventories, all but one of the interviewees indicated that suppliers were compensated for hubbing. The focal companies were paying more than the standard price for hubbed components. Furthermore, hubbing contracts could involve different liability clauses, which meant that the risk of obsolescence was not always entirely transferred to the supplier. Thus, although in the case of many components, the focal companies were not liable to take the inventories in the hub at any stage, in other cases, particularly those of customized components, the focal companies had to take the material in the pipeline after a certain period. Anyway, the risk of obsolescence of hubbed materials was generally kept to a minimum by the intensive sharing of information on inventories and forecasts of demand.

So if suppliers are compensated for maintaining inventories in the hubs and the focal companies have to bear the cost of inventories anyway, the question arises: what drives the rise of hubbing? There are several advantages of hubbing. First, a hubbing system, as opposed to a system in which each individual focal company carries its own inventories, provides economies of scale in the management of industry-standard inventories and allows total inventories to be reduced, since inventories in the hubs can be, and are, switched among various focal companies. Second, most focal companies were extremely focused on indicators of short-term performance, such as return on investment, and hubbing allowed them to improve some of these indicators. As one interviewee put it: "[our company] is a public company; . . . the first thing a Street analyst will look for is our inventory and our turns. Obviously this is a huge opportunity" (interview with the operations manager, Gateway EMEA, 1999).

The use of 3PL hubs creates additional advantages over the use of vendor hubs. Both customers and suppliers can tap into the full set of integrated services offered by the 3PL providers. The bigger 3PL providers have developed or acquired core technologies and competencies in the area of logistics and supply-chain management, notably sophisticated electronic data interchange, satellite tracking, radio-frequency scanning, and automated customs handling systems.

Logistical Efficiency

The focal companies imported the vast majority of components and parts from regions outside Ireland and Britain, notably from the Far East, and the pipelines of most components involved inventories, often hubbed in local warehouses. This section discusses whether this situation reflects a suboptimal inbound logistics system that is organized on traditional Fordist, mass production principles, or whether it came about in the context of a more efficient inbound logistics system, taking account of

the modern comprehensive logistics management principles underlying JIT and TBC.

The interviews with the focal companies made clear that the costs of holding inventories in the inbound pipeline were well appreciated in all the focal companies. This point was reflected in the high level of control that the focal companies kept over the inbound inventories and pipelines, as is illustrated by the following comment:

I give [the suppliers] my material requirements plan every week for that product, and I expect them to manage the chain between them and the hub. I expect them to turn it up, down, slow it, fasten it, and manage it, so that I always have 10 days [worth of inventory] in the hub. . . . We run queries here every day by part number, which sends out an exception report which shows me what suppliers have less than 10 days. And the buyers call them. And it also shows us what we have too much of. And we than proactively take actions twice a week. . . . All the vendors are on-line to Irish Express Cargo [the 3PL hub]. All the vendors have the same kind of contact. That is a criterion that Gateway gives. (Interview with the operations manager, Gateway Ireland, September 1999)

To gain insights into how tightly the inbound inventories were managed, we asked the focal companies to provide a set of key logistics data for individual components from the various source regions. Table 2 summarizes these data. The first column lists the various material inputs. With the exception of data on microprocessors and memory, no data are presented on the components for the board assembly lines. Only four focal companies were assembling limited amounts of printed circuit boards on site. The second column lists the target buffer or inventory levels (the average for the respondent companies) that the companies tried to maintain for the various components. The data on target buffer levels represent buffers that are kept at hubs, suppliers' local/regional manufacturing facilities, warehouses of the focal companies,

supply-chain managers, or a combination of these facilities. The data do not include the (small) inventories that are kept at the plants of the focal companies in the context of hubbing or true JIT supply. In most cases, the size of these on-site buffers was minimal. Finally, the third column lists the target number of days between shipments from the location of manufacturing into the main buffer (the average for the respondent companies). This is a measure of the shipment frequency.

The key logistics data paint a picture of tightly managed inbound inventories with modest target buffer levels and high shipment frequencies. To some extent, the target buffer levels for individual component pipelines varied, depending on a number of interrelated issues that are discussed later in this section. However, all of the companies worked with a generic figure for target inbound inventory that applied to most parts and components. All but two focal companies worked toward a buffer of 10 days (of the forecasted demand) for most of their material inputs. One managed its inventories even more tightly, working toward a 5-day generic buffer level and applying a higher shipment frequency than other companies for most of its material inputs. The second worked toward a mixture of 10-day and 5-day target buffer levels.

Broken down by geographic origin, most components that were manufactured in the Far East and the Americas involved target buffers of 8 to 10 days and weekly to biweekly shipment frequencies (the averages for the respondent companies). For most materials from these regions, the typical mode of transport was an airplane,⁶ leading to relatively small inventories caught

⁶ An airplane was the typical preferred mode of transport for the following items: microprocessors; memory; partly integrated portables; autoloaders; AC adapters; hard disk drives; CD-ROM drives; zip drives; sound, video, and graphics cards; DVD drives; modem and network cards; motherboards; riser cards; mice; screws; and fasteners.

Table 2

Summary of Key Logistics Data (Averages for Focal Companies)

| | Target Buffer Levels (Days) | Target Number of Days Between Shipments |
|--|-----------------------------------|--|
| <i>Material Inputs from the Far East and the Americas</i> | | |
| Microprocessors | 4 | 2 |
| Flat-panel monitors | 5 | 5 |
| Memory | 8 | 3 |
| LCD displays | 8 | 4 |
| Partly integrated portables | 10 | 4 |
| Tape backup/autoloaders, AC adapters, hard disk drives, CRT monitors, small plastic metal parts, floppy drives, CD-ROM drives, CD-RW drives, combo drives, zip drives, docking stations, joysticks, scanners, server racks, sound/video/graphics cards, power supplies, DVD drives, modem/network cards, enclosures, motherboards/backpanels, English-language keyboards, printers, enclosures for portables, heat sinks, microphones, cooling fans, riser cards | 8–10 | 5–10 |
| Batteries for portables, speakers, mice, power cables | 13–14 | 6–10 |
| Other cables | 15 | 11 |
| Screws and fasteners | 35 | 40 |
| <i>Material Inputs from Europe</i> | | |
| Power supplies | 5 | 2 |
| Motherboards/backpanels | 10 | 1 |
| CRT monitors, tape backup/autoloaders, memory, enclosures for portables, cooling fans, hard disk drives, other cables | 8–10 | 2–4 |
| Printers, sound/video/graphics cards | 10 | 5 |
| <i>Material Inputs from Ireland and the United Kingdom</i> | | |
| Packaging; non-English-language keyboards, country kits | 2 | |
| CD-ROMs (wrapped), printed media (wrapped) | 4 | |
| Heat sinks, enclosures | 5 | |
| Hard disk drives, server racks | 6 | |
| Small plastic metal parts, modem/network cards, motherboards/backpanels, power supplies, CRT monitors, printers, Flexcircuit | 9–10 | |
| Printed labels, power cables, other cables | 13 | |

Source: Company interviews.

up in transit and relatively small fluctuations in the actual inbound inventory levels. Most components that were manufactured in Europe again involved target buffer levels of between 8 to 10 days, but shipments were more frequent—ranging from one to five times a week. All of the European materials were trucked by road/ferry, and the delivery lead time was generally less than 24 hours.

Finally, regarding material inputs that were manufactured in the United Kingdom and Ireland, although a number of compo-

nents involved very low target buffer levels—as low as two days (the average for the respondent companies)—most components involved buffer levels that were comparable to those that were applicable to items manufactured in other regions. Table 2 does not show shipment frequencies for locally sourced components, since, in most cases, the main buffers were positioned at the suppliers' manufacturing facilities and were fed directly from the manufacturing lines. The focal companies typically pulled mate-

rials from these suppliers on a daily basis or even more frequently.⁷ When the main buffers were not positioned at the suppliers' manufacturing facilities, the hubs or the customers' facilities were typically supplied very frequently—often daily or every second day. The main exceptions included modem/network cards, which were typically shipped on a weekly or biweekly basis.

Thus, the general picture is one of modest inbound target buffer levels and high shipment frequencies.⁸ Although modest compared to the traditional Western logistics systems, these inbound target buffer levels were slightly higher than one would expect on the basis of comprehensive logistics management principles alone. The market conditions that the focal companies faced, in combination with their production strategy, provide an explanation for why the inbound buffer levels were not less than optimal.

All the focal companies offered a great variety of product configurations, often customized to individual orders, in combination with extremely short order lead times—typically, the companies applied a target order lead time of fewer than five days. At the same time, the companies aimed to minimize the inventories of finished computer systems. These objectives are fully consistent with textbook TBC (Hise 1995; Stalk and Hout 1990). All focal companies addressed this combination of objectives with a built-to-order (BTO) (Schroeder

1993) production strategy for the majority of their output. The focal companies generally did not build systems to stock. Instead, computer assembly activities usually started only after a customer's order was received.

The problem was that the focal companies were facing strongly fluctuating and unpredictable demand. In such an environment, a BTO strategy, in combination with very short lead times, results in strongly fluctuating and unpredictable demand from the final assembly on upstream functions. Although a JIT manufacturing system is designed to deal with small fluctuations in demand from the final assembly, it cannot deal with highly fluctuating and unpredictable demand, since such demand brings the danger of inefficient use of labor and machinery upstream and the buildup of in-process inventories (Sayer 1986). In the factories of the focal companies, this problem was partly solved by a reduction of the number of separate phases in the production process. Production typically involved a very short uninterrupted sequence of system assembly, software downloading, testing, and packing with no in-process buffers. In a sense, the first upstream activity to be encountered was component production, virtually all of which took place outside the boundaries of the plant at the component suppliers. The problem of zero productivity of workers was addressed with numerical labor flexibility.

However, as the first upstream function, the suppliers were confronted with a highly irregular and unpredictable sequence of pulls by the focal companies. In such a situation, the virtual elimination of buffer inventories on the basis of the comprehensive logistics management principles would lead to an inefficient use of labor at the suppliers or an increased risk of stock-out. A BTO production system with short order lead times in an environment of erratic final demand simply requires certain buffers between the suppliers and the manufacturing lines of the customer, except in situations of extremely short manufacturing cycles at the suppliers. All this is totally consistent with the comprehensive logis-

⁷ Thus, most enclosures, racks, heat sinks, configured hard disk drives, and cables that were manufactured in Ireland or the United Kingdom were pulled daily or even more frequently from buffers that were positioned at the suppliers. Similarly, country kits, wrapped media, non-English-language keyboards, and packaging were generally pulled daily or even more frequently from very small (true JIT) buffers that were kept at the suppliers' premises.

⁸ The figures should be compared to the traditional Western logistics systems during the 1970s, in which it was not uncommon for components like processors to be delivered every two to three months and to be transported by ship (personal communication, Dr. Philip McCann).

tics management principles underlying JIT and TBC. In effect, the focal companies were simply trading off the costs of inbound pipeline inventories against the loss of market share and revenue because of stock-out.⁹

The same requirements of the BTO production system partly explain why the supply pipelines of components that were manufactured in Ireland, the United Kingdom, and Europe often involved similar target buffer levels as those that applied to inputs that were manufactured in the Far East or the Americas. Many of these components involved target buffer levels of 5 to 10 days. A number of items that were manufactured in Ireland or the United Kingdom tended to involve lower target buffer levels of (finished) components. However, in most of these cases, the suppliers were committed to holding the balance of the generic target levels in the form of unfinished or nonconfigured components while the final assembly or configuration process was made extremely short.

For example, four focal companies that received hard disks from Quantum in Ireland worked toward relatively low target levels of fully configured/preassembled hard disks. However, Quantum was committed to holding the balance of the 10-days' generic target buffer level in nonconfigured form, while the configuration cycle was very short and added minimal value. Three other focal companies applied the generic target buffer levels for finished hard disks.

To reiterate, there is abundant evidence that the inbound inventories and logistics pipelines were tightly managed. What can also be shown is that the impact of contextual conditions and component characteristics on the way companies managed their inbound logistics and the geography of the supply linkages was in line with the compre-

hensive logistics management principles. In the following paragraphs, we show the empirical importance of the four main issues that we introduced at the theoretical level. It is essential to note that in all cases, the eventual outcome was the result of a complex tradeoff among a variety of component characteristics and contextual conditions. Therefore, the eventual outcome does not always directly reflect the importance of an individual factor. Moreover, the characteristics of some components, notably monitors, were such that companies had a choice of different supply-chain solutions, any one of which would have been equally efficient.

Regional Differences in Labor Costs.

Regional differences in labor costs remained a strong force against a reduction of the linkage distance. The interviewees stated that producers in other regions, particularly in the Far East, could offer material inputs at a substantially lower price than could producers in Ireland or the United Kingdom, mainly because of far lower wage rates and high flexibility of the labor force, but also because of currency exchange rates. To attain total supply-chain cost-effectiveness, companies balanced the efficiencies in logistics that were gained by using local suppliers against material cost-price advantages that were gained by using suppliers in low-wage regions. In many cases, the more efficient solution involved suppliers that were located in the Far East. As one interviewee noted:

It [the reason for not sourcing monitors locally] is basically an argument between the actual unit cost and the actual component part in terms of labor content, etc. So if labor content is a high proportion of the unit cost, then it makes sense to manufacture that in a low labor cost arena. . . . So you take into account the differential between labor content and the actual transport cost, your [inventory] financing costs, and money while on the sea, etc., etc. (Interview with the logistics manager, Apple Computer Ireland, December 2000)

⁹ Bradley (1989) described a similar challenge of combining JIT principles, global sourcing, and BTO production for a volatile market in regard to the logistics operations at Bose's speaker plant in the United States.

Value, Volume, and Weight of Components. Also in line with the comprehensive logistics management principles was the fact that the inventories of components with a high unit value were the most tightly managed. In regard to material inputs that were manufactured in the Far East and the Americas, the inventories of high-value microprocessors, flat-panel monitors, and memory tended to be managed the most tightly (see Table 2). For example, on average, the focal companies and their suppliers worked toward microprocessor inventory levels that fluctuated between four and six days. The high value of these components led to a higher shipment frequency, which theoretically should have increased the tendency toward proximity. However, this force toward proximity was simply outweighed by the labor-cost savings and exchange-rate advantages involved in producing these items in the Far East, in combination with the relatively low costs involved in transporting these items frequently by air. On the other hand, the inventories of items with a low unit value, such as mice, cables, screws, and printed labels incurred limited inventory-holding costs and were managed the least tightly.

The effect of the bulkiness of individual components is most clearly illustrated by packaging material. Packaging material, although of a low unit value, required much warehouse space, thereby incurring extremely high inventory-holding costs. Therefore, packaging tended to be sourced locally on a true JIT basis involving buffer levels of fewer than one to two days and one or more shipments a day. In this case, the characteristic of bulkiness weighed stronger than the characteristic of low unit value, resulting in true JIT supply.

The bulkiness and weight of the components also had a more indirect effect on the logistics management and the geography of the supply linkages—through their implications for the mode of transport. Most material inputs that were manufactured in the Far East or the Americas were typically transported by airplane, which led to low in-transit inventories and low fluctua-

tions in the target buffer inventories. The interviewees mentioned transit times typically ranging from three to five days, including time lost at customs on both sides. However, airfreight rates rise steeply for components with a high physical volume or weight, with the result that for many components, airfreight is simply not an option on a continuous basis.

The alternative was ocean freight. The downside of ocean freight is that, compared to airfreight, it involves substantial in-transit inventories. The interviewees typically mentioned transit times of four to five weeks in the case of ocean freight from the Far East and two to three weeks from the United States. Furthermore, ocean freight involves larger fluctuations in the actual inbound inventory levels than does airfreight, even though the target buffer levels may be similar. In spite of these downsides, for many components with lower value-to-weight or value-to-volume ratios, the outcome of the trade-off of all factors was sourcing in the Far East and shipment by sea. Thus, power supplies, cooling fans, heat sinks, CRT monitors, keyboards, joysticks, microphones, scanners, speakers, printers, power cables, and enclosures that were sourced in the Far East were typically transported by ship. The downsides of ocean freight were reduced by using different ocean-freight services that offered a range of transit times and by occasionally using airfreight services.

In other cases, the combination of component characteristics and differences in regional labor costs/exchange-rate advantages led to the use of local or regional suppliers. For example, most focal companies sourced enclosures from local suppliers.¹⁰ Sourcing bulky enclosures in the

¹⁰ A number of companies imported their volume enclosure models from the Far East, because of the relatively limited volumes required—volumes that did not warrant the costs of developing a local source and the cost of a second tool. Two companies that used imported enclosures were in the process of contracting a local supplier. Less-current enclosure models and server racks were often imported from the United

Far East incurred high inventory-holding costs because of the space costs of local warehousing and high in-transit inventories that were associated with ocean freight. This strong force for proximity was not offset by the labor-cost savings associated with production in the Far East.

MES of Component Production. MES explains some of the detail in the geographic configuration at the national and regional levels. Components, such as country kits, packaging, and services like keyboard localization, can be produced or offered efficiently at a relatively low scale that requires only one customer. This allowed suppliers to set up relatively small operations in close proximity to individual customers, often in the same town or city. The production of motherboards, monitors, enclosures, and higher-end technology components involves a higher MES that requires a level of business that can exceed that offered by one or a few individual microcomputer companies. As a result, the larger operations of these suppliers tended to be located at greater distances from at least some of their customers, often in a different country on the British Isles.

Component Variety. The variety of options per component category was a relevant issue as well. The research showed that the components with a high variety of options—country kits, shrink-wrapped media, non-English-language keyboard models, and the customer-configured hard disk drives of Quantum—were indeed produced on a true JIT or virtually true JIT basis, generally by local suppliers. Holding standard target buffer levels of these components in all their possible configurations and languages would greatly increase the inventory holding costs. The local supplier facilities were involved in the delayed or postponed final assembly or configuration activities, while they were

States, again because the volumes involved did not warrant the development of a second source locally.

generally committed to holding higher buffer levels of unfinished or nonconfigured components, often produced in other regions.

Clearly, component characteristics, regional differences in labor costs, and changes in exchange rates affected the way companies managed their inbound logistics and the geography of the supply linkages. In many cases, these characteristics led to logistics systems that diverged substantially from the prototypical true JIT system. However, in all cases, the divergences were consistent with the comprehensive logistics management principles.

Conclusion

Schoenberger (1997) stated that after the era of Fordist mass production, which lasted until the mid-1970s, the capitalist world entered a new era of TBC. She argued that this transition will lead to a new geography of production, a kind of concentrated deconcentration that is organized around geographically coherent multinational market regions. One aspect of this model is the idea that the increased focus on reducing order-to-delivery cycles and logistical efficiency will lead to a greater proximity between buyers and their suppliers and an increase in local and regional production linkages. We tested the relevance of this idea in a case study of the microcomputer hardware industry in Ireland and Scotland.

It was shown that the microcomputer assemblers imported the vast majority of components and parts from regions outside Ireland and Britain, notably from the Far East, and that the pipelines of most components involved inventories, often hubbed in local warehouses. Some have interpreted such supply systems as apparent JIT or pseudo-JIT, a suboptimal inbound logistics system that is organized on traditional Fordist, mass production principles. We have argued that the logistics systems and the geography of the supply linkages were not suboptimal. The necessary inbound inventories were tightly managed, which led to modest target buffer levels and high ship-

ment frequencies. By sourcing from the Far East, companies were simply trading off price advantages that could be gained by using suppliers in low-wage regions against the efficiencies in logistics that could be gained by using local suppliers, totally consistent with the modern comprehensive logistics management principles underlying JIT and TBC. Similarly, the effects of various component characteristics were consistent with what could be expected on the basis of these principles.

The inbound inventory levels were slightly higher than one would expect on the basis of comprehensive logistics management principles alone. However, we have shown that this situation was not indicative of a suboptimal supply-chain solution. Rather, the main reason for the slightly higher levels lay in the BTO production strategies of the focal companies. Clearly, the modern comprehensive logistics management principles underlying JIT and TBC can lead to supply systems that diverge substantially from the prototypical true JIT system.

What are the lessons for industrial development policy in Ireland and Scotland? Industrial policy and the strategies of the industrial development agencies in Ireland and Scotland have long included the idea of building integrated vertical production clusters around subsidiaries of multinational enterprises (MNEs) (see Industrial Policy Review Group 1992; Turok 1997), which can be called the "local sourcing route" to cluster development (Young, Hood, and Peters, 1994, 669). The findings of this research suggest that such a strategy is becoming increasingly unsuitable, at least in the context of the microcomputer industry.

The suitability of a strategy of building integrated clusters around subsidiaries of MNEs in the microcomputer assembly industry may well become of theoretical interest only, since Ireland and Scotland have recently experienced a wave of plant closures and job losses in the microcomputer assembly industry. During the 1980s and most of the 1990s, Ireland and Scotland were important locations for computer assembly activity. Supplying the European market

with built-to-order, often customized, bulky, and relatively valuable systems with short order lead times required a production location in Europe. Within Europe, Ireland and Scotland offered the required combination of relatively low wages (on a European scale), flexible labor markets, and literate and trainable labor forces. In terms of Schoenberger's (1997) model of concentrated deconcentration, both countries functioned as the "new semi-periphery" of Europe.

The situation started to change during the second half of the 1990s. Wage rates in Ireland and Scotland were rising rapidly. At the same time, Eastern Europe was progressively opening up for capitalist economic activity, which created new production locations that offered low wages and a relatively skilled labor force, at a short distance from, and soon to become part of, the EU market.

As a result, since 1998, much system assembly activity has been shifting to Eastern European countries, such as the Czech Republic and Hungary (van Egeraat and Jacobson 2004). This shift of assembly activity, in combination with a competition-induced shakeout of branded microcomputer makers, has led to a severe reduction in microcomputer assembly activity in Ireland and Scotland. Of the original five focal companies that were operating in Ireland in 1998, only Dell and Apple were still assembling microcomputers, and Apple's system assembly operation was substantially downsized by 2003. Similarly, of the six original focal companies in Scotland, only Sun, Packard Bell-NEC, IBM, and Compaq/HP were still assembling systems by 2003, and IBM and Compaq/HP had significantly downsized their assembly operations while Packard Bell-NEC was planning to close its plant. The reduction of computer assembly activity resulted in further job losses in the component sector, notably in plants that produced the bulky enclosures that had always required relative proximity to the system assemblers.

Clearly a strategy of building integrated vertical clusters around manufacturing

subsidiaries of MNEs does not look promising in the context of Ireland and Scotland. The alternative route identified by Young, Hood, and Peters (1994, 669) is through "technological innovation." Here, technological cluster development may be stimulated through cooperative research-and-development projects involving companies, university research laboratories, and governmental research institutions. This appears to be the more appropriate route for Ireland and Scotland to take. Both IDA Ireland and Scottish Enterprise have indeed adopted elements of such a strategy.

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