Product Innovation in Small and Large Enterprises

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ABSTRACT. Innovation networks, establishment characteristics and the regional environment are likely to play different roles in product innovation in enterprises of different size. This paper focuses on the influence of the regional environment on the early adoption of micro-electronic components in product development in small and medium-sized enterprises (SMEs) and large enterprises (LEs). Drawing upon existing literature we compare the role of enterprise characteristics, innovation networks and, in particular, the regional environment for an early use of micro-electronic components in product development in SMEs and LEs using a tobit model. Our central hypothesis is that SMEs are more dependent upon their regional environment than LEs for an early adoption. However, this hypothesis is rejected by our empirical results that show that location in a large, dense region has a significant positive effect on product innovation in LEs, while it has a negative but non-significant effect on product innovation in SMEs. Our results imply peripheral regions are able to provide an innovative environment for SMEs, whereas LEs need the richer environment offered by the core regions. The results are also interesting from a policy point of view because they indicate that SMEs can be early users of new technologies even if they are located outside the large urban areas.

1. Introduction

Despite lying at the heart of a market economy product innovation has not been of a major interest to main stream economists.

It has been argued that product innovations are the outcome of a process, which is based upon the principle "novelty by combination" (Georgescu-Roegan, 1970). This characterisation applies well to the type of product innovation analysed in this paper, which comprises the development of new products and the renewal of old products through the incorporation, i.e. the adoption, of micro-electronic components and their pertinent software.

Product innovation does not take place in isolation. It results from either 'random collisions' or a cautious matching between technical opportunities and customer needs. A necessary condition for such 'collisions' or matching is communication. Hence, communication in innovation networks is one key factor in product development. Another key factor seems to be the availability of sufficient background knowledge and competence within the enterprises themselves. A third key factor is the regional environment, since these provide very different conditions for product innovation in terms of agglomeration economies, infrastructure supply, and so on.

Innovation networks, establishment characteristics and the regional environment are likely to play different roles in product innovation in enterprises of different size. This paper focuses on the influence of the regional environment on the early adoption of micro-electronic components in product development in small and medium-sized enterprises (SMEs) and large enterprises (LEs). Drawing upon existing literature we compare the role of enterprise characteristics, innovation networks and, in particular, the regional environment for an early use of micro-electronic components in product development in SMEs and LEs. Our central hypothesis is that SMEs are more dependent upon their regional environment than LEs for an early adoption.

The outline of the paper is as follows: In Section 2, we provide a general introduction to the nature of innovation. Section 3 tries to answer

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questions such as i) which factors give enterprises the impetus to perform innovative activities, ii) what role do the suppliers, customers and innovation networks play for innovation adoption, and iii) which regional environments are most favourable to innovative activities. Innovative activities in SMEs and LEs are considered in Section 4. Our own framework is presented in Section 5, where we formulate our hypotheses. The empirical data and the estimation procedures are described in Section 6. The empirical results are presented and discussed in Section 7, while in Section 8 we draw some conclusions.

2. The nature of innovation

Innovation is not a homogeneous term. As Biemans (1992, p. 6) remarks: "*Each writer presents a new definition, emphasizing the elements he or she deems relevant.*" In a neo-Schumpeterian tradition, Roberts (1988) makes a clear distinction between invention and innovation. Invention, he argues, is the generation of an idea while innovation incorporates both invention and exploitation. In the same tradition, Elam (1993, p. 102) defines innovation as ". . . *the combining of materials in a novel fashion to produce other things, or the same things by a different method*." However, Urabe (1988) claims that an innovation, per definition, also must result in some kind of positive development such as growth in the national economy, increased employment, or pure profit for the innovative enterprise.

The term innovation usually refers to one of three concepts (Biemans, 1992): i) The process of developing a new item. ii) The process of adopting a new item. iii) The new item itself. To avoid any confusion we will refer to innovation as the new item itself (iii) while the process of developing the new item (i) will be referred to as 'product or process development'. The process of adopting the new item (ii) will be referred to as 'innovation adoption'.

The most common classification of innovations is probably the distinction between **product** and **process** innovations (Karlsson, 1988; White et al., 1988; Utterback and Abernathy, 1975), to which Thom (1990) adds a third category: **social** innovations, which incorporates various improvements in human resource management. However, these different types of innovations do not develop separately, with for instance, an innovation in the process of manufacturing usually leading to product changes.

Another classification criterion is the innovation's degree of "radicalness". Four categories can be distinguished (Freeman, 1992): i) **Incremental** innovations which occur more or less continually and have minimal economic impacts. ii) **Radical** innovations which are discontinuous events resulting in major technical change. iii) **New technological systems** which are constellations of innovations with major economic impacts and a major degree of technical change. iv) **Changes of techno-economic paradigm** which completely alter the whole society and appear in long waves.

These long waves are equivalent to Josef Schumpeter's Kondratieff cycles, which are considered to last 50–60 years (Schumpeter, 1939). A Kondratieff cycle emerges when new technologies make whole industries obsolete in a process characterised by "creative destruction". The result of this process is a new techno-economic paradigm, i.e. a new way of scientific thinking, and once this has been established, the development follows a new technological trajectory (Nelson and Winter, 1977; Dosi, 1988). The existence of technological trajectories implies that innovative activities are highly selective and finalised in quite precise directions.

To understand the nature of product innovations it is also vital to understand the product's life cycle. Vernon (1966) assumes that a product after its initiation passes through a period of adaptation and improvement, usually referred to as the innovation phase. This is followed by a growth phase, a maturity phase and eventually, a decline phase. Hence, the product life cycle theory suggests that product development occurs mainly in the early stages of a product's life. In a further development of this theory, Utterback and Abernathy (1975) claimed that process development reached its peak in the maturity phase of the product's life cycle.

3. Determinants of innovation adoption

Section two defined innovation adoption as the process of adopting a product, process or social innovation. This part discusses several theories of innovation adoption focusing upon product and process innovation. We will try to answer questions such as why firms adopt innovations and what gives firms the impetus to perform innovative activities. The discussion will include internal factors such as R&D and the availability of skilled labour, as well as the roles played by customers and suppliers. Lastly, we will introduce the spatial dimension in our analysis and present the latest contributions to innovation network theory.

3.1. *Internal sources of product and process development*

This part discusses the determinants of innovation adoption and innovative behaviour at the firm-level. However, at this stage it must be emphasised that product and process development are not important features of every industry. Dosi, Pavitt and Soete (1990) distinguish between three main groups of industries: i) supplier-dominated industries in traditional sectors, ii) production-intensive industries with scale economies or specialised suppliers, and iii) science-based industries with knowledge-intensive production. Of these, product and process development are generally not performed at all in supplier-dominated industries while some process development is done in production-intensive industries with scale economies. These industries are seldom referred to as innovative.[1] The remaining categories, however, have product development as a particularly important feature and are considered as innovative industries. It is among these enterprises we find the high-technology firms in which students of innovative behaviour have shown so much interest.

The next stage in our investigation is to identify the sources of innovative behaviour within these firms. To do this, it is convenient to commence with linear models of product and process development. Such models usually depict different stages in the development process (Biemans, 1992). Here, we will discuss activity-stage models, sometimes referred to as "value-chains" (Botkin and Matthews, 1992; Porter, 1990), and departmental-stage models.

An activity-stage model typically has the following appearance (Docter et al., 1989): i) formation of ideas, ii) economic feasibility, iii) tentative technical elaboration, iv) concretization, v) adjustment of production means, and vi) introduction. Though this particular model refers to product innovations, the process of process development is quite similar. However, as one might expect, empirical studies have shown that the process is much more complicated in reality (Docter et al., 1989).

A departmental-stage model usually assumes that a product innovation passes through the following departments (Biemans, 1992): i) R&D, ii) design, iii) production, and iv) marketing. Naturally, this is also an over-simplification. In reality, there is often a complicated pattern of interaction between the various departments. Process development, on the other hand, certainly does not engage the marketing department. In both cases though, the R&D department plays a crucial role.

There appears to be much support for the view of R&D as "the engine of innovation" (Botkin and Matthews, 1992), but it has also been pointed out that this engine in fact has two main functions: firstly, as a direct source of product and process innovations, and secondly, to develop and maintain the broader capabilities to exploit and assimilate externally available information (Cohen and Levinthal, 1989). Furthermore, Gamser (1988) suggests that commitment to R&D and maintenance of a wide variety of skills will make it easier for the firm to adapt to changing requirements for successful product and process development. The probability of a firm engaging in R&D has been found positively related to its size, to its export intensity, and, not surprisingly, to activities in innovative markets (Kleinknecht and Poot, 1992).

Another vital factor for successful product and process development is the firm's access to skilled labour, especially in the early stages of the product life cycle (Karlsson, 1988). As we have seen, these stages are characterised by R&D activities. Naturally, there will be no progress in the R&D department unless it has highly skilled engineers and scientists. But product and process development are not only related to R&D activities. Development also occurs in the units of production through "learning-by-doing" (Arrow, 1962). This simple concept has been further developed in a number of ways (Malecki, 1991). It has also been recognised that the speed of learning is a crucial factor, especially in high-technology industries. As a result, "learning curves" have become an important concept and a tool of analysis of, for instance, monopoly profits for innovative firms (Stinchcombe, 1990).

Although the general level of skill is important, there are a number of key roles in a firm that are critical to the success of innovative activities (Roberts, 1988): i) idea generators, ii) product champions, iii) program managers, iv) gatekeepers or special communicators, and v) sponsors. The effective development of a technical organisation requires recognition of these roles. It is also necessary with some form of functional integration between the various departments (Roberts, 1988). Here, the strategic management plays an important role.

Although the management department mainly deals with strategic planning and co-ordination, a number of studies have shown that owners of SMEs play a direct role in the product development process, often as idea generators (Hartman et al., 1994; Docter et al., 1989; White et al., 1988). However, one of management's most important tasks is to encourage "intrapreneuring" (Botkin and Matthews, 1992) by developing a creative climate. Kono (1988) suggests that four factors affect the creativity of organisations: i) competent and creative personnel, ii) good research facilities and abundant input of financial resources, iii) freedom of research, and iv) adequate rewards for creativity. Another possible strategy is to promote flexibility, which is assumed to enhance the rate of innovation (Bramanti and Senn, 1990). Dosi (1988) shows there is a possible trade-off between flexibility and economies of scale.

Finally, during the last decade strategies aimed at the firm's external environment have become of greater interest. This will be discussed later.

3.2. *Customers and suppliers, and the demand-pull/science-push debate*

The innovation process differs in different sectors. For instance, in supplier-dominated industries, suppliers play an all important role but almost no role at all in most production-intensive industries with scale economies. However, our analysis will mainly deal with innovative industries where product development dominates.

Demanding customers/users and advanced suppliers are essential sources of new ideas (Porter, 1990). Von Hippel (1978) claimed to have observed how customers in the industrial sector developed an idea for a new product, selected a supplier capable of making the new product, and eventually took the initiative to send a request to the chosen supplier. To describe this phenomenon, he invented the concept *Customer Active Paradigm* (CAP) as opposed to the *Manufacturer Active Paradigm* (MAP) which he had observed in non-industrial markets. Later, von Hippel (1988) presented evidence that suppliers and, more often, customers in certain industries actually developed a complete prototype before introducing it to the manufacturer.

Apart from von Hippel, little recent research has investigated the roles played by suppliers and customers in innovation adoption. Today, most studies utilise a network perspective. However, from the mid 1960s there was an intense debate on whether innovations were mainly caused by "demand-pull" or "science-push" (for an overview, see Dosi, 1988).

Proponents of science-push were initially inspired by Schumpeter. In his early works, Schumpeter considered scientific progress as an exogenous variable with clusters of innovations occurring in the beginning of each long wave (entrepreneurial innovation). Later on, Schumpeter claimed the innovation process had become endogenous and "routinized" with the emergence of ambitious R&D departments within large firms (managed innovation). This duality in Schumpeter's works has been referred to as "the two Schumpeters" by later observers (Freeman, 1992). Both explanations, however, highlight the importance of scientific and technological advances as a determinant of product development.

The opposite view, the demand-pull argument, is usually considered to originate from Schmookler (1966). By studying the evolution over time of patents and investment, Schmookler concluded that market growth and market potential were the main determinants of innovative activities. With this, the debate started. Today, when the focus has shifted to other issues, most authors suggest that demand-pull is a more important influence than science-push (Dosi, Pavitt and

Soete, 1990; Roberts, 1988) although Davelaar and Nijkamp (1989), for instance, find some support for the opposite viewpoint.

By introducing the aspect of time into the analysis, some important insights can be gained. In the short run, demand can be assumed to be the most influential factor, causing incremental changes along the technological trajectory. In the long run, however, science leads to the emergence of new paradigms, product cycles, and radical innovations (Green, 1992). This is probably the best conclusion to a debate that nowadays is seen as rather naive. It has been recognised that a sole focus on the demand side, on the supply side, or on the firm itself is not sufficient to explain the complex nature of innovation adoption. In other words, we need an inter-active model.

3.3. *Innovation networks and the spatial dimension*

The most popular approach during the last couple of years in the study of innovation adoption is probably the network view. It has been claimed that the view of actors collaborating in a network is an alternative to the traditional theories in economics where competition and power are key concepts. It has also been pointed out that the network approach incorporates market imperfections like the presence of uncertainty and externalities, factors that traditional theory has neglected (Camagni, 1991). And although the field has attracted students of both business and regional economics, there have also been important contributions from sociologists and geographers.

In its most elementary form, a network consists of nodes, connected through links. Between these nodes, flows of different character are heading from "sources" to "sinks" (Johansson, 1993). In this form, networks can be studied mathematically (Nagurney, 1993), but no such exercises will be performed here. Håkansson (1989) has further developed this model. According to him, a network consists of: i) actors, ii) resources, and iii) activities. The nature of these three components differ depending on what type of network is studied. Here, we are studying innovation networks. Thus, the actors (nodes) in our network are mainly enterprises of different size, operating upstream and downstream. Resources include input goods, financial capital, personnel, and above all technology. These resources flow from "supply nodes" (sources) to "demand nodes" (sinks) through different kinds of activities (including "transformation" and "transaction" acts) performed by actors.

Transformed resources (Håkansson, 1989), ready for transaction from one node to another, are called intermediaries. In a discussion of "techno-economic" networks, Callon (1992) distinguishes between four types of intermediaries: i) texts, such as reports, books, articles, and patents, ii) technical artefacts, such as scientific instruments, machines, robots, and consumer goods, iii) human beings and their skills, and iv) money, in all its forms. These intermediaries flow from one enterprise to another through various formal transaction activities such as i) joint ventures, ii) technology exchange agreements, iii) licensing, iv) sub-contracting, and v) computerised data banks (Freeman, 1992). However, exchange of intermediaries also occur through more informal channels, and evidence suggests these channels are equally important (von Hippel, 1988).

Of course not all enterprises engage in collaborative relationships. Some prefer to stay isolated (Håkansson, 1989). One might indeed ask why enterprises establish networks based on collaboration at all? Are they not supposed to be rivals? Wissema and Euser (1991) list six reasons for collaboration: i) to share costs, ii) to share risks, iii) to gain additional market knowledge, iv) technical and market knowledge complement each other, v) to serve an international market, and vi) to develop industry standards together. Thus, the goals of network interaction can be summarised as i) economies of scale and scope, and ii) to reduce uncertainty (Camagni, 1991). Bramanti and Senn (1991) further suggest that networking will appear mainly in industries operating in that phase of the product life cycle when innovation is incremental. Freeman (1992) points to the key role of information technology systems in the evolution of networks in the 1980s.

We now attempt a clearer and more robust definition of an innovation network. According to Camagni (1991, p. 135), an innovation network reflects formal, manifest relations between enterprises:

> . . . a network may be defined as a closed set of selected and explicit linkages with preferential partners in a firm's space of complementary assets and market relationships, having as a main goal the reduction of static and dynamic uncertainty.

The informal and latent relationships between economic and social actors that are not included in this definition, but nonetheless are parts of a local economic system, constitute what we, following Camagni (1991), will refer to as the **local environment**. Thus, we have introduced the spatial dimension in our analysis.

What we call the local environment has great similarities to other concepts such as the "Marshallian industrial district" (Becattini, 1991) and the "territorial production system" (Crevoisier and Maillat, 1991). Apart from autonomous actors such as universities (which might or might not be present) and governments, a local environment consists of various latent relationships that are hard to clearly define such as "image" or "sense of belonging" (Camagni, 1991). It has been discussed by many authors that certain factors in the local environment stimulate innovative and entrepreneurial activities (Malecki, 1991; Davelaar and Nijkamp, 1989). Kamann and Nijkamp (1990) identify the following eight factors as highly important for the creation of innovations: i) creative entrepreneurial environment, ii) presence of research institutes that may act as breeding places, iii) presence of a highly-skilled labour force, iv) public support for R&D activities of new innovative firms v) availability of venture capital, vi) availability of inexpensive areas for new innovative entrepreneurs vii) access to information, and viii) international accessibility.

However, not all localities are endowed with these factors. Some areas dominate over others. The most common way of describing this is through the "core-periphery" paradigm. The core is a centre of economic activities. It is connected via many means of transport and has many network links with the surrounding area and to other cores. The production of goods and services is diversified and uses advanced technology and highly skilled labour. The periphery, on the other hand, is quite the opposite. Its accessibility is low and it is politically and economically dominated by the core. Production tends to be standardised with low wages and no advanced technology. It exports labour and imports finished wares (Malecki, 1991). The diffusion of innovation is thought to "filter down" from an international core to national and regional cores, and through their networks to the periphery (Ratti, 1991).

Obviously, the core presents the best opportunities for innovation, at least in theory. In terms of the product life cycle, the core performs the innovative first phase when production is knowledge intensive. As the manufacturing process becomes standardised, production is shifted to the periphery where innovation, if it occurs, tends to be incremental and aimed at process development (Utterback and Abernathy, 1975; Vernon, 1966). The core, in terms of an urban area, often acts as a "seedbed" or "incubator" of innovative firms (Kamann and Nijkamp, 1990). However, the same authors also suggest the possible existence of an urban life cycle. Dynamic metropolitan areas with attractive environment often develop bottleneck factors such as high wages, high rents, and traffic congestion that eventually might lead to a crowding-out of the most flexible firms. It has further been suggested that attractive living conditions have become an important factor in firms' choice of location (Kamann and Nijkamp, 1990;) and that development generally seems to be faster in rural areas (Suarez-Villa and Karlsson, 1996).

Innovations tend to appear in clusters, both in time and space (Porter, 1990). The most famous example of a highly innovative area is probably Silicon Valley in the United States. As might be assumed, innovative areas are often located within or adjacent to core regions (Malecki, 1991) in locations characterised by the favourable environmental factors noted above. However, empirical findings have shown the pattern is far from homogeneous. Different factors play different roles in different places. An extensive empirical study by Davelaar and Nijkamp (1989) shows that the link between a favourable production milieu and a firm's innovativeness (output of innovations) is generally weak and that remote areas are in fact well equipped with firms with innovation potential (input of factors considered to be innovation enhancing).

4. Large versus small/medium sized enterprises

This section investigates the different characteristics of large and small/medium sized enterprises and discusses the implications of these differences for innovation. External factors such as industrial structure and local environment will be discussed, as well as internal factors such as management, marketing, R&D and finance.

4.1. *External factors*

To begin with, what determines an enterprise to be called small/medium sized (SME) or large (LE)? Most authors use an employment criteria: SMEs are enterprises employing less than 500 people. There is also often a distinction between small enterprises (<100 or <50 employees) and medium sized enterprises, but the general discussion is usually in terms of LEs versus SMEs.

Which category of enterprises is the most innovative, SMEs or LEs? This question has been debated for a long time and, as usual in economics, two camps have reached diametrically opposed conclusions. On the one hand are the Schumpeterians in favour of the LEs, on the other are the proponents of classical theory favouring SMEs (Rothwell and Zegveld, 1982). The Schumpeterian version states that because of high barriers to entry, innovative activities require considerable market power and hence take place in LEs. Thus, a monopoly market, stemming from one company's production and market advantages (Stinchcombe, 1990), provide the most favourable circumstances. Eventually, the innovation process will become routinized and the economy as a whole therefore stabilised.

This view has been challenged from many angles. Oakey et al. (1988) show that SMEs' share of all innovations since 1945 has increased, in contrast with Schumpeterian predictions. Acs and Audretsch (1990) find innovation is not stimulated by monopoly power or high concentration. Pottier (1988) suggests that LEs often ignore innovative opportunities and seek to safeguard their existing monopolistic position. SMEs are actually not deterred from entering capital-intensive industries (Acs and Audretsch, 1990) and persisting barriers to entry such as uncertainty can be reduced by network collaboration (Camagni, 1991). To summarise, whilst monopoly power does not stimulate innovation, the question on whether LEs or SMEs are the most innovative is unsettled.

Intuitively, one might assume that SMEs are more dependent on their external environment than LEs. SMEs are usually locally based and strongly influenced by what happens in their home community, whereas LEs tend to be international and more flexible in the location of their production. Pottier (1988) distinguishes between endogenous regional development, based upon locally integrated SMEs, and exogenous development, initiated by LEs from the outside. The endogenous development model has attracted attention from regional policy-makers because of SMEs' proven capacity to generate new jobs (Acs and Audretsch, 1990; Maillat, 1990). LEs' role in regional development has declined because of their propensity to close plants irrespective of the local consequences. It has also been recognised that standardised production in the maturity or decline phase of a product life cycle contributes comparatively little to dynamic regional development. However, if the large plant is located at the same site as the headquarters and the R&D department, innovative activity is much greater (Oakey et al., 1988).

Although SMEs are generally more dependent on local customers and suppliers, this is less characteristic of innovative firms (Oakey et al., 1988; White et al., 1988). Instead there seems to be a positive relationship between innovativeness and propensity to export (White et al., 1988). Nevertheless, LEs do have advantages in external communication since it is much harder for an SME to update its technical knowledge than for an LE which is also to send people to conferences and seminars all over the world (Rothwell and Zegveld, 1982). Therefore, the existence of local networks is vital for SMEs. This importance also stems from SMEs' inability to internalise all the elements of the innovative process (Maillat, 1990) and because network co-operation will provide economies of scale that SMEs otherwise would not have attained (Camagni, 1991). A number of studies also confirm the importance of external sources of information for SMEs (SBRC, 1992).

The provision of network channels has consequently become a relevant issue in discussions on regional policy (Wilson, 1992).

One field where SMEs seem to be at a serious disadvantage is their ability to cope with government regulations (Rothwell and Zegveld, 1982). Large firms, on the other hand, have the ability to fund legal services and direct their R&D department to identify the measures that need to be taken. LEs also have a pre-regulatory advantage since they are usually able to fund various lobbying activities. They also have a stronger position vis-à-vis public agents when it comes to negotiations, because of their role as a major local employer.

4.2. *Internal factors*

Labour can naturally be seen as both an external and internal factor. Externally, LEs have an advantage in the sense that they can decide to locate wherever there is the manpower with the required skills, while SMEs with a stronger territorial base, have to rely more on the labour that the home region can offer. SMEs also have difficulties in attracting skilled labour (Rothwell and Zegveld, 1982). LEs usually offer higher wages and greater security.

Yet it is the management of labour inside the firms that produces innovations. In the R&D department, skilled labour is particularly important. Apart from their difficulties in attracting prominent scientists and engineers, SMEs also suffer the disadvantage in conducting R&D because of the inherent risks (Acs and Audretsch, 1990; Rothwell and Zegveld, 1982). Even if a research project in a LE does not result in what the project leaders had hoped, its outcome may be beneficial to the firm because of its greater diversity of production, whereas a failure in an SME might be financially disastrous. Even so, Oakey et al. (1988) and White et al. (1988) refer to investigations which show that a considerable number of SMEs perform some kind of R&D. And although it might be possible for SMEs to survive on solely external sources, some form of internal R&D capacity appears to be essential (Oakey et al., 1988).

Some of the most obvious advantages that LEs have over SMEs concern the economies of scale and scope in production (Acs and Audretsch, 1990; Rothwell and Zegveld, 1982). If high fixed costs are involved in the setting up of a plant, these often pose a serious barrier to entry for SMEs. However, high technology small firms usually do not operate in industries with scale economies except as subcontractors of advanced components.

When the product is produced, marketing is the next stage. Rothwell and Zegveld (1982) claim that this area presents an advantage to SMEs. SMEs are more flexible and less bureaucratic and are able to react quickly and efficiently to both market and technological changes. On the other hand, Oakey et al. (1988) state that, apart from the logistical problems that stand in the way, poor or non-existent selling efforts are major barriers to increased sales in SMEs.

The balance of advantage between LEs and SMEs in finance seems unambiguous. LEs can spread their risk through having a portfolio of projects at different stages of completion (Rothwell and Zegveld, 1982). LEs also have less difficulty in raising venture capital. SBRC (1992) shows that lack of finance is one of the most important factors limiting SMEs' introduction of new technology. Venture capitalists often seem to be reluctant to generally fund high technology investments because of their long lead times. Bank financing for longer term investments is also hard to attract for SMEs. This leaves as remaining options either internally generated funds, informal risk capital or joint projects with LEs. However, White et al. (1988) suggest that the problem of financing is often a more serious obstacle in process development than in product development due to the high costs of machines and their installation.

The most frequently cited advantage of SMEs is their dynamic, entrepreneurial management, which can react quickly to a changing environment, whereas LEs are bureaucratic and less flexible (Rothwell and Zegveld, 1982). In SMEs, management takes active part in the innovation process, even as idea generators (Hartman et al., 1994). The best researchers remain at the heart of the innovative activities and are not promoted to conduct administrative functions as is often the case in LEs (Acs and Audretsch, 1990). Internal communication is generally faster and more efficient in SMEs (Rothwell and Zegveld, 1982). Howard (1992), referring to an investigation by James Quinn, lists three principal barriers to innovation in LEs: i) top management is isolated both from customers and from conditions on the factory floor, ii) entrepreneurial fanatics are not tolerated, and iii) the emphasis on the short term and the use of inappropriate accounting practices which cause executives to favour cost-cutting over longer-term infrastructural enhancements. However, Rothwell and Zegveld (1982) also suggest that SMEs might become dependent on a few entrepreneurial persons without whom the enterprise simply could not survive. The entrepreneurial management's lack of formalised planning might be another source of SME disadvantage.

SMEs' advantages in innovation can be summarised as **behavioural**, including a dynamic and entrepreneurial management and efficient network co-operation, while LEs' advantages are mainly **material**, with easier access to skilled labour and finance, economies of scale and scope in production, and a greater influence on their environment (Rothwell, 1989). An ideal type of innovative SME devotes effort to develop external business contacts and links, exploits its network to get new product ideas and technical information, avoids being dominated by local customers and industries, and uses its product capability to diversify and export (White et al., 1988).

5. A framework for the empirical study

The empirical part of this paper focuses on product innovation in the form of the development of new products and the renewal of old products through the adoption of micro-electronic components and their pertinent software. In the traditional von Hippel framework product development is analysed in terms of a relationship between manufacturer and customer and their respective behaviour. For our purposes this is a too simplified model of an innovation network. Instead, we suggest that the basic innovation network should include not only the manufacturer and the customer but also suppliers of fundamental inputs – in this case the micro-electronic components and the relevant software.

The central function of the innovation network is to enable a reciprocal exchange of information between the manufacturer and the customer and between the supplier and the manufacturer. However, not all information and technical know-how is transferred directly from the supplier to the manufacturer. Instead it can be transferred via intermediaries, such as technical journals and trade magazines, consultants, fairs and exhibitions, courses and conferences, universities and R&D-institutes, and so on. Thus, the innovation network of a manufacturing enterprise consists not only of links with customers and suppliers, but also of links with different intermediaries.

The ability of an enterprise to construct an innovation network depends upon the knowledge and competence found within the enterprise as does the ability to use innovations supplied by suppliers to develop new or renewed products. The knowledge and competence found within an enterprise can be assumed to be strongly correlated with the formal educational achievements of the existing staff. In other words, educated staff is important for the early use of innovations for product development.

The regional environment also influences product development through innovation adoption. As was shown in Karlsson (1994), the more developed the intra- and interregional infrastructure, the higher the probability that an enterprise will be an early adopter of micro-electronics in their products. A more developed infrastructure can be assumed to increase the accessibility to knowledge and information essential to product development, as well as, to qualified manpower. Accessibility to qualified manpower in a region increases, for example, the probability that key personnel within an enterprise will meet other persons carrying useful knowledge. This knowledge may have been created within the region or, more often, in other regions. Regional environments also differ in terms of the availability of different kinds of services, of specialised suppliers, and so on. The size of a region in terms of the total number employed or the labour density of a region measured, for example, by the number of employed/km^2 could be used as indicators of this availability and, hence, of the presence of agglomeration economies. Thus, all other things being equal, enterprises located in "richer" regional environments can be expected to adopt innovations earlier for product development than enterprises located in "poorer" regional environments (Karlsson, 1994).

Within this framework we now analyse how dependent enterprises of different sizes are on their innovation networks, the educational qualifications of their staff and their regional environment. Because of their size SMEs contain a smaller number of highly educated persons than LEs. Hence, we expect SMEs to be more dependent upon their innovation networks and their regional environment for product development through innovation adoption than LEs. This is the general hypotheses that we test in the rest of this paper.

6. The data and the estimation procedures

The data used in this study comes mainly from a postal survey of establishments[2] with more than nine employees in the machinery, electrical equipment and instrument industries. The data has been collected in three Swedish counties – Stockholm, Värmland and Älvsborg – and in the mining district that consists of parts of six Swedish counties. With the exception of the county of Stockholm a total survey covering all establishments in the relevant industries was made. For the county of Stockholm a stratified sample was used.[3] The data was collected in the mid 1980s. Full information exists for about 75% of the total number of the establishments included in the surveys. The results presented here are based on the statistical analyses of 270 establishments. In our empirical study we define an establishment as an enterprise and define LEs as enterprises employing more than 50 employees and SMEs as those employing between 10 and 50 employees.

To the data from the postal survey we have added census data for the municipalities and the labour market regions (A-regions) where the establishments are located. A-regions are defined as aggregates of municipalities connected by labour force commuting. From the census data we include the working day population of each municipality and each A-region which gives us a measure of the size of each municipality and each A-region. We also have data on the area of each municipality and each A-region which enable a density measure (working day population/km^2) for each municipality and each labour market region to be computed.

We also added the infrastructure index for each municipality developed by Johansson et al. (1991). This provides an overall measure for each region of the intra- and inter-regional infrastructure supply as regards the engineering industry. Descriptive statistics of the variables used in the study are presented in Table I.

The current study seeks to identify the characteristics of early adopters of innovations, including factors such as their regional environment. Karlsson (1988) reviewed the characteristics of early adopters of innovations. The use of regression analysis to characterise early adopters of new techniques dates back to Mansfield (1963), whose approach has been used in several more recent studies. In some of these studies the authors had to deal with a problem – the censored data problem – which Mansfield did not have to contend with, namely that the innovation(s) had not diffused to 100%, i.e., their material contained enterprises which were classified as potential adopters but which had not yet become adopters at the time of investigation. Four approaches to this problem are possible:

(i) To ascribe a hypothetical adoption date to the non-adopters (Karlsson, 1988).
(ii) To base the assessment on adopters only thereby leaving out the information available about non-adopters.
(iii) To use logit analysis (Anderstig and Karlsson, 1989).
(iv) To use tobit analysis (Akinola and Young, 1985).

Each method exhibits certain weaknesses. Methods 1 and 2 are likely to produce biased estimates. The logit model does not distinguish between early and late adopters. The application of logit and tobit models to spatial data might generate inconsistent estimates (McMillen, 1992). We have chosen here to use tobit analysis, as we consider it to be the most useful of these methods. The model used is described in Karlsson (1994).

7. Empirical results

The empirical results of the current study are summarised in the Tables II and III. The basic model used here was developed in an earlier study using

TABLE I
Descriptive statistics of variables used in the study

VARIABLE	MEAN		STD. DEV.		MIN.		MAX.	
	LEs	SMEs	LEs	SMEs	LEs	SMEs	LEs	SMEs
Micro-electronics in products (years)	5.89	2.22	6.47	3.83	0	0	26	18
Universities important information channel (yes/no)	0.07	0.01						
Corporation important information channel (yes/no)	0.25	0.07						
Suppliers of micro-electronics important information channel (yes/no)	0.47	0.28						
Courses, etc., important information channel (yes/no)	0.28	0.12						
Customers important information channel (yes/no)	0.19	0.12						
Share of college engineers	0.16	0.19	0.15	0.23	0	0	0.86	1.0
University engineers employed (yes/no)	0.79	0.29						
Electrical engineering industry (yes/no)	0.30	0.21						
Instruments industry (yes/no)	0.13	0.08						
Labour force density in the labour market region	156.5	70.8	126.4	107.4	3.17	3.17	265.8	265.8
Labour force density in the home municipality	960.2	292.2	1235.6	753.9	2.0	3.0	2720	2720
Infrastructure index for the engineering industry (home municipality)	38.07	32.3	10.8	8.4	20.7	23.9	72.1	72.1
Labour force in the labour market region (000)	529.3	267.5	408.4	348.3	11.9	11.9	877.6	877.6

the data for the 270 establishments as a whole (Karlsson, 1994).

Equation 1 in Tables II and III includes data on innovation networks and enterprise characteristics. The dependent variable is the number of years since the first adoption of micro-electronics in products. The model is well specified for LEs (Table II) but less so for SMEs (Table III). Examining the differences between LEs and SMEs we find that having universities and customers as important information channels stimulate an early adoption among LEs, but does not for SMEs.

The university engineer exerts a positive influence on early adoption of micro-electronic components among LEs but not among SMEs. For the latter it looks as if good links with suppliers, in particular, are valuable. There are no clear sectoral differences in adoption behaviour.

Equations 2 to 5 in Tables II and III introduce four variables seeking to isolate the influence of the regional environment on innovative behaviour among LEs and SMEs. Equation 2 includes the infrastructure index variable but finds it is non-significant for both SMEs and LEs.

Equation 3 uses the size of the regional labour force, i.e. the size of the total working day population in the labour market region. This can be considered as a proxy for the presence of agglomeration economies. This exerts a significant positive influence on the early adoption of micro-electronic components for product development among LEs. Among SMEs, however, it has a (non-significant) negative influence. Product development among LEs in the form of adoption of microelectronic components seems therefore to be stimulated by agglomeration economies, whereas this is not the case for SMEs.

Equation 4 in Tables II and III introduces another aspect of the regional environment, namely the labour force density in the labour market region. It finds the early use of micro-electronics in products in LEs is positively stimulated by a high labour force density in the labour market region where the enterprise is located. However, for SMEs the influence is negative (but non-significant). The labour force density index reflects, among other things, the chances of meeting people. Thus, the opportunity to have

TABLE II
Innovation networks, enterprise characteristics, regional characteristics and the use of micro-electronics in products among large enterprises (LEs)

Variable	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
Intercept	–9.28* (–4.38)	–12.05* (–4.11)	–10.28* (–4.72)	–10.14* (–4.67)	–9.75* (–4.51)
Universities import. information channel[1]	5.24* (2.31)	4.66* (2.06)	4.68* (2.12)	4.78* (2.16)	4.66* (2.05)
Corporation import. information channel[1]	5.43* (3.79)	5.53* (3.77)	4.93* (3.35)	4.93* (3.33)	5.53* (3.78)
Electronics suppliers import. info channel[1]	3.43* (2.59)	3.57* (2.69)	3.58* (2.73)	3.58* (2.73)	3.61* (2.72)
Courses, etc. import. information channel[1]	5.37* (3.80)	5.28* (3.76)	4.99* (3.60)	4.96* (3.57)	5.38* (3.84)
Customers important information channel[1]	3.57* (2.23)	3.73* (2.35)	3.30* (2.11)	3.30* (2.10)	3.50* (2.21)
Share of college engineers employed	19.70* (4.61)	18.68* (4.37)	17.52* (4.12)	17.41* (4.07)	18.44* (4.29)
University engineers employed[1]	5.60* (3.01)	5.25* (2.81)	5.33* (2.90)	5.35* (2.91)	5.66* (3.05)
Electrical engineering industry[1]	–0.92 (–0.63)	–0.98 (–0.67)	–1.03 (–0.71)	–0.96 (–0.66)	–0.92 (–0.63)
Instruments industry[1]	0.42 (0.22)	–0.04 (–0.02)	–0.30 (–0.16)	–0.26 (–0.14)	–0.17 (–0.09)
Infrastructure index for the municipality		0.086 (1.41)			
Labour force in the region			3.86×10^{-6}* (2.32)		
Labour force density in the region				0.012* (2.21)	
Labour force density in the municipality					0.69×10^{-3} (1.28)
Number of cases	140	140	140	140	140
L-ratio	585.2	806.2	691.0	677.3	627.8
Sigma	6.92	6.82	6.72	6.73	6.82

[1] Dummy variable.
* significant at the 5%-level (The t-values are in parentheses).

many contacts with other people in the region seems to be important for LEs, but not for SMEs.

Finally Equation 5 in Tables II and III incorporates a fourth variable characterising the local environment – the labour force density in the municipality. This variable in both cases is non-significant. Nevertheless it is positive for LEs and negative for SMEs. At a general level this result indicates that the local environment is less important for innovative activities than the regional environment.

8. Conclusions

The regional environment does appear to influence the early use of micro-electronic components for

TABLE III
Innovation networks, enterprise characteristics, regional characteristics and the use of micro-electronics in products among small and medium-seized enterprises (SMEs)

Variable	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
Intercept	–7.48* (–4.54)	–8.70* (–2.39)	–6.89* (–3.88)	–6.92* (–4.02)	–7.34* (–4.32)
Universities import. information channel[1]	7.35 (1.44)	7.14 (1.47)	7.98 (1.51)	8.23 (1.55)	8.35 (1.56)
Corporation import. information channel[1]	5.20* (2.13)	5.28* (2.03)	5.11 (1.94)	5.12 (1.94)	4.78 (1.80)
Electronics suppliers import. info channel[1]	6.51* (4.11)	6.54* (3.97)	6.28* (3.82)	6.22* (3.79)	6.13* (3.67)
Courses, etc. import. information channel[1]	4.67* (2.25)	4.50* (2.04)	4.50* (2.03)	4.43* (2.00)	4.69* (2.11)
Customers important information channel[1]	3.40 (1.62)	3.19 (1.39)	4.02 (1.76)	4.28 (1.86)	3.58 (1.61)
Share of college engineers employed	8.54* (2.92)	8.45* (2.81)	8.19* (2.71)	8.36* (2.78)	8.45* (2.80)
University engineers employed[1]	0.72 (0.44)	0.89 (0.53)	0.63 (0.37)	0.75 (0.44)	1.09 (0.63)
Electrical engineering industry[1]	1.24 (0.70)	1.14 (0.62)	1.51 (0.82)	1.53 (0.83)	1.66 (0.88)
Instruments industry[1]	–2.13 (–0.76)	–2.75 (–0.89)	–2.18 (–0.69)	–1.95 (–0.62)	–2.35 (–0.75)
Infrastructure index for the municipality		0.037 (0.38)			
Labour force in the region			-2.45×10^{-6} (–1.05)		
Labour force density in the region				–0.011 (–1.39)	
Labour force density in the municipality					-1.12×10^{-3} (0.95)
Number of cases	130	130	130	130	130
L-ratio	133.5	148.1	103.7	105.6	114.0
Sigma	6.69	6.80	6.84	6.83	6.82

[1] Dummy variable
* significant at the 5%-level (The t-values are in parentheses)

product development. In particular the size of the labour force and the density of the labour force in the labour market region have a significant influence. The local infrastructure supply and the local environment represented by the density of the labour force in the location municipality do not seem to exert an influence. The "regional variables" appear to exert a positive influence in the case of LEs and a negative influence in the case of SMEs. This contrasts with our basic hypotheses that SMEs are more dependent upon their regional environment than LEs for an early adoption of innovations in products. Our results imply peripheral regions are able to provide an innovative environment for SMEs, whereas LEs need the richer environment offered by the core regions. This is compatible with the results in Suarez-Villa and Karlsson (1994) where it for the Swedish electronics industry is shown that regions outside the metropolitan regions can provide a good environment for innovative activities. But they contrast with the forecasts of the product life cycle, where it is assumed that for enterprises of all sizes the larger urban areas provide the best environment for product development.

So, what reasons could there be for the observed differences between LEs and SMEs? One is that LEs and SMEs, even if they are active within the same branches of industry actually produce different products. If this is the case, then the adoption of micro-electronic components in products actually means different things in LEs and SMEs. Alternatively, product development could be determined by different factors in LEs and SMEs, i.e. that the innovation networks of LEs and SMEs differ. Support for this is found in the result that suppliers play a much more important role for SMEs than for LEs, and that customers do not seem to be very important for SMEs, but are an important information channel for LEs. In other words, product innovation in SMEs is stimulated by technology-push, whereas in LEs it is stimulated by both technology-push and demand-pull. This could eventually, explain why a large and dense regional environment is important for product development in LEs, but not for SMEs.

We believe the results presented here are sufficiently interesting to merit further investigations in other regions and other countries. From a policy point of view they are interesting because they indicate that SMEs can be early users of new technologies even if they are located outside the large urban areas. To what extent this is the result of regional policies or technology policies remains an open question. But our evidence is that very few enterprises mention public institutions, except universities, as important sources of information for product development. And as we have seen the university variable is non-significant for SMEs in all equations. This might question the value of traditional high-technology policy for SMEs which, to a great extent, has focused on the creation of Science Parks and clustering of firms where networks of SMEs can interact with each other and with universities.

Notes

[1] However, the structure of production-intensive industries may be highly concentrated oligoplistic markets characterized by mature, mass volume products. In such markets we may observe a 'competitive fringe' of smaller specialist or niche firms, which clearly has implications for the level of innovativeness.

[2] An establishment is a production unit that does not need to be a legal entity. It could be an independent legal entity, a legal entity that is owned by another legal entity or just a production unit owned by a legal entity located somewhere else.

[3] In the regression analyses we tested for a possible influence on the regression results of the sampling method through a weighting procedure but found no such influence. The results presented here are the unweighted results.

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