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The structure and evolution of industrial clusters: Transactions, technology and knowledge spillovers

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Abstract

In this paper, we investigate the relationship between location patterns, innovation processes and industrial clusters. In order to do this we extend a transactions costs-based classification into a knowledge-based taxonomy of clusters, along the lines suggested by a critical revision of the main assumptions underlying most of the existing literature on spatial clusters. Our arguments show that the transactions costs approach and the innovation and technological regimes framework are broadly consistent, and that real insights into the microfoundations, nature, and evolution of clusters can be provided by these classification systems.

JEL classification: R12; R3; O3

Keywords: Industrial clusters; Firm location; Innovation processes; Technological regimes; Cluster classification

1. Introduction

Over recent years, the interrelationships between technology, innovation and industrial location behaviour have come to be seen as essential features of regional development. Much research and policy-thinking has been devoted to understanding the factors explaining why particular types of technologies appear to blossom in particular localities, and how this affects local economic growth. Lessons are often drawn from observations of particularly successful 'innovative' regions as a means of re-modelling both industrial and regional policy.

It will be argued in this paper that insufficient consideration is still devoted to both the nature of innovation processes and the structural conditions under which technical change occurs across space. In order to explain the observed variety of geographical models, it is necessary to take into account the nature of new knowledge in different production sectors. In particular, technological regimes, industrial structures and organisational practices, as well as their dynamics, are often overlooked in favour of simplified and stylised constructs, which appeal to consultants or government policy-makers wishing for easy answers to complex problems. An example of this is the literature promoting industrial clusters.

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This paper attempts to classify industrial clusters on the basis of the existing literature, trying in particular to integrate transactions costs views and innovation and technology perspectives to give account of both the diversity of cluster structures and the multiplicity of their evolution paths. In doing so, the following questions are here indirectly addressed. How can we explain the variety and distinctiveness of geographically bounded industrial clusters? Why particular types of technologies tend to thrive in particular localities? How do different types of clusters evolve over time?

The paper is structured into 10 sections. In the following section we discuss the various hypotheses which exist concerning innovation and geography. In Section 3 we outline the generally-held arguments regarding the relationship between geography and knowledge spillovers, and in Section 4 we present a transactions costs classification of different types of industrial clustering previously developed elsewhere, which is explicitly based on the implicit assumptions underlying most of the existing literature on agglomeration and clustering phenomena. Such a classification is very informative regarding identifying the nature and organisational logic of clusters, and on this basis Section 5 of the paper addresses the limits of the hypothesised advantages of clustering by considering the effects of unintended knowledge flows. Section 6 then explains the limitations of the transactions costs view in analysing the processes of cluster evolution, whilst Section 7 briefly introduces evolutionary perspectives on technical and structural change. Such perspectives are adopted in Section 8 to extend the transactions costs classification proposed in Section 4, in order to give an account of the diversity and multiplicity of possible evolutionary paths of industrial clusters. Section 9 uses selected empirical examples to show the importance of both transactions costs and knowledge regimes in explaining patterns of cluster development. Section 10 outlines some brief conclusions.

2. Hypotheses concerning the geography of innovation

In order to begin our analysis, it is necessary to review what is already known or assumed in the literature concerning geography, industrial location and innovation. Across the broad range of literature on innovation and growth processes, four distinct and substantially alternative hypotheses (Gordon and McCann, 2005a,b) have emerged in order to account for the widely observed uneven spatial distribution of innovative behaviour (Sternberg, 1996). We will examine each of these in turn.

Hypothesis 1. The contemporary geography of innovation is essentially a geography of the currently more innovative sectors of the economy.

This hypothesis takes off from the observation that in any period there are some sectors of economic activity which will be more heavily involved in innovation of products or processes than others. This may be because of the particular phase which has been reached in the life cycle of their product set, or because some activities with very short product cycles are more or less permanently locked into the innovative phase. If each of these industries is subject to rather different location factors, because of the nature of their production technologies, or their marketing or consumption processes, the geography of innovation may then be reducible simply to a geography of industrial location. With activities remaining in the same broad locations through all of the phases of the product cycle, places which they dominate will also appear to move through that cycle.

Hypothesis 2. The contemporary geography of innovation is essentially a result of spatial differences in the phases of product or profit cycles.

This alternative interpretation of product cycle geographies emphasises significant and typical shifts in the locational requirements between the phases of an industry's product or profit cycle (Vernon, 1960; Markusen, 1985). From this perspective, during the early innovative phases, access to appropriate skills and subcontractors are a crucial condition for successful innovation and the management of uncertainties. Later on, in the more mature phases of the cycle, when output scale has been achieved and when production methods have become routinised, cost factors are assumed to become increasingly important, thereby allowing both geographical dispersal to lower cost locations and also the spatial division of labour.[1] From this perspective, therefore, what is generally significant about the geography of innovative activities is the relationship between space and production cost conditions at different stages in the product cycle.

In terms of the assumptions underlying the relationship between innovation and geography, there is a fundamental difference between the first and the second

[1] This process may be slowed and such spatial decentralisation delayed or avoided by successful 'oligopolisation' of particular sectors (Markusen, 1985), which increases the likelihood that industries are born, mature and die in the same locations, as is assumed in Hypothesis 1.

hypotheses, both of which are developed on the basis of the product cycle model. The first hypothesis works on the assumption that as innovation takes place, the innovating firms are primarily static in terms of their location behaviour, such that different phases of the product cycle are not reflected in changing industrial geographies. On the other hand, the second hypothesis works on the assumption that the innovating firms are largely dynamic in terms of their location behaviour, such that the different phases of the product cycle are reflected in terms of evolving industrial geographies.

Hypothesis 3. The contemporary geography of innovation is essentially the outcome of variations in the characteristics between different places which lead to differences in the geography of creativity and entrepreneurship.

This third approach to understanding the distribution of innovative activity focuses on the geography of creativity and entrepreneurship, in the sense of place characteristics favouring the development and commercial launching of potentially successful new or improved products and services, either through established or new business organisations. The emphasis here is on the factors which stimulate and enable novel developments while also facilitating the selection of those with real competitive potential. The three key sets of factors involve: a rich 'soup' of skills, ideas, technologies, and cultures within which new compounds and forms of activity can emerge; a permissive environment enabling unconventional initiatives to be brought to the marketplace; and vigorously competitive arenas operating selection criteria which anticipate and shape those of wider future markets.[2]

Two aspects of this fertile environment highlighted by Chinitz (1961) in his classic comparison of New York and Pittsburgh are the minimal requirement that new enterprises can combine relevant technical and market expertise, and the lower likelihood of meeting this in an urban economy dominated by large bureaucratic structures.[3] From a different perspective, Porter (1990) also highlights some of these factors in arguing for the importance of both a discriminating local market and rivalry among local producers within a particular sector as spurs to quality improvements in their goods or services.[4]

Hypothesis 4. The contemporary geography of innovation is essentially a result of the fact that innovation is most likely to occur in small and medium-sized enterprises, whose spatial patterns happen to be uneven.

This fourth approach to explaining the uneven geographical patterns of innovation involves another type of 'milieu' argument, which is focused on the geography of co-operation. This rests in particular on the perception that innovation is most likely to occur in small and medium-sized enterprises (SMEs), which have neither the scale nor the risk-bearing capacity to provide all of the key inputs on their own account. Observations from so-called 'new industrial districts' (Scott, 1988) such as Silicon Valley (Saxenian, 1994), and from traditional districts such as those of the Emilia-Romagna region in Italy (among others Brusco, 1982; Scott, 1988; Castells and Hall, 1994), have suggested that the geographical proximity of SMEs is a necessary criterion for the development of mutual trust relations based on a shared experience of interaction with decision-making agents in different firms. In these contexts, the social network model (Granovetter, 1973, 1985, 1991, 1992) has highlighted the role which social as well as purely instrumental business links may play in fostering localised growth.

Of the four hypotheses described above concerning the relationship between innovation and geography, only the third and fourth hypotheses directly assume that innovation is intrinsically linked to spatially bounded industrial clustering. For these latter assumptions to be correct, it is necessary for the knowledge required in the innovation process to be systematically 'sticky' within particular localities. Indirect arguments equally applicable to all sectors also point to the localised nature of knowledge and the spatial limitations of knowledge flows. Indeed, over the last three decades, widespread ICT and transport technological changes have largely reduced many aspects of spatial transactions costs, thereby potentially benefiting peripheral economies. Glaeser (1998) argues

[2] In some circumstances, particularly when the driver is patentable scientific knowledge which can be profitably produced and exploited in-house, the relevant environment may be primarily that of a global business corporation. More typically it is likely to be a place (Storper and Venables, 2004) with the "unique buzz, unique fizz (and) special kind of energy" (Hall, 1998, p. 963) along with the appropriate discretionary spending power.

[3] Duranton and Puga (2001) in their life cycle model emphasise diversity as the key requirement of nursery environments in which firms introducing new products have access to an array of models of production processes to borrow and try out, before routinising and relocating to more specialised cities.

[4] These hypotheses all relate to the innovative behaviour of typical local firms, although a dynamic environment may also attract to it mobile investment from businesses seeking a conducive environment for an innovation-based growth strategy.

that if we consider the changes in the transactions costs of goods-shipments alone, then the rationale for industrial clustering and the existence of modern cities disappears. On the other hand, however, he argues that in the modern world the costs involved in ensuring that people have sufficiently widespread and frequent face-to-face contact across a range of individuals in order to facilitate the transfer of knowledge and information, are the crucial driving force behind the generation of cities and industrial clusters. This argument clearly points to the geographical stickiness of knowledge. Indirect evidence for this also comes from observations of telephone usage patterns (Gaspar and Glaeser, 1998), in which geographical proximity is found to be highly correlated with telephone usage. This is because ICT and face-to-face contact are not necessarily substitutes for each other, but rather they are often complements. Another possible outcome of this also relates to the generally increasing levels of global urbanisation (UN, 1997). As such, there is strong evidence to suggest that the ability to overcome the modern spatial transactions costs involved in knowledge acquisition is the primary rationale underlying the existence of modern cities. These considerations therefore suggest that many aspects of knowledge are indeed geographically specific, and as such, support most of the implicit assumptions regarding the nature of knowledge spillovers which exist within the agglomeration and clustering literatures.

3. Geography, information and knowledge spillovers

Currently the most popular explanation of the benefits of industrial clustering focuses on the role played by localised external agglomeration economies. Underlying this thinking are Marshall's (1920) three explanations for the existence of positive agglomeration externalities, namely local information and knowledge spillovers, local supply of non-traded inputs, and a skilled local labour pool. In addition to these localization economies, a parallel stream of literature focussing on the role of diversity in agglomeration models has been developed both by the proponents of the new economic geography (e.g. Krugman, 1991; Fujita et al., 1999) and also by proponents of more traditional approaches to urbanisation economies (e.g. Jacobs, 1960; Glaeser et al., 1992). This literature suggests that inter-industry spillovers may actually be generally more important that intra-industry spillovers in explaining economic growth (Martin and Ottaviano, 1999), although intra-industry effects may dominate certain manufacturing sectors (Henderson et al., 1995).

However, the relationship between geography and local economic growth appear to be rather more subtle, complex and varied than the simple Marshallian agglomeration model suggests, particularly at a time when the inducements derived from global market competition and changes in demand, and from technological change arise at an incredibly high speed. The original Marshallian-Arrow-Romer (MAR) stream of literature plus the diversity literature on urbanisation economies have therefore both been broadened by including technological indices as endogenous variables in explaining local economic growth (e.g. Jaffe et al., 1993; Acs, 2002). Examples of such indices are local patent counts, local R&D expenditures, and local R&D employment. These models are also extended by including various alternative measures of knowledge creation and innovation. In the main, however, while these neoclassical interpretations have focused on localised spillover effects as the major analytical framework to explain cluster existence and growth, they have largely disregarded other possible mechanisms underlying spatial agglomerations (Breschi and Lissoni, 2001; Autant-Bernard et al., 2003). In particular, production function-based models do not give a full account of the diversity of possible industrial cluster types. Nor do they tackle issues such as the evolution of clusters and the disruptive changes imposed by technological progress and globalisation processes (Guerrieri et al., 2001; Hilpert, 2003) on agglomeration economies.

The difficult analytical problems relating to the diverse evolutionary features of clusters and agglomerations are compounded by severe problems of cluster identification and definition.[5] The microeconomic foundations and logic implicit in cluster descriptions need to be made explicit in order to allow the behavioural logic of the cluster to be examined. In order to simplify our analysis, in the following section we explain a consistent method of classifying cluster types which is independent of either the sector or the location, but instead is based on the microeconomic behaviour and objectives of the clustered firms, and on the relations and transactions existing in the cluster.

[5] It is beyond the scope of this paper to engage with the ongoing debate on the issue of the relevant spatial scale for economic analysis (see, for example, Schmitz, 1995; Martin and Sunley, 2003; Moulaert and Sekia, 2003). Here we build an analytical framework directed to interpret different geographical agglomeration models, or co-location pattern of firms, organisations and institutions interconnected and interdependent in their activities directed to the production of goods and services (on the use of the term 'cluster' in the literature see also Maskell, 2001).

4. A transactions costs classification of cluster types

A transactions costs approach can be adopted to present three various stylised sets of geography–firm–industry organisational relationships which exist in the literature (Simmie and Sennet, 1999; Gordon and McCann, 2000; McCann, 2001; McCann and Sheppard, 2003; McCann and Shefer, 2004). As also emphasised above, these classifications are not theories, but are based on the (often implicit) assumptions underlying most of the existing literature on agglomeration phenomena. As such, they are not meant to be interpreted as representing any particular geographical category or place. These stylised characterisations of industrial clusters are distinguished in terms of the nature of firms in the clusters and the nature of their relations and transactions undertaken within clusters. They can be termed the *pure agglomeration, the industrial complex*, and the *social network*. The characteristics of each of the cluster types are listed in Table 1, and as we see, the three ideal types of clusters are all quite different.

In the model of pure agglomeration, inter-firm relations are inherently transient. Firms are essentially atomistic, in the sense of having no market power, and they will continuously change their relations with other firms and customers in response to market arbitrage opportunities, thereby leading to intense local competition. As such, there is no loyalty between firms, nor are any particular long-term relations. The external benefits of clustering accrue to all local firms simply by reason of their local presence. The cost of membership of this cluster is simply the local real estate market rent. There are no free riders, access to the cluster is open, and consequently, it is the growth in the local real estate rents which is the indicator of the cluster's performance. This idealised type is best represented by the Marshallian model of agglomeration as adopted by the new economic geography models, where the notion of space is essentially urban space, in that this type of clustering only exists within individual cities.

The industrial complex is characterised primarily by long-term stable and predictable relations between the firms in the cluster, involving frequent transactions. This type of cluster is most commonly observed in industries such as steel and chemicals, and is the type of spatial cluster typically discussed by classical (Weber, 1909) and neo-classical (Moses, 1958) location-production models, representing a fusion of locational analysis with input–output analysis (Isard and Kuenne, 1953). In order to become part of the grouping, component firms within the spatial cluster each undertake significant long-term investments, particularly in terms of physical capital and local real estate. Access to the group is therefore severely restricted both by high entry and exit costs: the rationale for spatial clustering in these types of industries is that proximity is required primarily in order to minimise inter-firm transport transactions costs. Rental appreciation is not a feature of the cluster because the land that has already been purchased by the firms is not for sale.

Table 1
Industrial clusters: a transactions costs perspective

Characteristics	Pure agglomeration	Industrial complex	Social network
Firm size	Atomistic	Some firms are large	Variable
Characteristics of relations	Non-identifiable Fragmented Unstable frequent trading	Identifiable Stable and frequent trading	Trust Loyalty Joint lobbying Joint ventures Non-opportunistic
Membership	Open	Closed	Partially open
Access to cluster	Rental payments Location necessary	Internal investment Location necessary	History Experience Location necessary but not sufficient
Space outcomes	Rent appreciation	No effect on rents	Partial rental capitalisation
Example of cluster	Competitive urban economy	Steel or chemicals production complex	New industrial areas
Analytical approaches	Models of pure agglomeration	Location-production theory Input–output analysis	Social network theory (Granovetter)
Notion of space	Urban	Local or regional but not urban	Local or regional but not urban

The notion of space in the industrial complex is local, but not necessarily urban, may extend across a sub-national regional level, and depends crucially on transportation costs.

The third type of spatial industrial cluster is the social network model. This is associated primarily with the work of Granovetter (1973), and is a response to the hierarchies' model of Williamson (1975). The social network model argues that mutual trust relations between key decision-making agents in different organisations may be at least as important as decision-making hierarchies within individual organisations. These trust relations will be manifested by a variety of features, such as joint lobbying, joint ventures, informal alliances, and reciprocal arrangements regarding trading relationships. Trust relations are assumed to reduce inter-firm transactions costs, because when they exist, firms do not face the problems of opportunism.[6] The predictability associated with mutual non-opportunistic behaviour can therefore partially substitute for the disadvantages associated with geographic peripherality. Inter-firm cooperative relations may therefore differ significantly from the organisational boundaries associated with individual firms, and these relations may be continually reconstituted. All of these behavioural features rely on a common culture of mutual trust, the development of which depends largely on a shared history and experience of the decision-making agents. This social network model is essentially aspatial, but from the point of view of geography, it can be argued that spatial proximity will tend to foster such trust relations over a long-term period, thereby leading to a local business environment of confidence, risk-taking and cooperation. Spatial proximity is thus necessary, but not sufficient to acquire access to the network, which as such is only partially open, in that local rental payments will not guarantee access, although they will improve the chances of access.

In reality, all spatial clusters or industrial agglomerations will contain characteristics of one or more of these ideal types, although one type will tend to be dominant in each cluster. On the other hand, if the objective is to understand the evolution of these various cluster types in different locations and sectors, then a description, albeit a very detailed one, of the nature of the relations and transactions between the actors within the cluster is only part of the solution. It is also necessary to consider issues relating to the nature of knowledge and innovation processes.

[6] As such, trust relations circumvent many of the information issues raised by the markets and hierarchies dichotomy (Williamson, 1975).

5. The advantages and disadvantages of industrial clustering

At this stage, we can now consider why particular types of clusters will emerge in different situations. However, in order to do this, we must consider what are the perceived costs and benefits to the firm of spatially grouping its activities with those of other potential competitor and collaborator firms. This is because, following our discussion in Section 3, in terms of the relationship between the firm and the cluster the central issue is how the firm perceives the possible benefits of local knowledge and information spillovers.

We can look at knowledge spillovers from two different perspectives, namely knowledge inflows and knowledge outflows. Regarding knowledge inflows, we may safely assume that all firms regard knowledge inflows positively. However, unintentional knowledge outflows can have both positive and negative effects on the firm. The private effect of an unintentional knowledge outflow on the owner firm is a leakage of its valuable intellectual capital and intangible asset, and this would always be viewed negatively (Grindley and Teece, 1997). On the other hand, the potentially positive effect of an unintentional knowledge outflow is the public good aspect of knowledge (d'Aspremont et al., 1998). This would be important in situations where local knowledge outflows contribute to a virtuous cycle by strengthening the knowledge base of the location, thereby making it more attractive for other innovation-bearing firms, leading to larger knowledge inflows in the future. This is a classic idealised evolutionary process.

The firm's view of the net benefits of knowledge spillovers, allowing for both knowledge outflows and inflows, will therefore depends on its assessment of the relative importance to itself of these two effects. Obviously, however, the structure and organisation of an industry will affect the firm's perceptions of knowledge outflows. For example, we can consider the case of a broadly competitive market structure that is characterised by a large number of firms, each with a relatively small market share and profits. In this case, competitor firms will have less to lose from knowledge outflows and more to gain from inflows stemming from a strong clustered location. In such a situation, therefore, the public good aspect of local knowledge will predominate and knowledge outflows will be viewed as being generally positive. In the transactions costs model in Table 1, this combination of features is exhibited by the pure agglomeration model.

In an oligopolistic industry structure, on the other hand, which is characterised by a few large firms, each with a large market share and considerable strategic interdependence, firms often perceive that knowledge outflows to industry rivals can be extremely costly in terms of lost competitive advantage. The reason is that in these circumstances the private good aspect of knowledge is generally the dominant consideration. In situations where any knowledge outflows from a firm are more valuable to its competitors than are any potential knowledge inflows to the firm from its competitors, the overall net effect of unintended knowledge outflows will be perceived by the firm to be negative. This will lead the firm to decide not to locate in clusters characterised by pure agglomeration, although, depending on the transportation costs, they may consider locating in complexes characterised by stable planned and long-term inter-firm relationships.

This argument provides a powerful counter-argument to the Porter logic in favour of industrial clustering. This is because if we apply Akerlof's (1970) market-for-lemons model, industrial clusters which include large oligopolistic competitors will be plagued by adverse selection and should either fail to form, or become concentrations of mediocrity, unless the clustering of firms exhibits the characteristics of an industrial complex in Table 1. This counter-argument to the Porter logic appears to explain the empirical finding that many of the largest firms do not co-locate their knowledge creation activities with those of their competitive rivals (Cantwell and Santangelo, 1999; Simmie, 1998). From this argument, therefore, the only possible reason why such a firm would locate in a cluster characterised primarily by either a pure agglomeration or a social network, would simply be as a means of facilitating the hiring of specialist labour. However, oligopolistic firms are often able to hire appropriate specialist labour or tapping into local technical expertise by simply locating within the same broad regional vicinity as other firms (Cantwell and Iammarino, 2003), rather than within the same urban location. The inter-firm spillover arguments implicit in the pure agglomeration and social network models of industrial clustering are therefore not always applicable to oligopolistic multinational or multiplant firms (Arita and McCann, 2002a,b).

Similar arguments are often also pertinent in the case of the social network model of Table 1. Such social networks are assumed to operate on the basis of 'trust' relations. However, on the basis of these inward and outward knowledge spillover arguments, the conditions under which such trust relationships will emerge naturally are largely opaque. If the firms in a cluster are to be small, then the arguments for pure agglomeration may be largely applicable in the case of the social network, although distinguishing between the two becomes problematic. However, if some of the firms in the cluster are to be large, then it is not clear how such a social network would evolve.

All this implies that the development of clusters in general, and also of particular types of clusters, is not an automatic phenomenon. This is because all clusters must have a logic to them, of a form broadly consistent with one of the three transaction costs types in Table 1. If no such logic exists, then no cluster emerges, while if a particular logic is dominant, then a particular type of cluster will emerge. As yet, the Porter school has failed to address or even acknowledge these counter-arguments (Martin and Sunley, 2003), because the balance between the costs of locating within a cluster, as against the opportunity costs involved in locating at any particular distance away from a cluster, is never specified in the simple Porter clusters literature. As such, understanding the reasons why particular observed clusters exist requires a careful consideration of central issues in industrial organisation such as industry structure, firm strategy, the nature of intra-industry competition, and the relationship between knowledge and technology.

6. Clustering dynamics: knowledge, technology and structural change

In the light of the arguments presented in Sections 4 and 5 above, it is clear that most cluster discussions in both the academic and the policy literature adopt a rather general and stylised model of local economic geography, which is a hybrid composite description based on different understandings of knowledge, information, inter-firm relations and transactions costs. These stylised cluster approaches tend to be largely unconcerned with the actual detailed interplay between industries and geographical locations, or of the specific evolutionary features of different clusters, and are mainly responsible for the recent hectic efforts to identify localised knowledge spillovers, irrespective of the characteristics of any functional dimension of knowledge processes depending on the type of industry and cluster.

One of the advantages of the transactions costs classification scheme is that it provides an organising framework capable to deal with the diversity of spatial concentrations we observe. At the same time, a weakness of this framework is that in the transactions costs perspective itself, hierarchies (particularly, but not exclusively, firm structures) are viewed and reduced to a consequence of changes in transaction costs, whereas dynamic factors such as learning, accumulation, and knowledge creation are largely ignored. However, this type of transactions costs perspective does offer possibilities for the inclusion of a technical change component as an additional explanation for the diversity of spatial typologies.

As already mentioned, in the transactions costs approach the main organisational forms of economic activity are generally represented by the dichotomy within and between markets and hierarchies. However, in the case of the third cluster type, the social network model, which is explained on the basis of the assumption of non-opportunistic behaviour, the possibility of the network as an increasingly predominant form of economic governance needs to be accounted for, particularly as it pushes the concept of 'proximity' well beyond just a spatial dimension.[7] The transactions costs approach underlying Table 1 also encounters some limitations when analysing cluster evolution, due to its: (1) essentially static nature; (2) narrow definition of knowledge and technology; (3) discounting of the relationship between innovation processes and industry structures.

Regarding point (1), the classification presented in the previous section is static, as is typical of transactions costs models, and reflects the bulk of the existing literature on the cluster concept that it summarises. Underlying most of such a literature, there are static agglomeration economy efficiency gains (in terms of economies of scale and scope, transactions and transport costs and input–output linkages). However, the relationship between firm location and technology is also dynamic (among others Dosi, 1988; Nelson, 1991; Dosi et al., 1997; Audretsch, 1997), both in terms of industrial demography (firm entry, exit, growth, relocation, etc.) and in terms of cluster life cycle (cluster birth, growth, decline, openness, etc.). Thus, clusters are not necessarily static in that they may evolve over time, possibly blending the features of the three typologies into different combinations, and possibly shifting from one main type to another according to the relative stage in their life cycle. Dynamic agglomeration economies and the central role of learning and new knowledge creation may therefore lead to distinctive paths of cluster evolution. These evolutionary issues cannot yet be analysed by the classification scheme adopted in Table 1, which therefore needs to be integrated.

Regarding point (2), the logic of the contractual transactions costs arguments about appropriability in markets depends to a large extent upon a narrow definition of technology. The distinction between information and knowledge, or 'codified' versus 'tacit' knowledge, is crucial in this respect (Polany, 1966). As also rehearsed in Section 5, the traditional approach in economics has regarded knowledge as a public good, therefore assumed to be 'non-excludable', 'non-depletable', and free to be used without limits by anyone, at any time, and anywhere across geographical boundaries. In such a perspective, it is apparent that knowledge and information are treated as being largely synonymous. However, once tacit knowledge is taken into consideration, it becomes clear that technology as a whole cannot be easily traded or exchanged, and only the potentially public knowledge component is liable to be assessed in terms of transaction costs analysis.

When narrowing the notion of technology to something akin to information, and concentrating on the organisation of the exchange of such information, there is a tendency to overemphasise the appropriability issue (Winter, 1987, 1993). On the other hand, however, the return on innovation to a firm may well be mainly a return on its creation of tacit capability, a process supported by, but not reducible to, the generation of new potentially public knowledge. In addition, as discussed in Sections 2 and 5 above, knowledge can be at the same time both 'sticky' within the organisation or firm boundaries, while also being 'leaky' or mobile, generating outflows of knowledge in the environment external to the firm (von Hippel, 1994; Wernerfelt, 1984). Ideas, inventions and practices which are unable to move within organisations, under some circumstances may prove to be quite capable of moving outside of them (Winter, 1987; Seely Brown and Duguid, 2001), thereby putting in question the centrality of the appropriability issue. The main reason for knowledge to be confined to certain geographical contexts is assumed to be its inherent complexity – particularly with regard to technical knowledge – that may make it difficult to share among different interacting actors or organisations. Such an inherent complexity may prevent knowledge from being codified and made explicit and mobile, and thereby stored and transmitted by way of information. In other words, not only is the conversion from tacit to codified knowledge itself problematic, but the former is also required in order to make codified knowledge usefully traded (Seely Brown and Duguid, 2001). These arguments underlie the knowledge 'filter' hypotheses (Acs, 2002), and the wider notion of knowledge may also embrace cultural and institutional differences, which shape the spatial patterns of its functional dimensions, i.e. knowledge production, absorption and diffusion.

Once we allow for a broader definition of knowledge, further issues appear critical in understanding the factors

[7] On the different dimensions of proximity and their impact on innovation processes, see Boschma (2005).

explaining why particular types of technologies tend to thrive in particular localities and how this affects cluster evolution. We can now reasonably assume that the nature of agglomeration effects is likely to be highly sensitive not only to the industry structure, but also to the stage of product life cycle and cluster life cycle, and to changes in the underlying technological base (Audretsch, 1998; Breschi and Malerba, 2001; Boschma and Frenken, 2003). Following the various hypotheses outlined in Section 2 regarding the interplay between spatial agglomeration and industry life cycle, for instance, if we maintain that tacit knowledge is largely sticky and geographically immobile, then the propensity for innovation to concentrate geographically is likely to be higher in industries, or stages of the product cycle, where tacit knowledge plays an important role.

Another important implication of viewing knowledge as akin to information is that it determines our long-run analytical expectations. For example, shifts towards new technological paradigms, such as the current one based on information and communications technologies, are likely to lead to conclusions pointing to convergent growth paths. In a manner mirroring traditional neo-classical factor-allocation and growth models (Borts and Stein, 1964), the logic here is that new technologies will be assumed to reduce spatial transactions costs, thereby improving the position of geographically peripheral economies, and at the same time weakening the rationale for industrial clustering (Barro and Sala-i-Martin, 1992). On the other hand, by viewing knowledge-creation processes as complex, systemic, cumulative, partially tacit and sticky (whether codified or not) phenomena, there are strong grounds for arguing that innovation is very likely to stay highly concentrated across space, organisations and hierarchies, thereby giving rise to rather distinctive growth patterns. These are the arguments underlying evolutionary views of economic growth and convergence (see Section 7 below).

Regarding point (3), if we take seriously the issues raised in points (1) and (2), then we must also consider how each of these issues is related to the structure and the sources of innovation of the industry. On this point, reference to the Pavitt's (1984) classic taxonomy – which was used to explain firm and sectoral patterns of technical change and innovation among innovative manufacturing sectors – is deemed to be essential.[8] Subsequent works based on Pavitt's seminal contribution (among others, Pavitt et al., 1989; Archibugi et al., 1991; Malerba and Orsenigo, 1996; Evangelista, 2000; Marsili, 2001; Archibugi, 2001) have adapted the framework to take into account structural changes, such as the emergence of information intensive and life science-based firms, the increasingly blurred boundary between manufacturing and services, and even the shifting of sectors among patterns.[9] On these bases, some recent Pavitt-based research, focusing on the determinants of cross-sectoral differences in agglomeration forces and dynamics, has emphasised the role of technological and learning processes which are "likely to affect the relative importance of phenomena such as localised knowledge splillovers; inter-organisational versus intra-organisational learning; knowledge complementarities fuelled by localised labour mobility; innovative explorations undertaken through spin-offs, and more generally, the birth of new firms." (Bottazzi et al., 2005, p. 5). Therefore, if we are to better relate questions of innovation to the emergence and evolution of clusters, it is necessary to map knowledge and technology characteristics onto the simple transactions costs models described in Table 1. The reason for this is that it is the changes in the nature of knowledge and the emergence of new knowledge capabilities that will determine whether (and how) the logic of a cluster will evolve over time.

7. Technological regimes, growth and clustering

The arguments in the previous sections concerning the nature of knowledge provide a rationale for the extension of the transactions costs classification into a system which also accounts for the differing knowledge features of spatially defined industrial clusters. Such a method requires us to distinguish explicitly between knowledge and information, and then to examine how the various characteristics of knowledge creation, absorption, interpretation, adoption and implementation, and the technological outcomes of these various processes, relate to the current transactions costs features of the cluster. In order to do so, it is necessary to render briefly explicit some of the assumptions regarding the relationship between knowledge and economic growth, keeping in mind that transaction costs and evolutionary

[8] As is well known, in terms of innovation sources the Pavitt taxonomy (1984) splits firms and sectors into three broad categories, namely supplier dominated, production intensive (distinguished in specialised suppliers and scale intensive), and science based firms and industries. The logic of these categories is related to the nature of the information and knowledge in the sector, and to the role which both of these play in the competition and innovation process.

[9] Pavitt himself predicted the shrinking of the 'supplier dominated' category on the basis of a tendency for such firms to adopt 'scale intensive' or 'information intensive' strategies (Pavitt et al., 1989).

views are by no means to be intended as competing explanations, but rather as complementary methods to encompass transactions involving both information and knowledge.[10]

In the evolutionary economics approaches to technological change, the dynamism of any geographical system that builds on access to and efficient use of knowledge, is assumed to rest upon three main functional dimensions: the *absorption* of new knowledge, technology and innovation for the adaptation to local needs; the *diffusion* of innovations to strengthen the existing knowledge base; and the *generation* of new knowledge, technology and innovation. In order to benefit from external knowledge firms need to have their own adequate knowledge base (Cohen and Levinthal, 1990), so that clusters of such firms can be sustained through several channels related to these three functional dimensions. This can therefore provide possible collective learning processes, through which knowledge and technology can be used, diffused and created, and which are central to the evolutionary economics explanations of localised growth patterns (Malmberg, 1997; Maskell, 2001; Bathelt et al., 2002). Learning dynamics and the employment of informal channels for the exchange of tacit and 'sticky' knowledge are assumed to be embedded in distinct environments (not necessarily spatial) of interactions among various actors and organisations, manifested in terms of the sharing of common attitudes, habits and conventions, and institutional settings facilitating idiosyncratic types of learning (among others, Hägerstrand, 1967; Lundvall, 1988, 1992; Audretsch and Feldman, 1996). As Teece et al. (1994, p. 15) have suggested, "learning processes are intrinsically social and collective phenomena". Therefore, concepts such as 'social capability' and 'technological congruence' are particularly relevant when interpreting the growth of firms and clusters (e.g. Abramovitz, 1986; Fagerberg, 1987; Fagerberg et al., 1994), whereby 'social capability' refers to the overall ability of the geographical system to engage in innovative and organisational processes and to make institutional change for innovation; and 'technological congruence' refers to the distance of the cluster from the technological frontier, or, in other words, its capacity to implement the technical properties connected to the new technologies.

Several studies have emphasised the importance of specialisation in mastering a common knowledge set at the early stages of industry and cluster life cycles. Alternatively, diversity in complementary sets of competencies and knowledge has been argued to be more advantageous in later stages of growth of firms and clusters, when interdependent pieces of knowledge have to be integrated and recombined to sustain innovation rate (among others, Arora and Gambardella, 1994; Feldman, 1999). Therefore, the evolution of firms in a specific industry and in a specific cluster is mainly shaped by the underlying knowledge conditions, the so-called 'technological regime', which is a particular combination of appropriability (of the returns of innovation) conditions, technological opportunities (likelihood to innovate, given investments in research), degree of cumulativeness of technological knowledge (extent to which the amount of innovation produced in the past raises the probability of current innovation) and characteristics of the knowledge base (type of knowledge upon which firm's activities are based). Technological regimes identify common properties of innovative processes in different sets of production activities, thus helping to explain asymmetries in the dynamics of industrial competition at sectoral and geographical level (among others Nelson and Winter, 1982; Dosi, 1988; Malerba and Orsenigo, 1995, 1996; Marsili, 2001; Bottazzi et al., 2002, 2005).

Therefore, according to this evolutionary view (which will provide the basic features for revising the cluster classification in a dynamic sense in the following section), cluster types are heterogeneous and path dependent (Cooke et al., 1997; Boschma and Lambooy, 1999; Dopfer et al., 2004; Iammarino, 2005).[11] As such, clusters can be viewed as acting as a selection mechanism that may provide conditions favourable to meet the new requirements of technical change, i.e. the social capabilities for institutional change. Moreover, not only do the characteristics of the selection environment and their changes influence the actors, but the latter also change the environment (Cohen and Levinthal, 1990; Lambooy and Boschma, 2001). In this evolutionary view, growth opportunities are therefore assumed to be shaped and constrained by path dependency, i.e. by the inheritance of local structural characteristics from past knowledge accumulation and learning, and these may often be geographically determined (Boschma, 2005).

[10] See also Maskell (2001).

[11] Historical contingency explains the actual existence of selection mechanisms in socio-economic processes: change is neither solely based on structural elements subject to general rules, nor purely driven by random effects. At each point in time in a system's evolution, a number of paths are theoretically possible, but only a few will be chosen by the actors because each path must conform to the logic of socio-economic dynamics (Schwerin and Werker, 2003).

8. An extended technological classification of industrial cluster diversity

To discuss the dynamics of spatial agglomerations, the classification reported in Table 1 has been revised and extended in Table 2 by integrating evolutionary views of technological change. By adapting such an approach we can identify the main features of the nature of knowledge, technological regimes and industrial and governance structures which are evident in the three transactions costs characterisations of firms and clusters described in Section 4. Table 2 therefore presents an extension of the transactions costs-based cluster classification in which the underlying knowledge conditions of the cluster are now made explicit. This allows us to take into account the ways in which firms may interact with the industrial and technological environment, and the multiple linkages between knowledge conditions and economic growth. Again – as in the transactions costs-based taxonomy and contrary to most cataloguing exercises, prevalently product-based[12] – our classificatory attempt is process-driven, thereby it assumes that each typology may be dominant but not at all exclusive, allowing for clusters which will actually show features of more than one category at the same time (particularly when considered in dynamic terms).

In the model of pure agglomeration, where the notion of space is essentially urban, the bulk of knowledge is explicit and codified, available to any actor and organisation, and generated outside firms' boundaries, being largely created in public institutions. Variety and promiscuity are distinctive features of cities: the combination of different streams of knowledge occurs across a broad range of sectors (Jacobs externalities) and individual linkages or relations are unpredictable, due to the low degree of cumulativeness. Innovative firms in such settings are often operating in knowledge-intensive business services.

The industrial complex is associated primarily with cumulative learning from sources inside the industry and the firm, such as in-house R&D, and on the basis of knowledge that is specific to industrial applications. Such cases generally exhibit low entry possibilities and high industry concentration, which is likely to display a complementary strong concentration at the spatial level. Large incumbents account for most of the sector's innovative activity, and these firms can profit from their innovations in part because they have the potential to exclude rival firms from using the new product and processes they have generated. In these situations, knowledge based on non-transferable experience is an important input in generating innovative activity, and the incumbent firms tend to have the innovative advantage over new firms because innovation is relatively routinised and processed within the existing hierarchical bureaucracies. As such, lead firms play a crucial role and power asymmetry is central to the value chain and the system of innovation governance (Cooke, 2001).

Once the different types of cluster are distinguished in terms of technological regimes, structures and governances, as well as their transactional relations, it becomes clear that the social network model ceases to be a relatively homogenous and consistent analytical category. Thus, we are able to split the single transactions costs-based social network typology into two subcategories, namely the 'new social network' category and the 'old social network' category.

In the new social network model technological opportunities come in the main from sources outside the firm and the industry sector, such as academic research.[13] In this kind of technological environment, we can argue that the type of knowledge tends to be both generic and non-systemic, that there is a high rate of market entry and exit, a strong volatility of market shares, and a low level of market concentration. In this environment, the tacit and sticky nature of knowledge requires geographical proximity. On the other hand, the relatively leaky character of new knowledge – generated by the interaction between firms and other organisations, particularly public research institutes – the openness of the innovation system and the related emergence of new rules, standards, blueprints and verification procedures, all point to the importance of external sources of technical knowledge, which may not be necessarily localised. As such, innovation is frequently associated with a high level of uncertainty regarding both technology and demand, and a high level of market turbulence. As a consequence, a lower survival of new firms is likely to be associated with higher innovativeness and growth of surviving firms (Alchian, 1957). Innovations also therefore mainly come from knowledge that does not have a routinised nature, with new firm start-ups playing an important role and small firms accounting for the bulk of innovative activity.

[12] Other recent classificatory attempts are found, for instance, in van der Linde, 2002; Ketels, 2003; Porter, 2003; Sölvell et al., 2003. In these contributions clusters are mainly classified by type of product, by output market, or by cluster life cycle.

[13] On the role that public research and universities may play in local economic development see, among others, Etzkowitz and Leydesdorff (2000), Boucher et al. (2003), Arundel and Geuna (2004).

Table 2
Industrial clusters: knowledge, technology and cluster dynamics

Characteristics	Pure agglomeration	Industrial complex	Social network	
			New SN	Old SN
Nature of technical knowledge	Codified, explicit and mobile	Mixed, systemic, routinised, R&D-intensive	Tacit, new, generic, non-systemic, sticky and leaky	Mixed, mature, incremental
	Transmitted by way of information	Specific, based on non-transferable experience	Transmitted within cognitive networks	Transmitted within localised networks
Technological trajectory	Oriented to processes, problem-solving	Oriented to complex products, cost-cutting	Oriented to radically new products	Oriented to processes, customer-driven
Dynamics	Stochastic	Strategic	Mixed	Mixed
Sources of innovation	External to the firm	Internal to the firm	Mixed	External to the firm
Appropriability of innovation returns	Low, perfect or monopolistic competition	High, private creation of new knowledge, oligopolistic competition	Mixed, public-private creation of new knowledge	Low, collaboration and competition
Technological opportunities	Medium	Low	Very high, uncertain	Low
Degree of cumulativeness	Low	High	Low	High
Knowledge-base	Diversified	Specialised	Research-based	Specialised along the filière
Modes of governance	Market	Hierarchies	Relational and cognitive networks	Social and historical networks
Examples of industrial specialisation	Finance, banking, insurance, business services, retailing	Steel, chemicals, automotive, pharmaceuticals, machine tools, medical instruments, ICT hardware	SME high-tech clusters in general purpose technologies	Customised traditional goods textiles, footwear, furniture, tourism
Example of cluster	'Silicon Valley' (California)	'Silicon Glen' (Scottish Electronics Industry)	'Silicon Fen' (Cambridge UK)	Italian industrial districts (Emilia-Romagna)
Pavitt classification	Information intensive, Supplier Dominated firms	Production Intensive Firms (Scale Intensive & Specialised Suppliers)	Science-based firms	Supplier dominated firms

In the old social network type, there is not necessarily any clear hierarchical structure, and the overall coordination of the innovation system is left to a mix of cooperation and competition. Knowledge is largely codified and mature, it develops along trajectories which are mainly oriented to process innovation, and it is transmitted essentially by way of personal contacts, social and political lobbying, backward and forward linkages. Moreover, from the perspective of geography, there is also a fundamental difference in the particular systems of innovation governance (von Tunzelmann, 2003; Moulaert and Sekia, 2003; Simmie et al., 2004) between new and old social networks. In the latter case networks are mainly based upon geographically embedded social proximity, while relational and cognitive proximity is often the basis of new social networks. On the other hand, old social networks are usually also rooted in historical experience, whilst new social networks may rely on various kinds of communities of practises that do not necessarily require a spatial dimension.

The classification presented in Table 2 may offer a grid for interpreting the critical issue of knowledge spillovers. Indeed, all three categories are predicated on the existence of knowledge spillovers, which however differ in scope and nature across the cluster typologies. For example, some empirical analyses have shown that inter-industry knowledge spillovers are like to arise in regional centres of technological excellence, where spillovers seem to operate mainly through exchanges in and around core technological systems (i.e. rooted in 'general purpose technologies' as, for instance, background engineering, mechanical methods, electronics and ICTs), creating linkages between actors in quite separate alternative fields of specialisation. These centres of excellence, which are more likely to be classified either as 'pure agglomerations' or 'new social networks', experience a faster process of convergence between old and new technologies and a potentially greater competitiveness, eventually leading to a process of rise and decline of technological clusters (Cantwell and Iammarino, 2003).

It should be noted, however, that a possible weakness of the evolutionary approach to growth and clustering is that, because of the prominence of issues such as networks, path dependency and firm relatedness, there tends to be an over-emphasis on theoretical systems or observed outcomes which either stress or appear to exhibit such features. This probably accounts for the enormous interest in issues such as the social networks evident in Italian-type of industrial districts or in so-called high-tech clusters, the extent of which is completely out of proportion both to their scale, and also to their relevance to other industries and locations. For the purposes of both theoretical and policy analysis, simply adopting social network-type evolutionary arguments and applying them *ex ante* to clustering observations is not a sufficiently analytical standpoint.[14] This is in part because these arguments are largely unspecific concerning their applicability to either specialised or diversified clusters. More importantly, however, irrespective of the sectoral issues, in order to justify the application of these evolutionary arguments to an exploration of geographical variations in absorptive capacity, it is necessarily to look beyond firms' capacity and to consider the likelihood of such an endogenous or evolutionary 'feedback' mechanism actually operating in local institutional settings (von Tunzelmann, 2005). As such, it appears that we have two sets of fundamental questions to be addressed. Firstly, we need to determine *whether* local knowledge spillovers exist, and then secondly, we need to understand exactly *how* they do occur and change over time.

As a guide to informing our discussion of the likelihood and nature of local knowledge spillovers operating, we can use both our transactions costs-based taxonomy and also our new extended technology and knowledge-based classification to identify the evolutionary characteristics of some examples of high profile industrial sectors.

9. Discussion: the evolution of cluster types

The arguments developed in Sections 4–8 allow us to begin asking questions concerning how an observed industrial cluster may evolve over time. As we saw in Section 4, all real-world observations of industrial clustering will contain at least one of the individual stylised transactions costs categories of cluster described in Table 1. From an analytical and a policy perspective, however, what is important is to identify which of these idealised transactions cost types best approximates the dominant characteristics of the observed form of agglomeration. In a similar manner, it may well be that over time clusters may mutate from one typology to another. Therefore, if we want to interpret particular cluster types as being different stages of a possible evolutionary process, we have to keep in mind that our technology-based analytical typologies presented in Table 2 are themselves also stylised

[14] This is all the more so when considering the disruptive changes imposed by the interaction between the 'global' and the 'local', where localised production systems may correspond to globalised knowledge systems.

ideal constructs, and that observed real-world cases will also blend the characteristics of one or more of these categories. Once again, what is important here is to identify which of these idealised technological types best approximates the dominant characteristics of the cluster under analysis. In reality, it is likely that various mixed, diversified, and idiosyncratic patterns of growth can be observed, and no linear or deterministic development path can necessarily be established. Nor are firms necessarily clustered together in space; neither are clusters, where they do exist, necessarily innovative. However, in observed situations where clusters have emerged over time, some particular types of evolutionary or transition patterns are likely to be more common than others (Guerrieri and Pietrobelli, 2004). In order to identify typical evolutionary paths and transitions, some examples can be used to illustrate the different directions of shifts in cluster types, and their impact on geographical agglomeration.

If we take the case of the financial markets in the City of London, these emerged initially out of the tightly integrated social networks amongst the late 16th and early 17th century English upper classes, which amounted to no more than a tiny percentage of the total population (Hall, 1998). As these markets emerged over a long period, they mutated from the embryonic forms of the early 17th century, which were best classified by the 'new social network' model, to more mature 'old social network' structures of the late nineteenth century, in which the behaviour of, and access to these markets, was still controlled by narrowly defined elite social networks. Subsequently, market competition during the second half of the twentieth century (Casson and McCann, 1999) transformed these markets from social networks to something which now approximates the pure agglomeration model (Gordon and McCann, 2000, 2005a). The evolutionary process of this location-specific sector has therefore been from new social network, to old social network, to pure agglomeration.

A quite different evolutionary path has been exhibited by the global automobile industry. The early development of this industry on both sides of the Atlantic approximated to being something akin to 'pure agglomeration' (Hall, 1998; Boschma and Wenting, 2005), but over time this system evolved to represent the classic 'industrial complex' model we now see (Best, 1990), which is dominated by large oligopolistic producers, clustered in particular localities, with complex and highly organised input–output supply chain systems (Markusen, 1996). The evolutionary process of this location-specific sector has therefore been from pure agglomeration to industrial complex.

In the case of the high-fashion garment industry clusters of New York and London, this emerged initially in the 1880s according to the paternalist logic of 'old social networks' (Godley, in press) employing primarily eastern European Jewish immigrants. Soon, however, developments in fashion design and retailing meant that this sector evolved into a 'new social network' prior to the first world war (Godley, 2001). However, after the depression and the second world war these sectors were transformed into 'pure agglomerations' with little or no social capital, operating primarily via the exploitation of local supplies of cheap immigrant labour from all over the world (Godley, in press). Here the evolutionary path of these clusters has been from old social network, to new social network, to pure agglomeration.

If we consider the transformation of the Italian industrial districts in the light of the process of internationalisation, we may indeed argue that "the industrial district has often proved to be rather a 'stage' in one of the possible different paths of industrialization" (Becattini, 1987, p. 32).[15] As such, this case now provides examples of evolutionary transitions from old social networks to something which exhibits many of the relational characteristics of the industrial complex model, except for a greatly reduced geographic localisation of many of the input–output linkages (see also Garofoli, 2003; Belussi and Samarra, 2005).

There also other examples of industrial clusters in some newly emerging and rapidly changing industrial sectors such as biotechnology and multimedia (e.g. Swann and Prevezer, 1996; Baptista and Swann, 1998; Fuchs and Koch, 2005). Many of the innovations within these sectors take place in large multinational oligopolistic firms whose locational criteria primarily reflect those of the 'industrial complex'. However, in situations where activities in these sectors are geographically concentrated amongst small firms, they appear to correspond most closely to the 'new social network' type of system, where inter-industry spillovers emerge from the integration of different types of networks, and where the ability of MNC competence-creating subsidiaries depends

[15] Becattini's notion of 'industrial district' largely exhibits the characteristics of our old social network model, in which there is a lower degree of both the density of activity and the weight of services than that in his notion of the 'urban system', which corresponds largely to our transaction costs definition of the pure agglomeration model. His third notion of the 'industrial region', which exhibits largely a mono-sectoral character along with a lesser degree of technological and organisational complexity than the 'industrial district' (Becattini, 1987), corresponds most closely to our transaction costs definition of the industrial complex model.

on their local embeddedness (Cantwell and Piscitello, 2005). However, the recent emergence of these clustered sectors means that as yet it is too early to point to a particular evolutionary path.

At this stage, however, it must be made clear that differences in cluster types and also in cluster evolutionary paths, where they exist, are not necessarily related to industrial sectors. In particular, high-technology sectors do not exhibit a particular cluster characteristics or evolutionary trajectories. In order to see this, it is interesting to consider the example of the semiconductor and electronics industry, the quintessential high technology sector.

In the case of the global semiconductor and electronics industry, much of the industry initially emerged from oligopolistic firms in other sectors, such as defence contracting, lighting engineering, or radio- and telecommunications (Hall, 1998). The majority of the global semiconductor industry, involving wafer fabrication and assembly activities, is still largely dominated by these large oligopolistic firms both in the USA, as well as in Europe and Asia. The location behaviour of these firms generally reflects rather traditional location criteria involving a consideration of location-specific factor costs and the transactions costs involved in coordinating business activities over space (McCann, 1995). As such, in situations where we observe firms from these industries to be clustered together in space, their location-organisation characteristics reflect primarily those of the 'industrial complex' model (Arita and McCann, 2002a,b,c; McCann et al., 2002). These location-specific sectors emerged initially as an industrial complex, and have remained so for over 50 years. As such, no real cluster-evolutionary path is discernible in this case.[16]

On the other hand, there are some sub-components of the global semiconductor and electronics industry, which have emerged in quite different ways. For example, the Silicon Valley elements of this industry which have tended to focus on semiconductor design activities. Although the early post-war features of the Silicon Valley semiconductor industry were mainly typical of the 'old social network' model (Hall, 1998), this industry initially developed during the 1970s along the lines of a 'new social network', and has now emerged into something which is akin to a 'pure agglomeration' model (Arita and McCann, 2000, 2004), exhibiting the supplier dominated characteristics of Pavitt's classification. The majority of the design innovations developed in Silicon Valley are made possible primarily because of the miniaturization innovations generated in the wafer processing and wafer assembly parts of the industry which are primarily located elsewhere. As such, the evolutionary transition of the Silicon Valley cluster has been from old social network to new social network to pure agglomeration.

On the other hand, in the case of the Scottish Electronics Industry, which is often known as 'Silicon Glen', and which specialises in the production of ICT equipment, this location-specific sub-component of the semiconductor and electronics industry emerged as an 'industrial complex' in the 1960s and 1970s, and has remained so for over 40 years. As such, no real evolutionary path is discernible in this particular cluster. Meanwhile, if we consider the case of the high technology cluster of electronics firms around Cambridge UK (Castells and Hall, 1994), the emergence of this location-specific sector can be characterised by a movement from an 'old social network' to a 'new social network'. The system is still far too small to be really considered an agglomeration along the lines of Silicon Valley.

10. Conclusions

In the light of the arguments presented in this paper, it becomes clear that all industrial clusters can be characterised in terms of both transactions costs and relations characteristics as described in Table 1, and also in terms of technological regimes and knowledge characteristics along the lines depicted in Table 2. Our aim, as in all attempts to classify units of analysis by reducing the complexity of the whole population, was to maximise differences among the categories. However, as Pavitt himself said about his own taxonomy, the main weakness of our attempt "is the high degree of variance still found in each category" (Pavitt, 2000, p. xi). This is all the more true here as, while Pavitt approach was inductive and based on detailed empirical observation of individual units of analysis such as firms (Archibugi, 2001), ours is deductive, based on different streams of the literature on the geography of innovation, and it attempts to classify composite units of analysis such as clusters.

From theories of innovation and technical change we know that innovators will tend to emerge in locations where technological opportunities are the highest. When there are conditions of high opportunity, high appropriability and high cumulativeness, innovators will tend to be geographically concentrated, giving rise to emergent clusters. Nonetheless, whether these types of situations

[16] It should be noted, however, that the evidence reported on the variety of trajectories followed by MNCs in their global strategies for technological diversification indicate that further investigation is needed to classify their locational patterns.

will arise depend on the nature of knowledge in both the industry and the firms. Whereas technical knowledge tends to be prevalently tacit, complex and systemic, the transaction costs- and knowledge-based arguments here suggest that, in some circumstances, the transfer of such knowledge will be facilitated via informal personal contacts and exchanges in situations where firms are geographically clustered. Conversely, geographical concentration will be far less important when the industry knowledge base is simple, well codified and conditions of low opportunity, low appropriability and low cumulativeness prevail.

However, the possible alternative characteristics of clusters presented here indicates that technological and knowledge features alone are not a sufficient guide to the types of clusters that are likely to emerge, nor are industry characteristics. Rather, as we have seen, knowledge and innovation processes, organisational, firm and industry-specific characteristics, and institutional and governance settings, all play a role in explaining the diversity of industrial clusters and also their evolutionary trajectories. Indeed, as any single firm (particularly when large and multinational) can follow more than one technological trajectory (Pavitt et al., 1989), clusters may well be engaged in a prevalent but not exclusive trajectory at any given point of time. Process-based classificatory attempts, such as that presented in this paper, help thus explain multiple trajectories and patterns of evolution.

Once we account for innovation and knowledge creation processes, it becomes very difficult to apply simple stylised cluster constructs, because there is neither a representative Marshallian firm nor an illustrative ‘innovative’ cluster. Co-location therefore *may* or *may not* offer structures, organisations and institutions which improve the likelihood of local innovation. Understanding this diversity, and in particular both the transactions costs features and also the knowledge features of any particular cluster, should be the underlining base for any policy actions geared at finding actual solutions to particular regional or industrial problems.

On this basis, our future research will follow a two-fold path: (1) extend dynamic comparisons among empirical cases, to have feedbacks on the scope and limitations of our classificatory attempt; (2) achieve a workable definition of the appropriate unit of analysis for assessing knowledge spillovers, and ultimately drawing policy implications.

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