The Local Dimension of Information Spillovers: A Critical Review of Empirical Evidence in the Case of Innovation*

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"Knowledge traverses corridors and streets more easily than continents and oceans" (Feldman 1994: 2).

“For the first time in history, it might be possible to locate on a mountain top and to maintain intimate, real-time, and realistic contact with business or other associates. All persons tapped into the global communication net would have ties approximating those used today in a given metropolitan region” (Webber 1968 quoted in Moss 1987: 535).

While Feldman considers that distance impedes the diffusion of knowledge, Webber claims that information interactions have become location-independent.

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These two contradictory statements have very different consequences in terms of the agglomeration of economic activities. Although it can be argued that thanks to new communication technologies, distance is now irrelevant to many information interactions, it is widely accepted that the more complex and strategic information interactions are still conditioned by close proximity or face to face contacts. The question is to determine which effect is prevalent.

Basically, information exchanges generate spatial externalities. Indeed, information is, in some sense, a public good, because it is non-rival by nature: the individual who gives information still retains it. Information exchanges are therefore not really marketable and they generate a form of externality, i.e. non price interaction or spillover. Moreover, other things being equal, distance is a barrier to the spread of information (Hägerstrand 1965), so that information flows generate spatial externalities, that is non price spatial interactions (Fujita 1990), also called local spillovers. As far as information diffusion is spatially limited, information-intensive activities are expected to be located close to each other thereby maximising the benefits (Fujita and Ogawa 1982).

But the progress in communication technologies and their wide diffusion seem to release the need for proximity. Information can be massively transmitted everywhere at a very low marginal cost. In this context, information exchanges rather generate global spillovers, that is to say externalities without any limited spatial range. The agglomeration effects of information spillovers seem to disappear.

This paper tries to evaluate empirical evidence showing the importance of local information spillovers, and therefore the agglomeration effects of information spillovers.

While the development of communication technologies might justify Weber's claim, the empirical evidence supports Feldman's. Information-intensive activities are still spatially concentrated, despite the progress in communication technologies, which seems to mean that information flows are spatially bounded.

For example, in the United States, innovation output is highly concentrated in California, New Jersey and Massachusetts, where the rate of innovation per 100,000 jobs is twice the US average (Feldman 1994; Feldman and Florida 1994). In France, ten (of 95) departments account for 60% of R&D employment (Carrincazeaux et al 2001; Carrincazeaux 1999).

Moreover, information-intensive activities are clearly urban activities. In the United States, 90% of producer services employment was located in metropolises in 1985 (Beyers 1989). The same phenomenon is observed in many developed countries such as Canada or France, where, in 1990, the proportion of employment concentrated in cities of more than 100,000 inhabitants was around 76% for the high-order producer services sector, 83% for Research, and 72% for Banking, Insurance and Finance (Léo and Philippe 1998).

These crude observations suggest that information spillovers are still local and that information exchanges are still an agglomeration force. But such observations provide only a weak test of the effective role of information externalities in the concentration process. First, other factors may affect the concentration of information-intensive activities; second, the observations themselves offer no insight into why and how information interactions generate agglomeration. We therefore have to turn to more sophisticated empirical investigations and see whether they corroborate the agglomeration effect of local information spillovers, in the case of innovation. From the extensive literature on the subject we draw here on those studies most directly relevant to our objective.

In this paper, we seek to evaluate to what extent the empirical evidence supports the existence of local information spillovers, i.e. the hypothesis that information exchanges lead to agglomeration. We emphasize methodological difficulties, and state both the relevance and the limits of the empirical results reviewed.

First, we recall the main theoretical principles explaining the agglomeration effect of information exchanges through the analysis of the nature and characteristics of information, and we justify our decision to focus on empirical tests relative to innovation activities. Then, we explain the principles and evaluate the results of the empirical investigations. We address the following questions: Are the different agents interacting in the innovative process geographically concentrated? What is the actual spatial range of information interactions and on what factors does this range depend? Is the type of information exchanged a significant factor of this range? Finally, we ask to what extent do empirical tests really corroborate the agglomeration role of information externalities.

Preliminary Statements

First of all, the terms used must be properly defined. We do not make any precise distinction between knowledge and information, as made by Polanyi (1966), or Feldman (1994) for whom, roughly, information is always easily transportable while knowledge is not. What seems to be the most important thing for shaping space is the degree of transportability of knowledge or information, which is determined in the main by the more or less tacit character of the ideas exchanged.

Therefore, we rely on the distinction between tacit and codified information. We explain why the persistence of tacit information in the economy leads to the agglomeration of information-intensive activities and we state three theoretical conjectures to be corroborated. After that, we justify the claim that innovation activities are an important subject matter for empirical investigation.
Agglomeration and Tacit Information: Theoretical Conjectures

Information does not contain its full meaning in itself, but only in a process involving one or more particular senders and one or more particular receivers. Successful transmission of information is not enough: information must be fully understood by the receivers for it to be put to its proper use. In the context of the development of communication technologies, understanding how information exchanges shape space involves determining whether interaction at a distance can be a substitute for face to face interaction without information loss. The question of the impact of information exchanges on space takes the following form: are electronic interactions sufficient for the understanding and use of information by the receivers? A meaningful answer can only be given after studying the consequences of the distinction between tacit and codified information.

Information may be systematic, repetitive and articulated, and thus can be easily communicated and shared independently of the individual from whom it comes. This is codified information, that is to say information that can be expressed in a compact, standardised form with non-ambiguous words, numbers or scientific formula, and that can therefore be diffused mainly by digital technology. Codified information can be understood, used by everyone and transported by communication technologies in a reliable fashion.

Unlike codified information, tacit information is not standardised, but personalised and contextualised. Its meaning is closely linked to the individuals who hold it. It cannot be immediately and completely understood by other individuals without dialogue between the parties and gradual clarification. Face to face interaction between the individual who holds tacit information and the individual who seeks it, is a necessity.

But the need for face to face interactions does not necessarily imply permanent geographical proximity and agglomeration. Business trips can be used for exchanging tacit information. Such business trips are facilitated by high speed trains (TGV, Thalys and Eurostar in Europe) or air links (Rallet 1999). When evaluating the influence of tacit information on spatial organisation, the locational behaviour of individuals exchanging information has to be examined.

The more tacit in character the information exchanged, the more intense the need for geographical proximity. Indeed, geographical proximity governs the efficiency of tacit information exchanges because it permits more frequent contacts and a better quality of contacts.

First, the diffusion and reception of tacit information is often informal and random. The probability of face to face encounters is greater where individuals are agglomerated. By contrast, business trips for a face to face interaction must be planned. Second, even where encounters are planned, the opportunity to exchange information is greater if individuals are located close to each other. Proximity provides time for encounters and permits more frequent encounters. Thus, proximity allows “timely” information exchanges and consequently insures efficiency when a decision must be taken quickly.

Second, the risk of misunderstanding is an incentive to develop interactive communication (Gaspar and Glaeser 1998). In a face to face interaction, an individual can ask questions if he or she misunderstands or does not understand. The explanations are given immediately. Moreover, an individual who gives information can adapt his/her methods of communication to the receiver’s preference for a particular method of learning. Some people prefer an intuitive approach to problems, others theoretical or analytic approaches. Some people like graphs and figures, while others prefer verbal argumentations, anecdotes or examples. For perfect understanding of information, the diffusion must be made in the most appropriate way (Leonard and Strauss 1997) and this is achieved by means of frequent encounters.

From the instant individuals meet, they get to know one another. Gradually, they understand things in the same way and share the same culture, which is the prerequisite for efficient communication (Arrow 1974; Cohen and Levinthal 1990). Frequent encounters between individuals permit the formation of a common language and tacit information can be diffused and treated more efficiently and reliably. More generally, geographic proximity leads to the emergence of a distinct form of proximity, namely “relational proximity”, which guarantees a better quality of contact. Indeed, geographical proximity allows the emergence of rules, norms and formal or informal conventions that regulate competition and coordination between firms. These generate an atmosphere of trust which is beneficial to the diffusion of information, and to an easier interpretation, selection and appropriation of the information received.

Finally, the persistence of tacit information in the economy is an agglomeration force, and the development of communication technologies does not weaken this force. It only amplifies the potential for transmitting massively codified information over distance and does not alter the proximity constraint relating to the exchange of tacit information (Rallet 1999).

These factors explain why the city can still be viewed as a place that promotes information exchanges in general and tacit information exchanges in particular. The city can be defined basically in terms of the two concepts of agglomeration and diversity (Baumont et al 1998). It brings together different agents such as firms, households but also more specific urban actors such as research centres, universities, libraries, administrative and political authorities. Because individuals are different, they hold differentiated information. This heterogeneity between agents is the source of information exchanges. The city is therefore a place where diversified information can be readily exchanged.

On the basis of this rapid analysis, we can propose three simple conjectures which we would submit to empirical literature relative to innovation activities:

- Agents (such as scientists, technicians, decision-makers and producers) who participate directly or indirectly in a specific innovation process are located relatively close to each other. This means that innovation takes place near to its information inputs and we shall term this phenomenon the input dimension of the innovation process.

- This proximity is more often realised at the urban scale, which specifies the
urban dimension of the innovation process.

- This proximity stems from the need for diversified and tacit information. Insofar as observation never proves causality, only indirect tests can be used to reveal this hidden dimension.

Testing these conjectures raises a number of methodological problems, mainly because it is virtually impossible to observe information flows. "Knowledge flows, ..., are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes." (Krugman 1991: 53-54). On the strength of this empirical argument, Krugman (1991) rejects the idea that spatial externalities and information spillovers especially could be considered as a primary reason for agglomeration. However, we cannot assume anything we like: empirical evidence has been gathered confirming the role of technological spillovers in the agglomeration of a number of information-intensive activities. Innovation is at the core of most of these empirical investigations because it is highly dependent on information exchanges.

Innovation and Information

Commercialisation of a new product is not a simple application to the market of a discovery made in a laboratory. This view of innovation does not reveal the complexity of the innovation process. Three main steps can be distinguished (Feldman 1994): the actual innovation, which may be the discovery of a new technology or of a new product; the development of the innovation, i.e. refinement which leads to marketable products; its commercialisation, i.e. the sale on a market of the technology or of the product. Of course, these steps are not strictly sequential: feed-back processes may occur. For example, commercialisation could bring new ideas for the development stage.

Uncertainty is present during these three stages of innovation. For example, during the development stage, no one can foresee what scientific or technical troubles may arise. Then, it is difficult to know if the innovative product will be a commercial success. In order to reduce this uncertainty, agents exchange information for evaluating the consumer needs and for solving scientific and technical problems.

Which agents are engaged in the innovation process? Universities and research corporations are the main institutions providing information for innovation. Insofar as university research leads to publications in journals, one may expect that proximity between universities and firms does not really matter. But the publication process can be lengthy. Proximity makes encounters easier and firms can benefit from yet unpublished information. Then, during face to face contacts, tacit information can be exchanged between a firm's representatives and university scientists, e.g. about the connections with previous research, the impression about his or her research, about his or her experiences. Encounters

The Input Dimension: The Technological Infrastructure of Innovations

If innovation occurs close to its information input sources, then we can suspect that spillover effects are instrumental in the agglomeration of information-intensive activities.

Innovation draws primarily on research inputs from universities and R&D departments of corporations. These information inputs enter Jaffe's knowledge production function and are combined with other significant inputs in the wider concept of technological infrastructure determining innovation production.

Research Inputs in the Knowledge Production Function

Silicon Valley and Boston's Route 128 are two of the most famous innovation centres in the world. The proximity of Stanford University and of MIT is instrumental in these innovative successes (Saxenian 1994). Empirical studies analyse this phenomenon of university research diffusion in a wider context by introduc-
The seminal study in this area was conducted by Jaffe (1989). He proposes identifying the extent to which research generates spillovers by means of an econometric model based on the knowledge production function as first formalized by Griliches (1979). Firms try to acquire new knowledge as an essential input for innovation activity. The most important source of new knowledge is research and development, followed by the high degree of human capital, skilled labour and the high density of scientists and engineers. The function relates innovation output and knowledge inputs. Jaffe uses a modified Cobb-Douglas model with two inputs: industry R&D and university research. Innovation output is measured by the number of patents. The proxies of industry R&D and university research are respectively expenditure by private corporate research and expenditure by universities.

The spatial scale of observation is the state because data are more readily available at this level. But this scale is too large to grasp local interactions between universities and firms. Indeed, for a given total amount of university research and industry R&D in a state, there should be more spillovers if university research and industry R&D are located in the same metropolitan area. So an additional explanatory variable is introduced in the knowledge production function: the "geographic coincidence index", which measures the degree of geographic proximity between universities and industrial research centres within the state. This index is weighted by the amount of university research.

But this function only partly describes the links between the variables. The complete model takes the form of a system of simultaneous equations with two additional equations. In the first one, university research depends on the industry R&D and on a set of exogenous local characteristics. In the second one, industry R&D depends on university research and on a set of exogenous local characteristics that may be different from the previous ones. Such a model allows the investigation of the complex reciprocal dependencies between the variables and especially to capture the potential interactions between university research and industry R&D. In extended and refined forms, such a simultaneous equations system lies at the core of a number of subsequent empirical models.

Jaffe's model is tested over eight years for 29 states and five technological areas (drugs and medical technology; chemical technology; electronics, optics and nuclear technology; mechanical arts; others). It provides evidence that the number of patents increases with both industry and university expenditure within the state. But, surprisingly, "there is only weak evidence that spillovers are facilitated by the geographic coincidence of university and research labs within the state" (Jaffe 1989: 968). There is evidence that the spillovers from university research spills over by journal or review publications, geographic localisation does not matter for innovation activity. But if the main mechanism is informal discussions, it is important to be located near the research sources to capture the spillover benefits.

The principle of the knowledge production function is widely used in empirical studies of spillovers and many extensions of Jaffe's econometric model have been proposed. A number of these models aim at introducing new local factors of innovation. University research, industrial laboratories, presence of business services and related firms, form what is termed the "technological infrastructure" (Feldman 1994; Feldman and Florida 1994). The first two elements are present in previous studies. Related firms provide potential users of innovations and a pool of technical knowledge generating an innovative environment. Business services play a major part in the innovation process by providing marketing information which reduces the risks in the innovation process. Each of these four inputs enters the production function in the form of its average annual measure during the ten years (1972-1982) before the observation of the output, which introduces a time lag.

The scale of observation is still the state and the output data source is Small Business Administration. The proxies measuring university research and industrial laboratories are average annual expenditures. Related industries are identified by the official American SIC classification. Their contribution is measured in terms of value-added. There is insufficient data to provide a good measure of business services. Their presence is indicated by the annual average receipts of Commercial Testing Laboratories in constant dollars. The assumed relationships between the elements of the technological infrastructure are formulated by a system of simultaneous equations.

Jaffe's results for university and industry research are confirmed. The related industry effect is significant. The positive effect of the presence of business services is particularly strong. Innovation is thus clearly related to the local
technological infrastructure. Moreover, the simultaneous system shows that the components of the technological infrastructure are mutually reinforcing.

A number of general conclusions can be drawn from these approaches. First, innovation is not only the result of the innovative capacity of the firm as in Smith or Schumpeter. Innovation is the result of a cumulative process combining competitiveness and complex information inputs from different agents and different places. Second, the proximity between these input sources is clearly correlated with the capacity to innovate. This gives a first but incomplete empirical basis to the role of knowledge spillovers and to their limited spatial range, and thus to the agglomeration effect of tacit information exchanges.

Geography seems to play a strategic role in the innovation process. But the geographical dimension is still too crudely introduced in these analyses. The state or regional scale is not the most appropriate level of investigation.

The Urban Dimension

Jaffe’s geographic coincidence index is a first step for improving the spatial dimension of knowledge spillovers. But it bypasses the true urban dimension of the phenomenon. How can we introduce these refinements into empirical studies? Three contributions are examined: the first one deals with the spatial diffusion of knowledge through citations at different spatial scales including US metropolitan areas; the second one is a generalisation of Jaffe’s model at the level of metropolitan areas; the third one introduces the process of intercity diffusion of information alongside the classical proximity effect.

The Diffusion of Knowledge through Citations

Jaffe et al (1993) focus on the spatial extent of knowledge spillovers through patent citations. When a patent is granted, a public document is available containing information about the invention and especially about citations. These citations are relative to the antecedents of the invention and they provide an indirect means of detecting knowledge flows and of tracing the history of new knowledge. Data are made of two cohorts of patents: one for 1975, one for 1980. Citations of these patents in other new patents are recorded. The reasoning runs as follows: the location of a cited original patent X is compared with the location of the new patent Y that cites X. If the former location is in the same geographical area as the latter, then it can be said that the diffusion of patents is spatially limited. But innovative activities in a given technological area tend to be located near one another, so that there is a pre-existing technological specialisation of geographical areas. Because of this specialisation, the citations may originate in the same areas as the citing patents but not reflect any spillover effect. Thus a control sample must be constructed as follows: with each new patent Y which refers to an original patent X, another new patent Z is associated, originating from the same technological sectors at the same time but not citing the original X. We can then infer a spillover effect only if the probability (frequency) of being located in the same geographical area is higher for X and Y than for X and Z. Geographical dimension is introduced at three levels: nations (US or not), US states and US metropolitan areas.

Two main conclusions can be drawn. First, geography matters for spillovers. The citation effects vary with geographical scale, showing that distance affects the diffusion of information. Indeed, in each case, the metropolitan area is the most relevant level for identifying the location effect of citations.

Second, the geographical diffusion of these effects varies implicitly with the nature of the information transmitted. For the 1980 cohort, there is clear evidence of the influence of localisation on citations. For the 1975 cohort, the tendency is similar but weaker. At first, information diffusion is spatially limited mainly when it has just come to light. Subsequently, whether through coding of the information or through the market, the information is spread more widely. This confirms that the proximity effect is stronger for new and complex information, i.e. primarily for tacit information.

Of course, these results have to be considered very carefully for two reasons. First, citations are made by an examiner. So an inventor may have no idea of which patents he or she used for his or her innovation. Second, not all knowledge flows are expressed by citations. These technical limitations make it difficult to extend these results.

We are thus faced with a dilemma. On the one hand, the citation method allows us to grasp the precise spatial dimension of spillovers, but it is limited in the way in which spillovers are identified. On the other hand, this identification is improved if we use a knowledge production function, but this method usually includes a limited spatial dimension.

In and Around the City

While using Jaffe’s reasoning in terms of a knowledge production function, Anselin et al (1997) conduct a study at the level of metropolitan statistical areas (MSA), in order to get a more precise idea of the spatial extent of spillovers. No index of geographic coincidence is needed because the spatial unit of analysis is smaller. Two new independent “spatial lag” variables are introduced in the knowledge production function. They capture the effect on MSA’s innovation of university research and industry research in counties within a given radius of the geographic centre of the MSA. Two ranges from the MSA centre are considered: 50 miles and 75 miles.

As in Jaffe’s model, two equations are added to determine the direction of cause and effect between industry research and university research but at the city level. Innovative output is measured by data from the Small Business Administration to avoid the difficulties with patents.
As in the previous studies, the results confirm that industry and university research influences the level of innovation output. There is evidence that university research influences innovative activity not only when it arises from within the MSA itself but also from the surrounding counties. On the contrary, there is no evidence that industry research spills over outside the MSA. The results confirm Jaffe’s causality from university research to industry research. University research influences innovation outputs both directly and indirectly through its influence on industry research. It must be noted that distance effects vary from one sector to another.

With these studies, we corroborate the local character of spillovers. But the results in Anselin et al. (1997) for university research show that more precise consideration of the spatial range of interaction is important.

**InterCity Diffusion**

The spatial dimension could be introduced differently. In previous works, the purpose was to determine more or less directly the effect of physical distance on the diffusion of spillovers. But returning to the pioneering works of Hägerstrand (1953, 1965) on knowledge diffusion, we are faced with the distinction between contagious and hierarchical diffusion of information. In the contagious case, information diffuses first in the vicinity of its source and with increasing difficulties at greater distances. In the hierarchical case, information diffuses first more easily from city to city, even at great distances. This is due to the better access to information provided by large cities. Few studies adopt this point of view. Florax and Felmer (1992) take the two diffusion processes into account in evaluating the effect of university research on investment decisions of industrial firms in the Netherlands. They conclude that hierarchical diffusion is significant, while the contagious effect is not. This introduces a new interpretation of the role of distance in spillover effects and gives cities a new role. Apart from being a place of information exchanges between agents located in close proximity, big cities appear as primary places of emission and reception of information because they are privileged communication network nodes. Because these nodes concentrate complex communication equipment and transport terminals, information is supposed to diffuse more easily from node to node than around each node (this role of cities is developed in Guillain and Huriot 2000). It is as if we had replaced physical distance by a more elaborate distance measured on a network.

But this result must be handled with care. Distances between cities in the Netherlands are very small, and only the effect of university research is tested: we know that this effect is difficult to capture and that the diffusion of university spillovers is frequently wide.

All these studies refine the preceding results by assigning to distance a more precise role in the intensity of information spillover effects. In short, it seems that information is more easily diffused between closer locations. However, distance can take different forms and above all its effects depend on a number of important hidden characteristics of information exchanges.

**The Hidden Dimensions:**

At the Core of the Spillovers

So far, we have focused on the extent of spillovers. But what sort of spillovers are firms looking for? In order to understand spillovers more fully, we have to identify the nature and the contents of knowledge interactions more clearly. This hidden dimension is the most difficult to highlight. Two main lines can be followed: first, a number of empirical studies concentrate on the role of information variety. The debate takes the form of whether diversity or specialisation in the city favours innovative activity. At the same time, the influence of local competition on innovation is studied. Second, the tacit dimension can be indirectly identified and its effects estimated.

**The Preference for Information Variety**

The reasoning relates to endogenous growth theory which considers that externalities, and more particularly knowledge spillovers, lead to economic growth (Romer 1990). These theories differ in two ways. "First, they differ in whether knowledge spillovers come from within the industry or from other industries. Second they differ in their predictions of how local competition affects the impact of these knowledge spillovers on growth." (Glaeser et al. 1992: 1130).

Marshall-Arrow-Romer’s (MAR) and Porter’s theories emphasize the specialisation of the industries in the area as the most important source of spillovers, and thus of growth. In this case, people share the same language and the same business in the area and are rapidly able to catch on to information and knowledge spilling over between firms. On the contrary, Jacobs thinks that the most important knowledge externalities come from outside the industry. Diversified cities allow ideas to be adapted to other sectors, and more information from different horizons to be shared. MAR externalities and Jacobs’ externalities are respectively the dynamic versions of "localisation economies" and "urbanisation economies", introduced by Hoover (1937) and Isard (1956).

The MAR theory stresses the damaging effects of competition on innovation. With local competition, inventors lack property rights on the knowledge spillovers and this tends to discourage investment in research and development which in turn reduces innovation. On the contrary, Jacobs and Porter consider that, although it reduces the return on the discovery, local competition accelerates innovation. With competition, the pressure to innovate is greater because the firms are induced to adopt new technologies rapidly and to improve them.

The analytic framework of Glaeser et al. (1992) is endogenous growth. They seek to find out what sorts of spillovers and what market structures lead to
growth. The results at the city level corroborate Jacobs' theory which argues that diversity and local competition generate growth. The principles of Glaeser et al (1992) lead to the analysis of Feldman and Audretsch (1999) identifying the extent to which specialisation or diversity of cities generate innovative output and which economic structure (local competition or monopoly) best promotes innovation. This analysis can tell us whether firms really are looking for spillovers and if so for what sort of spillovers. This study relates to the city level. We shall only outline the econometric model. The innovation output is linked to three main independent variables. One variable reflects the degree of industrial specialisation of the city. A positive coefficient would mean that an increasing specialisation in the city leads to more innovative output, which would corroborate the MAR and Porter theories. A negative coefficient would mean that specialisation reduces innovation, which would support Jacobs' theory. The second variable is similar to the index of industrial specialisation introduced by Glaeser et al (1992). The aim is to measure the influence of the presence of related industries linked by a common scientific basis. A positive (negative) coefficient would show the influence of diversity (specialisation). To measure the impact of competition on innovation, one variable similar to that of Glaeser et al (1992) is introduced: the ratio of the number of firms to the number of workers.

The results show that innovation output is lower in specialised cities. The agglomeration of diverse complementary activities sharing common knowledge increases innovation more than specialisation does. In addition, local competition for new ideas is more conducive to innovative activity than local monopoly.

The importance of the diversity of information for innovation is shown in another way by a number of French surveys (Carrincazeaux et al 2001; Carrincazeaux 1999). The tacit dimension of knowledge required for innovation is closely related to a double degree of complexity: first the technical complexity inherent in each element of knowledge and second the combinatorial complexity measured in particular by the heterogeneity of the sources of knowledge, the number of projects and the intensity of external coordination at the firm level. This "complexity" variable is introduced among others into a function where the dependent variable is a Gini coefficient of intersectoral concentration of R&D at the level of French départements. It clearly appears that complexity of information has a positive effect on this concentration.

These body of research further corroborates our theoretical base. It seems that in order to innovate, firms need information from a variety of local sources. But the very core of the problem lies in the more or less tacit character of the information exchanged. How can we inquire into this tacit dimension?

**The Tacit Dimension**

When do spillovers play the most important role? Empirical analyses in endogenous growth provide some evidence that the question is not meaningless. Henderson, Kuncoro et al (1995) show that for traditional manufacturing industries, diversity (generating Jacobs' externalities) does not really matter. On the contrary, the diversity of the city attracts new industries and more particularly high technology industries. These results are consistent with product cycles: “new industries prosper in large, diverse and metropolitan areas, but with maturity, production decentralizes to smaller, more specialized cities.” (Henderson et al 1995: 1067).

In the product cycle, the need for tacit knowledge is greater in the earlier stages and after it decreases because of product standardisation. Under these circumstances, proximity will be more important during the development stage of the innovation and less important afterwards. Thus the intensity of the agglomeration force varies from one stage to the other in the product innovation cycle. This is confirmed by several studies. By classifying industries into four different stages in the life cycle, Audretsch and Feldman (1996) find evidence to corroborate this fact. In the first stage, sources of new knowledge, such as university research and skilled labour, lead to an increasing propensity of innovative activity to concentrate. But, during the growth and decline stages, the importance of these factors diminishes.

A related approach addresses the role played by market information in the development of product innovation. The users of complex, customised and costly products place considerable value on the proximity of the sellers because, in order to use the product efficiently, they need tacit information (Lundvall 1992). Conversely, producers who want to market a new product need information about demand, tastes, and need interactions with users in order to ensure the suitability of the product. This tacit information is easier to obtain in close proximity to customers. The problem may be related to the "home market hypothesis" saying that producers focus first on the home market and export only when this market is mastered. The question is one of finding out whether distance may hamper market information exchanges. In studying the Canadian software product sector, where the need for tacit information is particularly great, Cornish (1997) obtains the following results. First, during the initial product development, a significant proportion of market information is acquired locally, where the innovation is developed. In the later stage of ongoing innovation, the sources of market information shift away to external markets, where the product is sold and where users are better qualified to give relevant information. That is to say first, that the home market hypothesis is weakly confirmed and is valid only in the first stage of product innovation and second, that the spatial effect of tacit information exchanges seems to be confirmed in this case study.

Further corroboration of the fact that proximity matters for tacit information exchanges can be found in the analysis of biotechnology firms by Audretsch and Stephan (1996). These authors study the connections between biotechnology firms and university scientists. Because new knowledge is one of the major inputs in these firms, there is a valid reason to expect co-localisation of the two groups. But Audretsch and Stephan report that about 70% of the links are non local. This paradox is solved by examining the role and the characteristics of the scientists connected with the firm. The connections are multidimensional and the impor-
Do Facts about Information Provide Useful Information about Theory?

We have shown how a number of methodological problems were solved and how this allows empirical studies to deal with some major aspects of the agglomeration effects of information exchanges in the field of innovation. All these studies seem to corroborate the initial theoretical conjectures more or less directly. Are these results sufficient to recognize the real role of information externalities in the agglomeration of R&D, and more generally of activities of conception, decision and control, especially in urban areas? A first series of weaknesses lies in the difficulties in estimating the main variables of the agglomeration process under investigation. Next, we point out certain theoretical or empirical points that apparently contradict or weaken the previous logical links assumed between agglomeration and information externalities.

Logical Problems: The Agglomeration Effect of Information Externalities in Question

Economic geography and urban models state that information externalities can result in agglomeration of information-intensive activities, other things being equal. But the conjectures we presented can be challenged on the basis of both...
theory and observation, mainly because in the real world other things are not maintained equal.

First of all, agglomeration of producer services or related activities in cities can appear and expand without the help of information externalities. A sufficiently large number of other factors can bring about the agglomeration of firms and households. Agglomeration models show that vertical linkages or interactions between product differentiation and consumer preference for variety would be sufficient causes of agglomeration, even for information-intensive activities (Fujita and Thisse 2000). The connections between producer services and commodity production would be sufficient to explain that agglomeration of the former follows agglomeration of the latter. Other specific factors could be dominant, such as the location preferences of individuals working in information-intensive activities. Firms have to give attention to these preferences if they want to attract this highly-skilled labour. This problem arises in the location of High Tech activities. These activities employ professional and highly educated workers who prefer large cities and places with plentiful amenities. A preference for large cities relates to the education, cultural and leisure environment and to the security provided by a better employment match. The preference for amenities relates to climate, natural environment and leisure. These preferences have been introduced successfully as determinants of High Tech industry location (Malecki and Bradbury 1992; Sivitanidou and Sivitanides 1995).

Returning to the bases of the theoretical conjectures, we might question the nature of the causality between proximity and the effective realisation of intense information exchanges. More specifically, we may ask whether physical proximity is a necessary and sufficient condition of tacit information diffusion and therefore of innovation.

First, we might cast doubt on the necessity of physical proximity for tacit information exchanges in view of the fact that face to face contacts are made possible by business trips. However business trips are very expensive and time consuming, and they must generally be prepared in advance. As a consequence, business trips will probably be used only occasionally to meet specific information needs. They cannot be a regular means of tacit information exchanges. Therefore, the contacts they allow certainly do not offer the advantages obtained from proximity of locations as emphasised above. The fact is that we do not know exactly what proportion of tacit information is exchanged in this way. It follows that the above-mentioned necessary character of proximity remains uncertain, insofar as business trips are becoming easier and faster to make.

Besides, agglomeration of a large number of activities such as research and related industries allows the diffusion of a huge quantity of diversified information. But innovation can be a question of information quality rather than quantity. In other words, innovation can emerge because of a strategic piece of information, independently of the volume of research conducted in the vicinity (Carrincazeaux 1999). Such a phenomenon cannot be grasped by the previous type of study. This is another reason for questioning the absolute necessity of proximity for innovation.

Second, and conversely, it may appear that physical proximity is not always sufficient to generate substantial flows of tacit information. The comparison between Route 128 and Silicon Valley illustrates this claim. In both areas, we observe a concentration of industries, university and corporate research, related firms, and business services. In Silicon Valley, interactions between workers, and informal conversations are an important source of up-to-date information. On the contrary, secrecy is the rule in the Route 128. The regional economy remains a collection of autonomous activities without social or trade links (Saxenian 1994). Saxenian’s study shows that culture influences the economic structure and consequently the existence of spillovers. The sine qua non for the existence of spillovers is the intention to cooperate and the will of the agents to interact.

Moreover, suppose that proximity does lead to a lot of information interactions in a cluster of activities. The development of these interactions does not invariably lead to the expected reinforcement of agglomeration, because other factors can outweigh their effects. Dispersion factors may be powerful enough to decentralise information-intensive activities in more or less remote areas. These dispersion factors can take the classic form of traffic congestion or increased land prices (Fujita and Thisse 2000) which go some way to explaining the recent tendency toward decentralisation of high level services to the suburbs. Even certain forms of “intellectual congestion” can be generated by information interactions and innovation accumulation. A number of stylised facts suggest that after a time an innovative cluster can be faced with a congestion effect leading to dispersion. Audretsch (1998) cites the example of the agglomeration of computer industries in the Northeast Corridor in the 1980s. An intellectual lock-in in the area made it difficult for IBM or DEC to change from mainframe computers to mini-computers. “Perhaps it was this type of intellectual congestion that led to the emergence of the personal computer in California, about as far away from the geographic agglomeration of the mainframe computer as is feasible” (Audretsch 1998: 15-16). It is interesting to note that IBM personal computers have been developed in Boca Raton in Florida far away from the Northeast Corridor. The spillover congestion may lead to the emergence of new agglomerations in much the same way as other congestion phenomena in economic geography.

It follows that proximity is not a sufficient condition for a high degree of interaction and of innovation.

Conclusion: The Scope of the Results

We have obtained a series of confirmations of our theoretical conjectures on the basis on more or less indirect tests. Most of the studies we have mentioned show a close link between the need for more or less tacit information exchanges and the effective proximity of actors and/or between this proximity and the production of innovation. The scope of the results has to be appreciated from both methodological and theoretical points of view.
Methodological Scope

We mentioned observations which call into question the intensity or even the existence of the links between information interactions, proximity and innovation. Moreover, a number of difficulties remain in evaluating variables. These are the major weaknesses of empirical studies in our subject. Are they good reasons for invalidating the theoretical foundations of our subject? We do not think so, for a series of reasons:

- An empirical study, whether involving statistics or econometrics, can hardly prove anything. It is a methodological challenge to validate or invalidate causal links and we must settle for indirect and imperfect corroboration. Moreover, basic economic methodology says that you cannot invalidate a theoretical principle simply because you have found counter-examples. In other terms, Popper's falsificationism must be very carefully used. In order to invalidate a theoretical conjecture, you must be sure at least that the same conditions prevail in theory and in your observations. Theoretical principles concerning information exchanges have been stated other things being equal. Now the counter-examples we proposed have introduced variations of conditions other than information externalities. Under these circumstances, the theoretical links are not really invalidated.

- The difficulty in evaluating variables leads to the use of indirect approaches to externalities by imperfect proxies. It is certainly possible to improve the capture of knowledge and more generally of information exchanges, and therefore to apprehend unresolved questions mentioned in last section, but we are condemned to indirect capture as long as we are faced with genuinely tacit information.

Finally, we now have a number of good reasons to believe that information exchanges really have spatial effects and could promote, maintain or reinforce agglomeration in cities, notably in the innovative activities through knowledge spillovers. Despite the weaknesses of empirical studies on knowledge flows, we can consider that, contrary to Krugman's initial claim, the theorist cannot assume "anything about them that she likes".

Theoretical Scope

Despite a number of methodological limits, the existence of local information spillovers seems to be corroborated, and we have good reasons to think that the diversity and the tacitness of information are at the source of this local nature. This has several theoretical consequences and we shall mention two of them.

The first is closely linked to the introductory quotations. If local information spillovers still remain important, an economy dominated by services and information will remain concentrated and the end of cities is not for tomorrow. This non-market agglomeration force will reinforce market agglomeration forces emphasized by economic geography. This will provide a serious empirical foundation to urban agglomeration models like the Fujita-Ogawa-Imai models (Ogawa and Fujita 1980, 1989; Fujita and Ogawa 1982; Imai 1982; Ota and Fujita 1993; Fujita 1994). However, this foundation has to be built upon by investigations in fields other than innovation. A number of empirical works deal with the agglomeration of financial activities (Sassen 1991; Ansidei 2001; Choppin-Ansidei and Guillain 2000), and more generally with the location of high-order producer services (see reviews in Boiteux-Orain 2000; Boiteux-Orain and Huriot 2000). It remains to be shown in more detail how far the agglomeration of these information-using activities is explained by local information spillovers.

The second consequence refers to the introduction of knowledge or information spillovers in economic geography. The so-called "synthesis" between economic geography and endogenous growth theory (among the most advanced aspects: Ottaviano 1998; Martin and Ottaviano 1999; Baldwin 1999; Baldwin and Forssl 2000; for a review: Baumont and Huriot 1999) uses the assumptions of local and global spillovers alternatively. The two assumptions naturally lead to different theoretical conclusions for activity agglomeration. In any event, these models suggest that growth can be in itself a factor of agglomeration, through market forces, and thus can lead to regional divergence rather than convergence. In presence of global spillovers, only the pure effect of growth on agglomeration is revealed. If spillovers are local, this spatial externality reinforces the preceding agglomeration effect.

Finally, corroboration of the local character of information spillovers not only affects our understanding of the geography of innovation, and of the spatial organisation of information users: its impact extends to a large proportion of the more advanced theories of agglomeration and of regional equilibrium and growth.

References


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