HOW INFORMATION SHAPES CITIES: THEORY AND FACTS[1]

Rachel Guillain and Jean-Marie Huriot
LATEC, Université de Bourgogne (France)
guillain@u-bourgogne.fr
huriot@u-bourgogne.fr

---

1. Introduction

« 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. »

This pessimistic judgment is formulated by Krugman (1991), who rejects the assumption that technological spillovers are a primary reason for industrial location. He considers that « true technological spillovers play an important role in the localization of some industries », but holds that « Whatever drives industries to concentrate in one place, it is not solely a matter of technological spillovers ».

It is true that a great many of industries are highly concentrated and that many other reasons for their concentration can be put forward, most of them being related to some form of increasing returns. We agree that agglomeration forces such as labor pooling and vertical linkages are more easily observed and measured than any form of technological externality between firms.

But none of these reasons is sufficient to disregard the role of the most important technological externalities, namely information interactions, that take the form of knowledge spillovers in particular. We cannot follow Krugman's verdict because we do not believe that economics must necessarily follow the line of least empirical resistance[2] On the contrary, we have good reasons to stress the role played by information externalities in structuring space and cities: first, it is widely accepted that information intensive activities are important determinants of productivity and growth, and that they are increasingly prominent in cities; second, theoretical reasoning, especially on the basis of economic geography, is able to provide consistent and realistic explanations for the processes of information based agglomeration; and

---

[1] This paper have been prepared for the Thirty-eighth Annual Meeting of the Western Regional Science Association, Ojai, California, February 21-24, 1999.

[2] To paraphrase Krugman's claim: « Economics tends, understandably, to follow the line of least mathematical resistance » (1991, p.6)

finally, a wealth of empirical evidence can be gathered confirming the possible role of technological spillovers in shaping cities, mainly through the agglomeration of some clearly identified information using activities including producer services and especially R&D.

The primary aim of this paper is to show that information matters, in focusing on the existing empirical evidence that corroborates more or less directly the theoretical conjectures concerning the role of flows of information or knowledge in shaping economic space.

First of all, the terms used must be properly understood. The term *spillover* is simply taken as synonymous with *spatial externality*, that is nonprice spatial interaction as defined and used by Fujita (1990). We do not make any precise distinction between knowledge and information, such as that made by Polanyi (1966) for whom, roughly, information is easily transportable while knowledge is considered to be tacit. What seems the most important for shaping space is the degree of transportability of knowledge or information, and this is determined mainly by the more or less tacit character of the ideas exchanged. Therefore we will stress the difference between tacit and codified forms and we will essentially distinguish *tacit and codified information*[3].

From a theoretical point of view, economic geography, essentially in its urban developments inspired by Fujita, deals with information externalities. Models of city formation inspired by Fujita and Ogawa (1982) use information interactions between firms as an agglomeration force. But in doing so they consider information interactions precisely as abstract general spatial externalities, and they fail to integrate the specific nature of information flows (Guillain and Huriot, 1998). One significant exception is the model by Ota and Fujita (1993). This model considers information interactions between the front and back offices of individual firms and between thefront offices of different firms. We could consider these two forms of interaction as codified and tacit information exchanges respectively (Guillain and Huriot, 1998). This model reflects the agglomeration of headquarters in the center and the periurbanization of production observed in cities like New York. But it seems to correspond more to large firms split into several departments that can be spatially separated, and to the spatial structure of big cities. It still omits a large proportion of the specific and complex character of information exchanges.

Information externalities appear at the core of endogenous growth theories, especially in Romer's model (1990), in the form of Romer-type spillovers: knowledge produced by the R&D sector increases the productivity of this sector. Some recent works combine this principle with the forces that determine agglomeration in a Krugman-type center-periphery model (Baumont and Huriot, 1997). Two types of results can be mentioned. First, with local knowledge spillovers, i.e. with spillovers with a limited spatial range, the concentration process is reinforced: any initial inequality leads to regular growth of a regional system where all R&D and all production is concentrated in a single region (Englman and Walz, 1995, Walz, 1996).

[3] Moreover, those who begin their analyses by separating information and knowledge often mix up the terms in their subsequent developments.

Second, when we assume vertical linkages between R&D and intermediate goods, the location of economic activities matters for growth even if knowledge spillovers are global, i.e. even if the two regions receive spillovers regardless of their origin (Ottaviano, 1998). Here, information externalities are considered solely through their intrasectoral influence on productivity of R&D and their spatial dimension is very limited. Once again we require a more accurate integration of specific information interactions in a spatial model.

In most of these models, information externalities remain a black box and their existence is simply assumed. In order to open this box, even partially, we have to explore another body of literature. Valuable clues can be obtained from a number of studies and from knowledge theory, if we simply retain those features that play a significant role in shaping space and that can be integrated into an economic geography rationale. It is necessary to grasp the very nature of information, its modes of exchange and its diffusion processes.

In theoretical models, even if the level of information externalities can be endogenized and can result from the location of information-using activities, the existence of information externalities is simply assumed. But we know that other agglomeration and dispersion forces come into play and that we could explain agglomeration without any reference to information. Thus it is a real challenge for empirical studies to deal with the existence of information externalities.

More generally, empirical testing of information-based models of urban structure and growth raises a number of methodological problems. Two main difficulties arise. First, tacit information exchanges do not leave any mark. So it seems impossible to know how much information is exchanged and where and how the exchanges take place. Second, codified information exchanges seem easier to grasp. New technologies are used to exchange codified information, so that points of emission and reception can be easily identified. But the amount of information transmitted is unknown: for instance, when you send a fax, there is one information flow but more than one piece of information can be diffused. Furthermore, if we take into account only that codified information exchanged by new technologies, we forget the codified information that is exchanged by face to face contacts.

Nevertheless, many empirical studies have been conducted into the local character of the diffusion of tacit information. A large number of them confirm the importance of the exchanges of tacit information in the agglomeration of activities, arguing that activities using tacit information intensively are highly concentrated. Such an observation can only be considered as an indirect and imperfect test of the role of information, first because other things are not equal, so that other factors may affect the concentration of these activities, second because these studies do not grasp the underlying process which can explain why and how tacit information interactions generate agglomeration. But this is only a first approach. Over the last ten years, much progress has been made, and initial difficulties are progressively being overcome. Indirect tests afford a better grasp of both the consequences and the media of information externalities.

This is the second objective of this paper, to *show that theoretical analyses have some empirical basis. It is not possible to assume anything that you like, as Krugman claimed. Theoretical progress and empirical advances converge and even interact.*

These advances are essentially focused on one category of information externalities: the information spillovers generated and received by R&D. The reason is that the leading role of R&D has long been recognized, especially in analyses of productivity and growth. Thus external effects related to R&D have been the subject matter of theoretical and empirical studies from an early date and independently of any spatial concern. Moreover, interest in R&D probably favored the production of data. As a matter of fact, data on R&D activites, patents and innovations, is readily available but hard to come by for other sources of information externalities.

Section 2 deals with the theoretical point of view resulting from the introduction of the specific characteristics of information externalities in the framework of economic geography. Section 3 is a critical review of empirical analyses of the spatial dimension of knowledge spillovers, with a particular interest in showing how these analyses corroborate the theoretical reasoning of Section 2.

2. Information and agglomeration: theoretical principles

The following theoretical principles are developed in order to explain the contribution of information exchanges to the evolution of contemporary cities and to solve the apparent contradiction between two stylised facts. The first is the rapid progress in communication technologies that enables the transfer of enormous quantities of information across any distance and at very low cost; the second is the ongoing and even in some cases the increasing need for proximity in information interactions. A more complete analysis of these theoretical principles can be found in Guillain and Huriot (1998).

In the following subsections, we first introduce the main forces at work in the information-based agglomeration processes. Four principles underlie the analysis: the distinction between tacit and codified information, the complementarity between these two forms of information, the localized character of tacit information, and the working of scale economies in the nodes of communication networks. Then we propose a synthetic analysis of the role of proximity in information exchanges.

2.1. Tacit or codified information

Numerous theoretical models dealing with information externalities, e.g. in economic geography, assume homogenous information exchanges. This is a drastic simplification, making it impossible to solve the above contradiction. The first step towards a solution consists in separating tacit and codified information, because they have different spatial effects. In order to present this distinction, it may be helpful to look at the characteristics of information exchanges.

Information exchanges need a means of expression determining the form of the message, and a medium of exchange, i.e. a more or less technical mode of interaction between the exchangers. The means of expression and medium of exchange are both chosen and combined with the double objective of conserving the correct and complete meaning of the information, i.e. the quality of information, and of achieving the maximum efficiency in the exchanges, efficiency being defined in terms of the quantity of information transferred and the distance of diffusion per dollar or per unit of time.

The choice of a medium of exchange is closely tied up with the characteristics of the information and to the need for preserving its meaning. The difficulty in conserving meaning depends on the cultural and intellectual proximity between the sender and the receiver. The sender and the receiver may have different intentions, expectations, and more generally different habits of thinking that impede deep understanding between them. The result of the exchange is therefore uncertain. Information codification can reduce this uncertainty. This operation consists in expressing information in a standardized conventional form everyone can use and understand. The actual codification conventions have to be themselves simple and standardized so that a large number of individuals can understand codified information and so that *codified information* can be exchanged using *communication technologies*. It can then be diffused regardless of distance and in a reliable fashion and made available wherever suitable receiving equipment exists.

But this procedure can only be carried out with information that is systematic, repetitive and that can easily be separated from its context. Not all information has these properties. When the meaning of information is closely linked to the individuals who hold that information, it cannot be immediately and completely understood by other individuals without dialogue between the parties and gradual clarification. It is highly personalized, contextual, and can only be properly transmitted between people who share the same experiences, the same habits, and the same specific language. For this kind of information, codification entails too great a loss of meaning to be exploitable by economic agents. This personalized and contextual information, which is simply called *tacit information*, can keep its complete meaning only if it is exchanged by direct personnal contacts, i.e. by *face to face contacts.* It cannot be transmitted at a distance by communication technologies (Foray and Lundvall, 1996).

Tacit information is often of strategic value. An economic agent may have a great deal of codified information but make decisions that are not to his or her advantage because he or she lacks some piece of tacit information.

The preceding distinction has a limited but useful range.

Firstly, the distinction between codified and tacit information is partly conventional and the frontier between codified and tacit may look fuzzy. It would be more realistic to use a continuous scale representing a variable « degree of tacitness ».

Secondly, the complementarity reffered to above between a particular kind of information and a particular mean of exchange is not absolute. Codified information can be exchanged by face to face contacts too, but at the expense of efficiency, and tacit information can be exchanged by communication technologies, but with partial loos of meaning.

Finally, knowledge theory provides a more complex view of the characteristics of what we call information. Is it a major weakness to reduce this complex analysis to the tacit dimension alone?

We think not and would point out that what is of interest here is the transportability of information, because this property is the most significant in terms of spatial effects. In this sense, it seems that the distinction between tacit and codified information is a convenient and useful first step toward a better understanding of the spatial role of information exchanges.

We can conclude that:

Principle 1
Tacit information exchanges require face to face contacts and are therefore a potential factor of agglomeration while codified information exchanges are apparently not subjected to location constraints.

But our initial problem remains unresolved. Nothing explains the compatibility between the continued need for proximity in information exchanges on the one hand, and the increase of codification possibilities and the development of increasingly efficient communication technologies on the other hand. New explaining elements have to be introduced. Why does the role of tacit information exchanges not vanish? Is the ongoing need for tacit information the sole cause of the need for proximity?

2.2. Tacit and codified information

Most information interactions are not « tacit or codified » but « tacit and codified ».

A large part of the literature on the effects of the advances of communication technologies implicitly considers that codified information is a substitute for tacit information. From this point of view, technological progress in codification means that we can codify more and more of what was previously considered to be tacit information, so that it can be diffused by communication technologies. The development of the internet and of e-mail seems to be heading in this direction. This would result in a future decline of cities as places of information exchange.

But we have grounds enough to believe this effect is both intrinsically limited and dominated by complementarity effects between face to face and long distance information exchanges (e.g. Gaspar and Glaeser, 1996, Cowen and Foray, 1997).

The substitution effect is intrinsically limited, because we believe -but cannot prove- that direct human interactions will never be entirely replaced by electronic interactions. The strongly personalized and contextual character of tacit information will always prevent its codification. It may prove possible to codify an inceasing amount of information, but even a very small piece of tacit information can have a strategic role that makes face to face contacts necessary.

As for the complementarity effects, the question is more complex. And the fact is that both types of exchange have increased in the last twenty years. This complementarity can take several forms: organizational, technical, opportunity, induced.

Organizational complementarity

We say organizational to point out that the two kinds of information are needed for the realization of a project. Face to face contacts are often initiated by phone or e-mail. Conversely, a first direct contact, when used for putting into shape the conditions of future routine and standardized interactions, can initiate further utilization of telecommunications. A number of observations illustrate this link between face to face contacts and telecommunications (Gaspar and Glaeser, 1996). First, the telephone is most frequently used by individuals who are physically close to each other, especially within cities. Second, in parallel with the development of communication technologies, the number of business trips is increasing. Communications technologies allow people to organize face to face contacts and to keep in touch with home or the office while away. In the same vein, it can be observed that scientific conferences are increasingly organized by e-mail and over the internet. The utilization of more efficient means of telecommunication has not reduced the need for direct scientific interaction, and may even have boosted the number of meetings organized.

Technical complementarity

A given piece of information can be exchanged for the most part in a codified form, but complementary face to face exchange is necessary to make the most of this piece of information, for example at least to know how to decode that information (Cowen and Foray, 1997). Codified information exchanges are based on more and more complex and rapidly evolving conventions and rules that take the form of tacit information. Detailed information about the use of information technology equipment such as computers is itself largely tacit and is transmitted by face to face contacts.

Opportunity complementarity

Face to face contact is necessary for exchanging tacit information. But it allows the exchange of either kind of information. During a face to face discussion, people have the opportunity to exchange information that could otherwise have been exchanged by communication technologies, and they make wide use of such opportunities. This tacit and codified infomation may be linked to a joint project or independant of each others. The former case relates to the two previous types of complementarity. In the latter case, information exchange occurs purely by chance. Interactive face to face discussion is an important source of unexpected information exchanges, which are codified as tacit. You can meet somebody by chance or in order to exchange tacit information, and you have a discussion that reveales you still do not know last month's export data: he or she will immediately give you this unexpected, new and useful codifiable information.

Induced complementarity

Previous forms of complementarity are defined at an instant in time. A final form arises during the dynamic process of development of communication technologies, as a consequence of organizational and technical complementarity. As it is the case for most technical advances, it may be thought that the much greater ease of enganging in information interactions at a distance generates or reveals new needs for interaction. Because of these complementarities, new needs will appear for codified *and* for tacit information. For example, the rapid changes in technical efficiency go along with a rapid growth and renewal of information related to software. This complex and volatile information is and will remain tacit. We believe too that the better access to codified scientific information -e.g. who makes what and what are the more recent advances in each specialized field- induces an increased need for face to face contacts in order to penetrate the inevitable tacit dimension of scientific research.

Principle 2

If the complementarity relations really dominate, the advances in communication technologies are likely to increase both long distance exchanges and face to face contacts.

Therefore, complementarity between tacit and codified information provides a basis for the continued growth of the need for tacit information exchanges and of the continued need for proximity in information exchanges despite the advances in communication technologies. This can explain agglomeration in cities and city centers being maintained and even reinforced.

We have no formal proof of these intuitions, apart from their logical relevance and the fact that the last twenty years have seen a huge increase in all manner of information exchanges.

1.3. Information and the reinforcement of city systems

Two further points must be emphasized in that they constitute factors reinforcing agglomeration of information intensive activities at the nodes of city systems: the localized character of tacit information, and the existence of scale economies in the communication networks nodes. After a city system has been formed, its nodes are privileged locations for information intensive activities because they facilitate access both to local tacit information through proximity, and to global information -tacit or codified- through communication equipment and transport terminals.

City systems at a glance

So far we have studied the effects of information exchanges other things being equal. We have emphasized just those agglomeration forces resulting from information exchanges despite advances in communication technologies. If just these forces were at work, all information intensive activities in the world were concentrated in just one single city, as Gehrig (1999) argues in the case of financial activities.

Agglomeration theory (Fujita and Thisse, 1999) shows a wide variety of agglomeration forces and dispersion forces that can explain the formation of cities and city systems. In recent years, modelling of the endogenous formation of city systems has been developed mainly by Abdel-Rahman (e.g. 1994, 1996), and by Fujita, Krugman and Mori (Fujita and Krugman, 1995, 1999; Fujita and Mori, 1994; Fujita, Krugman and Mori, 1994). In these models, agglomeration forces are classically related to product differentiation, scale and scope economies, while dispersion forces are related to the costs of city growth, i.e. the increased costs of commuting or the increased costs of transporting agricultural produce to the city and manufactured goods to the periphery, as the agricultural hinterland spreads. This means city systems can arise from different processes, independently of information exchanges.

Localized sources of tacit information

In a city system, sources of information inputs consumed by information intensive activities are concentrated in distinct places. Now we know that tacit information can only been exchanged by face to face contacts. Therefore this generates a cumulative process of agglomeration of information intensive activities in the major nodes of a city system. It is then a cause of reinforcement of the polarization of a city-system.

These principles can be illustrated by the case of the location of financial centers which is well described by Sassen (1991) and modeled by Gehrig, Stahl and Vives (1994) and Gehrig (1999). The main financial centers are located in a handful major cities and the core of this financial system is formed by three metropolese: London, New York and Tokyo. Nevertheless, this tendancy is partly shaded by the development of secondary centers and the decentralization of certain financial activities, such as foreign exchange dealing. How has this global system been formed?

Finance is among the most information intensive activities and the sector is one of the prime users of communication technologies. But financial traders also use complex information which cannot be standardized and which is only available locally, and exchangeable locally through face to face contacts. Information relative to production, tastes, and economic policies is local. If it is a necessary component of strategic decisions, it creates a domestic bias which generates dispersion. Gehrig, Stahl and Vives (1994) have shown that sufficient information asymmetry between markets is a condition of a dispersed equilibrium of financial centers. If this asymmetry vanishes, a single concentrated market appears.

This analysis could be generalized to any type of information-dependent specialized service when the tacit information it consumes comes from already localized activities. Therefore, *cities provide the best access to local tacit information*.

Localized equipment and terminals

Even if codified information can be exchanged instantly at a very low variable cost, the need for agglomeration of activities using mostly codified information is not necessarily vanishing, because actual entry into the network can be costly and is often based on comparatively high investments.

Communication technologies are generally based on complex physical infrastructures, including real estate, which imply large investments in capital and innovation. This gives existing telecommunication centers a comparative advantage. Communication facilities have been concentrated in a small number of centers. If entry costs are sufficiently high, i.e. if economies of scale are sufficiently high, further entries will concentrate in these centers thereby increasing the polarization of the city system (Moss, 1987; Castells, 1989, 1996; Sassen, 1991).

Therefore, *cities provide the best access to global codified information*.

It should be remembered that tacit information exchanges require face to face interactions, but not necessarily location in the same place. Individuals located in remote cities can exchange tacit information by means of business trips. But this can only occur occasionally because of the high time and money costs of transporting people. Nevertheless, because information is only one factor determining location, firms interacting through tacit information exchanges may be remote from each other. Location in big cities then is then preferred because it provides the best access to time-saving means of travel. This is another form of scale economies. Thanks to their transport terminals, *cities provide the best access to global tacit information.*

We can finally state that:

Principles 3
In a city system,
cities provide the best access to local tacit information;
cities, as nodes generating scale economies, provide the best access to global codified information and to global tacit information.

1.4. Synthesis: information, proximity and agglomeration

What are the advantages of proximity for conducting information exchanges? How does the need for proximity in information exchanges imply actual agglomeration? The above principles can be used to answer these questions in the following points.

What we get from proximity
Geographic proximity is particularly valuable when the information exchanged is tacit. In this case, proximity facilitates and enhances face to face encounters for several reasons.

First, the probability of face to face encounters occurring is greater where there is a greater density of individuals. Therefore proximity increases the chance of obtaining an unexpected but important piece of information, or of meeting the person who holds the desired piece of information.

Next, proximity means that the time and money spent arranging contacts or travelling can be saved, and therefore more interactions are possible. Proximity is also a guarantee of efficiency when the decision that depends on the information sought must be taken quickly.

Finally, geographical proximity generates multiple contacts and so brings about other forms of proximity. Because of repeated contacts, formal and informal rules emerge between agents sharing the same world views, the same culture, and common objectives. These rules generate an atmosphere of trust which is beneficial to the diffusion of information, and easier selection and appropriation of the information received.

Through these three effects, proximity increases the quantity and the quality of tacit information exchanges and achieves the two initial objectives of retaining the meaning of information and of conducting efficient exchanges.

What we get from cities

We are now able to explain why the city is often viewed as a place that favors tacit information exchanges and more generally all information exchanges.

The city is essentially the place of diversity and agglomeration (Baumont, Beguin and Huriot, 1998). It concentrates in particular specifically urban activities such as producer services, research centers, universities, libraries, administrative and political authorities, that are information intensive. The heterogeneity and complementarity between these activities is the source of information exchanges. The city is by definition the best place for proximity interactions. The city is therefore a place where diversified tacit information can be readily exchanged by face to face contacts.

But face to face contacts also make possible to exchange codified information. Because of the complementarity relations, agents really perform these exchanges.

Moreover, the city is also integrated in a global spatial system and is the most efficient place from where we can obtain codified information from everywhere in the world.

Finally, being located in a city reduces the cost of both face to face and long distance information exchanges alike.

The potential for agglomeration

The following imaginary scenario resumes most of the preceding arguments.

Firstly, observe the concentration of certain information-dependent specific activities such as producer services or research centers. The advances in telecommunication technologies allow these activities to be located away from their respective customers and from commodity production. But these specialized services continue to use frequent face to face contacts with each other because the information needed is tacit. Therefore these activities agglomerate in cities. But they need long distance contacts too, because they are remote from other economic activities and because localized factors, such as local information, sustain a system of cities. Accordingly the new telecommunication infrastructures are built where existing firms are located, creating a series of information centers which in turn attract new user firms, thereby stimulating the expansion of the telecommunication infrastructure, and so on.

But this is an abstract and ideal process based entirely on information exchanges. It must be re-situated in a wider approach of agglomeration where the process appears less simple.

The conditions of agglomeration revisited

This scenario, based on the principles developed in this section, provides the grounds for us to state that information exchanges can result in agglomeration *other things being equal*. But these principles are neither necessary nor sufficient for the agglomeration of activities, even of information-intensive activities.

These principles are not necessary: agglomeration of producer services in cities can occur and develop without any contribution from information exchanges. A sufficiently large number of factors that can result in agglomeration of firms and households are known to be able to exclude information. A large part of agglomeration models in economic geography simply do not know information interactions. Vertical linkages or interactions between product differentiation in production and preference for variety in consumption would be sufficient causes of agglomeration, even for information-intensive activities. The connections between producer services and production would be sufficient to explain that agglomeration of the former follows agglomeration of the latter.

These principles are not sufficient: they do not invariably lead to the expected reinforcement of agglomeration in cities, because other factors can outweigh their effects. Dispersion factors may be powerful enough to decentralize information intensive activities in remote areas. We know that tacit information can be exchanged by face to face contacts made possible by business trips. But business trips are very expensive in terms of money and above all in terms of time, and they must be planned. Therefore, the contacts they allow do not offer the advantages obtained from proximity of locations as emphasized above. 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 exchange. Nevertheless, it is possible to imagine such a fall in the cost of business trips that they could more frequently replace physical proximity of activities in the realization of face to face contacts. The fact is that we do not know exactly what part of tacit information is exchanged in this way.

Other specific factors could be dominant, such as the preferences for location of workers in information intensive activities. If they correspond to the preferences of their firms, we are wright. Otherwise, the result might be uncertain.

These remarks lead us to the difficulty of empirical validation of our theoretical principles.

3. Attempts at empirical validation

It should be recalled that empirical tests focus on one particular kind of information externality, namely knowledge spillovers, especially related to R&D activities. These activities consume and diffuse what is mostly tacit information intensively. They constitute the best field of application of the theoretical principles set out in the previous section. Likewise, the problems encountered in empirical studies of knowledge spillovers are representative of more general problems with information externalities.

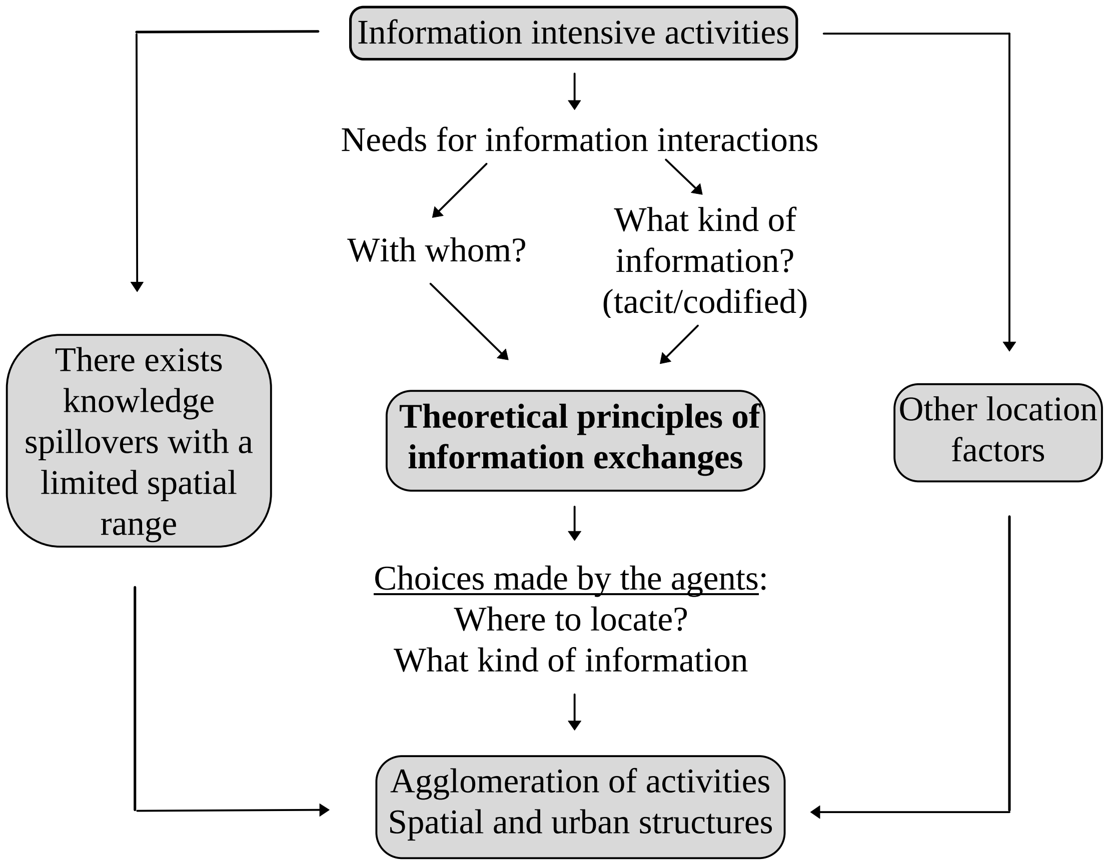
This section will be developed along the following lines. First we present some general methodological problems. Then we show how the first signs of the effects externalities were established, namely the agglomeration of R&D activities. The main objective is then to show ways of more closely investigating the information-based process that leads to agglomeration.

3.1. Some methodological pitfalls

The theoretical principles can be rearranged and combined in a supposed logical sequence leading from identification of information needs to the final effects in terms of spatial and urban structures (see the central sequence of figure 1).

This sequence is oversimplified. In particular it does not make explicit the feedback effects from spatial and urban structures on the information needs. But it can be used as a methodological benchmark for evaluating particular tests. Ideally, the whole logical sequence might be confirmed by observation. In fact, each empirical study uses observations located at some specific points in the chain. The question is to see how the empirical relations between these points can contribute to the validation of the theoretical principles. It is also to see if these points in the sequence are correctly grasped, and whether the links established are direct or indirect.

Figure 1: logical sequences



A number of empirical studies are based on the following simplified reasoning: externalities do exist in the form of knowledge spillovers and they have a limited spatial range that results in the spatial concentration of information using activities such as R&D (see the left-hand sequence of figure 1). Thus observation of the concentration of R&D is considered as a test confirming the existence of knowledge spillovers. It is a rough-and-ready method because (1) it is a logical short circuit that avoids entering the core of the process of information exchanges and (2) we know that agglomeration of information intensive activities can occur in the absence of any spillover as a consequence of other agglomeration factors (see the right hand side of figure 1). This method has been improved in different ways by empirical investigation of the other links of the central logical sequence we have stated.

But in doing this we come up against Krugman's problem of evaluating spillovers. For this reason, empirical tests deal with indirect indicators of spillovers. This is unavoidable and useful, but must be done with care.

1) It is unavoidable for reasons amply developed in the introduction to this paper. Information exchanges are really not directly observable.

2) It is useful because we cannot content ourselves with the rough method evoked above and we cannot test an implicit theory where spatial spillovers are the necessary and sufficient condition of agglomeration. These indirect indicators can give useful insight into the effects of information exchanges and a better foundation to the theoretical principles.
3) But these indirect methods must be employed very carefully and we must constantly keep in mind their limits above all when we interpret the results in terms of validation of theoretical links.

Finally, we can expect that these empirical pitfalls, as well as the empirical results, will point out theoretical weaknesses and will be incentives to improve theoretical approaches.

3.2. Agglomeration of R&D as a first step in empirical investigation

A first series of crude observations relates to the high regional concentration of information-intensive activities: producer services, R&D, finance, etc... These services are clearly urban activities, even if they are unevenly distributed among cities.

Regional concentration

At the regional level, high-level producer services and R&D are very unevenly distributed.

In France, R&D is highly concentrated in Île-de-France, one of the 22 regions, where we find 48% of R&D employment, especially in high-technology sectors with complex knowledge. The first six regions group together 75% of R&D employment, and the first six departments (of 95 departments) account for 60% of R&D employment and for 30% only of production employment (Carrincazeaux and Lung, 1997, Carrincazeaux, 1999).

In Great Britain, R&D is concentrated in the center and above all in South East with 62% of R&D employment in 1976. At a smaller spatial scale, a decentralization of R&D is however observed in less-urbanized counties, where more than a half of R&D jobs are located (Howells, 1984).

In the United States, the examples of high concentration of innovative activities in Silicon Valley and along Route 128 are well known. More generally, innovation output is highly concentrated in California, New Jersey and Massachusetts, where the rate of innovation per 100,000 jobs is twice the mean US rate (Feldman, 1994, Feldman and Florida, 1994). On the contrary, no innovation has been recorded in certain Midwestern states. In 1982, 11 states accounted for 81% of US innovations (Feldman and Florida, 1994). The states of the Manufacturing Belt, which show a strong industrial concentration, produce little innovation (Audretsch and Feldman, 1996). Moreover, the most concentrated manufacturing sectors are not only High Tech sectors (Krugman, 1991). Comparing the coefficients of geographical concentration of manufacturing and innovative activities in the US, Audretsch and Feldman (1996) show that the most concentrated manufacturing sectors differ from the manufacturing sectors with the most concentrated innovation activities. We have thus a series of indicators suggesting that *the concentration of innovative activities is not merely the reflection of the concentration of manufacturing activities. It is likely therefore that information externalities contribute to that concentration.*

But knowing that innovation activity in a given sector is naturally linked with the productive activity of that sector, the spatial concentration of production must be controlled if we want to show how information influences the concentration of innovation (Audretsch and Feldman, 1996).

Urban concentration

Throughout the industrialized world, producer services, R&D and finance are highly concentrated in cities. In France, in 1990, the proportion of employment concentrated in cities with more than 100,000 inhabitants was around 76% for the High Producer Servives sector, 83% for Research, 72% for Banks, Insurance, Finance (Léo and Philippe, 1998). The proportion of jobs in the producer services sector is positively correlated with the population of the city, meaning that this sector is relatively concentrated in the largest cities (Saint-Julien and Sabatier, 1996).

The same feature prevails in the United States, where 90% of producer services employment was located in metropolese in 1985 (Beyers, 1989), and in Canada (Coffey, 1996). In 1982, 45% of US innovations came from one of the four following Metropolitan Areas: New York, San Francisco, Boston and Los Angeles. But the size of the city may be an important determinant of the number of innovations. Evaluating the innovative activity supposes we have eliminated that size effect in calculating the number of innovations per inhabitant. According to this criterion, San Francisco is the most innovative US city, followed by Boston and New York (Feldman and Audretsch, 1998).

The intense concentration of financial activities in a small number of metropolese worldwide is another illustration of this general phenomenon (Sassen, 1991).

These evidence are reinforced or tempered if we distinguish the central city and its periphery. In the United States, the emergence of edge cities (Garreau, 1991, Stanback, 1991) first concerned manufacturing production, then consumer services and standardized producer services (back offices). At present high producer services, which are tacit information-intensive, are also decentralized in edge cities. Garreau has listed 200 edge cities in United States, notably around Los Angeles, but also Boston, Detroit, Atlanta, New York, Phoenix and Washington D.C.. In New York, there are more square feet of offices in the periphery than in the midtown Mahattan. This movement is much less obvious in Canada and in Europe. In France, high producer services continue to prefer central city locations (Léo and Philippe, 1998).

These features *reinforce our suspicion about the role of information externalities in agglomeration and lead us to consider the city as the best unit for investigating innovation* (Lucas, 1988).

Toward further steps

But we have to confirm this suspicion, and it remains to be see to what extent the concentration of innovative activities is the result of information exchanges. We cannot logically deduce the existence and action of knowledge spillovers directly from the observation of agglomeration. We have to investigate other stages of the complete logical sequence of figure 1. Therefore we must ask questions that lay at the core of the spillover phenomenon and see how they have been dealt and how the answers corroborate the theoretical principles.

Referring to figure 1, we consider innovative activities as a special case of information-intensive activities. To avoid the short-circuit of the left side of the figure, we have to deal with the following questions:

(1) With whom do innovative activities have information interactions, i.e. what are the information inputs to the production of innovation?

(2) What is the real spatial range of these interactions and on what factors does this range depend?

(3) What are the characteristics of these interactions? (What kind of information is exchanged? By what means?)

Finally, we shall ask to what extent empirical tests corroborate the role of spillovers as necessary and sufficient conditions of agglomeration. What hidden forces might soften the role of information interactions?

3.3. The input dimension. The technological infrastructure of innovations

Showing the effect of information exchanges on the spatial organization of innovative activities supposes first that we can identify the inputs to innovation production and their sources. This investigative stage is based on the following implicit reasoning: if we can establish the geographical proximity of innovation to its information input sources, then we can consider that the theoretical principles of spillover effects really work.

What are the inputs to innovation production? Primarily, research activities. Research is produced by universities and by R&D departments of corporations. These inputs depend in turn on other inputs, informational or otherwise, and influence each other. Different levels of analysis depend on how we estimate innovative output, and how far we go in investigating of the whole technological infrastructure that determines innovation production.

Research inputs

Silicon Valley and Boston's Route 128 are two of the most famous innovative centers in the world. It is well known that 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 introducing other innovative inputs, such as industry research.

One of the first studies in that line was conducted by Jaffe (1989). The main difficulty is in identifying the mechanism of research diffusion. If research spills over by journal or review publications, geographic localisation does not matter for innovative activity. But if the main mechanism is informal discussions, it is important to be located near the research sources for capturing the spillover benefits. Jaffe proposes an econometric model to identify the extent to which research spills over. The model is based on the *knowledge production function* first formalized by Griliches (1979). Firms try to acquire new knowledge as an essential input for innovative activity. The most important source of new knowledge is research and development, followed by the high degree of human capital, skilled labour and the presence of scientists and engineers in force. The function relates innovative output and knowledge inputs. Jaffe uses a modified Cobb-Douglas model with two inputs: research and development conducted by industry and research conducted by universities.

In Jaffe's study, the innovative input is measured by the number of patents. The unit of observation is the state because data are more readily available at this level. But this unit is too large to capture accurately the local spatial interaction between universities and firms. So another explanatory variable is introduced: the « geographic coincidence index », which is a measure of the degree of geographic proximity between universities and industrial research centers within the state. The idea is that, for a given total amount of university research and industrial R&D in a state, there should be more spillovers if university research and industrial R&D are located in the same metropolitan area. This leads to an additional term in the knowledge production function, where the geographic coincidence index is weighted by the amount of university research.

The model is extended to a system of simultaneous equations by introducing two additional equations in order to capture the potential interactions between university research and industry R&D. 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. The proxies of private and university research are respectively the expenditure by private corporate research and the expenditure by universities.

Jaffe's model is tested for 29 states, five technological areas, and over eight years. 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). On the basis of a classification into five technogical areas (drugs and medical technology; chemical technology; electronics, optics and nuclear technology; mechanical arts; others), there is evidence that the spillovers from university come through more clearly within the technological areas than accross them. This result suggests that the spillovers are specific to a technological area and that the diffusion of university research is irregular. Moreover, dispersed universities seem to generate fewer spillovers than the others. By estimating the two other equations of the model, it appears that university research and industry R&D are correlated, but it seems that private research depends on university research without reciprocal causality.

Acs, Audretsch and Feldman (1991) have extended Jaffe's results by introducing a different measure of innovative output. Indeed, patents are not a direct measure of the number of innovations. Some patents never lead to a commercial product and some innovations are not patented (Griliches, 1990). Patents are spatially more dispersed than product inovations, and their sectoral distributions differ. In particular, fewer innovations are patented in sectors where the technology is rapidly changing (Feldman and Florida, 1994). So Acs *et al.* use the Small Business Administration data which record innovations subsequent to their introduction into the market. Consequently, these data give more relevant proxies of innovative output. The results reinforce Jaffe's results. First, university research spillovers are more important for innovations in general than for patented innovations. Second, the impact of geographic coincidence is greater, suggesting that spillovers are more greatly facilitated by geographic proximity than Jaffe concluded.

The technological infrastructure

The principle of the knowledge production function is largely used in the empirical studies of spillovers and many extensions of Jaffe's econometric model have been proposed. A number of these aim to enlarge the inputs of innovation in introducing all local characteristics which are present in the innovative areas and may favor innovations. These characteristics, namely 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 already present in previous studies. Related firms provide potential users of innovations and a pool of technical knowledge acting as an innovative atmosphere. Business services play a major part in the innovative process by providing marketing information which reduces the risks in the innovative process. These four inputs enter the production function in the form of their average annual measures during the ten years (1972-1982) before the observation of the output, which introduces a time lag.

The unit of observation is always the state and the data source is Small Business Administration for output. The proxies of university research and industrial laboratories are average annual expenditures. Related industries are identified by the official American SIC classification, the code of which is used to identify the correponding relationship. Their contribution is measured in terms of value-added. There is insufficient data to provide a good measure of business services. The yardstick used is the annual average receipts of Commercial Testing Laboratories in constant dollars.

The assumed relationships are formulated as a simultaneous system allowing for interdependencies between the different components of the technological infrastructure.

Jaffe's results for university and private research are confirmed. The related industry effect is statistically 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.

Some 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 competence and knowledge inputs from different agents and different places. Second, the proximity between these sources of inputs has a clear positive influence on the capacity to innovate. This gives a firmer 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 plays a strategic part in the innovation process. But the geographical dimension is too crudely introduced in these analyses. The state level is not the more proper one.

3.4. More on the spatial dimension. From regions to cities

What can be done to improve this dimension? Jaffe's geographic coincidence index is a first step in that direction. But it does not introduce any distance, and it bypasses the true urban dimension of the phenomenon. How can we introduce these refinements into empirical studies? Certain authors believe that because we know that innovation is by nature an urban activity, we could deduce concentration in certain cities from the concentration in their regions, so that the regional scale would not be so bad. This reasoning cannot be accepted because it is another logical short circuit that neglects the eventual deconcentration of innovation and avoids the study of the true spatial range of spillovers.

The location of citations

Jaffe, Trajtenberg and Henderson (1993) focus on the spatial extent of knowledge spillovers through the citations in patents. When a patent is granted, a public document is available that contains information about the inventor, his or her employers, technological antecedents of the inventions, and citations which are an indirect way to detect knowledge flows. For a patent to be granted, new knowledge must be added to the previous one represented by the citations, that is to say citations trace the history of new knowledge. If patent X is cited in a new patent Y, then X is an original information prior to Y and on which Y relies. 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 to show the extent of spillovers 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 areas as the latter, then there are spatial limits to the diffusion of patents. But innovative activities in a given technological area tend to be located near one another, so that there is a pre-existing technological specialization of geographical areas. Because of this specialization, 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 conclusion can be drawn.

First, the results show that geography matters for spillovers. The citation effects differ according to the geographical scale, showing that distance affects the diffusion of information. Indeed, in each case, it appears that the metropolitan areas are the best level to show the location effect of citations.

Second, the geographical diffusion of these effects varies implicitly according to the nature of the information transmitted. For the 1980 cohort, there is clear evidence of the influence of localization on citations. For the 1975 cohort, the results show a similar but weaker tendency. 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 can have no idea of the patents that he or she used for his or her innovation. Second, all knowledge flows are not measured 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 accurate spatial dimension of spillovers, but is limited in the way in which the spillover is identified. On the other hand, this identification is improved if we use a knowledge production function, but this method includes a limited spatial dimension.

Around the city

While using Jaffe's reasoning with a knowledge production function, Anselin, Varga and Acs (1997) carry on a study at the level of metropolitan statistical areas (MSA). Some improvements are made to the model. The index of geographic coincidence disappears because of the use of a more appropriate spatial scale, smaller than the state. Two new independent variables, called « spatial lags » are introduced in the knowledge production function. They allow us to capture the effect on innovation in the MSA of university research and industry research in counties whithin a given radius from the geographic center of the MSA. Two ranges from the MSA center are considered: 50 miles and 75 miles. The aim is to get a more precise idea of the spatial extent of spillovers.

As in Jaffe's econometric model, two equations are added to determine the direction of cause and effect between private research and university research but at the state level. The innovative output is measured by data from the Small Business Administration to avoid the difficulties with the patent.

As in the previous studies, the results confirm that private and university research influences the level of innovation output. There is evidence that university research influences innovative activity not only when it arises within the MSA itself but also from the surrounding counties. On the contrary, there is no evidence that industry research spills over from outside the MSA itself. 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 these distance effects vary from one sector to another.

With these studies, we overcome the simple effect of agglomeration generated by geographic spillovers: the spatial extent of spillovers is depicted. We confirm the local character of spillovers. But the results in Anselin *et al.* for university research show that more precise consideration of the spatial range of interaction is important.

It is worth to note that other studies we quote elsewhere, also deal with spillovers at the urban scale (Feldman and Audretsch, 1998; Anselin, Varga and Acs, 1997).

Intercity diffusion

The spatial dimension could be introduced differently. In previous works, the point was to determine more or less directly the effect of physical distance on the diffusion of spillovers. But let us return to the pioneering works of Hägerstrand (1953, 1967) on knowledge diffusion. We are then 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 a central place to another central place even if they are remote. This is due to the better access to information provided by large cities. Few studies adopt this point of view. Florax and Folmer (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 would confirm the above theoretical principle that assumes a privileged role of the nodes of the communication networks. Because of communication equipment and transport terminals, information is supposed to diffuse more easily from node to node than around each node. It is as if we had replaced physical distance by a more elaborate time-distance.

But this confirmation must be taken carefully. 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 grasp and that the diffusion of university spillovers is frequently wide.

3.5. 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 grasp spillovers more accurately, we have to identify more clearly the nature and the contents of knowledge interactions. This hidden dimension is the most difficult to highlight. Two main lines can be followed: first, a number of empirical studies focus on the role of information variety. The debate takes the form of whether diversity or specialization in the city favors innovative activity. At the same time, the influence of the degree of monopoly versus 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 the literature on endogenous growth 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 others industries. Second they differ in their predictions of how local competition affects the impact of these knowledge spillovers of growth. » (Glaeser *et al.*, 1992).

Marshall-Arrow-Romer's (MAR) and Porter's theories stress the specialization 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 onto 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 refer to « location economies » and Jacobs externalities to « urbanization economies », in the classical terminology of Hoover (1937) and Isard (1956).

The MAR theory is in favor of monopoly. With local competition, inventors lack property rights with the knowledge spillovers and this tends to discourage investment in research and development which in turn lowers innovation. On the contrary, Jacobs and Porter are in favor of local competition arguing that, although it reduces the return on the discovery, it accelerates innovation. With competition, the pressure to innovate is higher because the firms are strongly incited to adopt new technologies rapidly and to improve them.

The analytic framework of Glaeser *et al.* is endogenous growth. They want to know what sorts of spillovers and what market structures lead to growth. The results at the city level are in favor of Jacobs' theory that is to say that diversity and local competition generate growth. Growth is not exactly our purpose but the principles of Glaeser *et al.* lead to the analysis of Feldman and Audretsch (1998) identifying the extent to which specialization or diversity of cities generates innovative output and which economic structure (local competition or monopoly) favors innovative activity. This analysis is more directly related to our purpose than that by Glaeser *et al.*, and it can tell us if firms really are looking for spillovers and for what sort of spillovers.

The study of Feldman and Audretsch relates to the city level. We shall only give the main lines of the econometric model. The innovative output is linked to three main independent variables. One variable reflects the degree of industrial specialization of the city. A positive coefficient means that an increasing specialization in the city leads to more innovative output, which confirms the MAR and Porter theories. A negative coefficient means that specialization reduces innovation, which supports Jacobs' theory. The second variable is similar to the index of industrial specialization introduced by Glaeser *et al*. The aim is to measure the influence of the presence of related industries linked by a common scientific base. A positive coefficient shows the influence of diversity and vice versa. To measure the impact of competition on innovation, one variable similar to that of Glaeser *et al.* is introduced: the number of firms in proportion to the number of workers.

The results show that innovation output is lower in specialized cities. The agglomeration of diverse complementary activities sharing common knowledge increases innovation more than specialization 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, Lung and Rallet, 1997; 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 combinatory 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 in a function where the dependent variable is a Gini coefficient of intersectoral concentration of R&D at the level of French departments. It clearly appears that complexity has a positive effect on this concentration.

These works further corroborate our theoretical base. It seems that in order to innovate, firms need information from a variety of sources. Diversified firms exchange information rather than protect it like priceless secrets. These factors promote agglomeration because, as we have stated above, proximity facilitates the exchanges of diversified information. Indeed, these interactions take place inside the cities.

But the very core of the problem lies in the more or less tacit character of the information exchanged. How can we find out about 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 and Turner 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 industries. » (Henderson, Kuncoro, Turner, 1995).

In the product cycle, tacit knowledge is greater in the earlier stages and after this level decreases because of the standardization of the product. In these conditions, proximity will be more important for the development stage of the innovation and the importance declines afterwards. Thus the agglomeration force depends on the stage 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 that confirm this fact. In the first stage, some sources of new knowledge, such as university research and skilled labour, lead to increasing propensity of innovative activity to concentrate. But, during the growth and decline stage, the importance of these factor declines.

A related approach is concerned by the role played by market information in the development of product innovation. It is well known that part of this information is tacit. The users of complex, customized and costly products give high value to the proximity of the sellers because in order to use the product efficiently, they need information that is tacit (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 the proximity of customers. This phenomenon may be related to the localized character of tacit information developed in the first part of this paper. 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 reported to be particularly great, Cornish (1997) gives 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 localized tacit information hypothesis formulated in part one seems to be corroborated in this case study.

Further confirmation 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 logical reason to expect co-localization of the two actors involved. But Audretsch and Stephan find that about 70% of the links are non local. How can this paradox be explained? The authors solve it by examining the role and the characteristics of the scientists connected with the firm. The connections are multidimensional and the importance of proximity varies with the type of connection. Only one part of the scientists' activity relates to the transfer of knowledge. Even in the case of knowledge transfer, scientists and firms may be geographically separated. Two factors govern the proximity between these two actors. First, if scientists help in creating a new firm with a new product, proximity is far more important than when they have only a supervisory role. Second, proximity is important in forging strong bonds between the scientists and firms in question. Proximity favors the formation of chance connections or creates a potential for quick and efficient research and encounters at short notice. When firms and scientist work together, they develop a common language, learn and progress interactively, and define common objectives and working methods. After this learning phase, proximity is no longer necessary and the face to face contacts can be occasional and pre-arranged.

Finally, we have evidence that proximity matters: (1) because it facilitates encounters allowing the individuals involved to meet the people who hold information or to receive information through chance encounters; (2) more generally to exchange *tacit* information, but as this information becomes gradually codified, the importance of proximity declines.

Although the tacit dimension of information remains largely hidden, an increasing number of studies are adopting indirect indices: Audretsch and Stephan stress the role of scientists with the implicit assumption that scientists diffuse tacit information. Another approach is proposed by Carrincazeaux, Lung and Rallet (1997) who try to measure the tacit dimension by the degree of technological complexity of the information needed by R&D. The index of technological complexity is evaluated by direct inquiry notably through the standardized character of the production process and the novelty of the technology and the skills needed. But only the combined effect of this index with the above index of combinatory complexity is tested and positively estimated.

4. Conclusions

We have obtained a series of confirmations of our theoretical principles on the basis on more or less indirect tests. We now have a number of good reasons to believe that information exchanges really have spatial effects and could favor, maintain or reinforce agglomeration in cities, notably in the innovative activities through knowledge spillovers. Clearly, the area of empirical studies must be extended to other kinds of information exchanges.

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. But some observations call into question the necessary and sufficient character of these links. Moreover, we still have certain difficulties in evaluating variables, and some questions remain unresolved. However, despite some remaining difficulties and certain inevitable weaknesses, the empirical investigations we have commented upon provide valuable results. That is what we hope to show in the following concluding remarks.

First, we should emphasize certain observations that apparently contradict or weaken our previous results in that the established links no longer appear necessary and sufficient.

In the theoretical part, we have emphasized the multiple possible causes of agglomeration that make information exchanges a *non necessary condition* of agglomeration. We offer simply an illustration in relation to the location of High Tech activities. These activities employ professional and highly educated workers whose location preferences are strongly in favor of large cities and of places with plentiful amenities. Preference for large cities relates to the education, cultural and leisure environment and to the security provided by a better matching of employment. 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 Bradburry, 1992; Sivitanidou and Sivitanides, 1995).

Agglomeration itself is not a necessary condition of innovation. Agglomeration takes into account the presence of a large quantity of activities such as research and related industries. But innovation can be a question of the quality more than the quantity of information. In other terms, innovation can emerge because of a strategic piece of information, independently of the quantity of research conducted in the vicinity. Such a phenomenon cannot be grasped by the previous type of study (Carrincazeaux, 1999).

We have shown how proximity can favor a high degree of interaction and of innovation. But this is *not a sufficient condition*. The comparison between Route 128 and Silicon Valley illustrates this statement. In both areas, we observe a concentration of industries, university and corporation 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, secret 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 absolute condition of existence of spillovers is the intention to cooperate and the will of the agents to interact.

With the previous studies, we have some evidence that spillovers positively affect the innovative activity, which leads to an agglomeration effect. But some stylised facts suggest that a congestion effect may appear which can lead to dispersion. Audretsch (1998) quotes the example of the agglomeration of computers industries in the Northeast Corridor in the 1980s. An intellectual lock-in in the area made it difficult for IBM or DEC to change mainframe computers for 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 » (Audretsch, 1998). It is interesting to note that IBM personal computers have been developed in Bocan Ratton in Florida far away from the Northeast Corridor. The spillover congestion may lead to the emergence of new agglomerations like other congestion phenomena in economic geography.

Other weaknesses lie in the difficulties in evaluating the result of the process we want to describe. Input and output variables related in an innovation production function are mostly estimated by proxies and the choice of a particular proxy may largely determine the results. This is the case, for example, when we adopt innovation rather that patent data as output proxy, or when we look for different proxies of university or industry research activities: employment, expenditure, or anything else.

Some questions remain totally or partially unresolved. The question of the influence of university research is still debatable. The spatial range of university knowledge diffusion is not clearly determined and the results vary from one study to the other. It seems generally that universities diffuse knowledge more widely than industry research departments. This may be related to the more or less effective public dimension of university knowledge. Moreover, the influence of university research remains difficult to estimate, because such research is more fundamental and diffuses both directly and indirectly through industry research. That is why Jaffe (1989) underestimated the effect of university research.

The spatial dimension is still present in an imperfect way. Even when we dispose of data at the urban scale, the spatial range of information exchanges is not very accurately grasped, because we cannot accurately follow the multiple information flows between actors.

These are only some of the major weaknesses of empirical studies in our subject. Are they good reasons for invalidating the previous results? We do not think so.

The links we have observed are not necessary and sufficient, and they are imperfect. But the effect of information flows on spatial structures is highly probable, for a series of reasons.

1) The counterexamples we have just proposed have introduced variations of conditions other than information exchanges. But if we consider other things to be equal, the theoretical links are not invalidated. Indeed, theoretical principles concerning information exchange have been stated other things being equal. A fundamental principle of economic methodology says that you cannot invalidate a theoretical principle simply because you have found counterexamples Popper's falsificationism must be very carefully used. In order to invalidate a theoretical conjecture, you must be sure that the same conditions prevail in theory and in your observations.
2) No empirical study, statistical, or econometrical, can prove anything. Therefore it is impossible to validate causal links and we must settle for the indirect confirmations we have obtained.
3) You can improve the capture of knowledge and more generally of information exchanges. But you are condemned to an indirect capture as long as you are faced with true tacit information.

Finally, despite the weaknesses of empirical studies on knowledge flows , we can consider that, contrary to Krugman initial claim, the theorist cannot assume « anything about them that she likes. »

Bibliography

Abdel-Rahman H.M. (1994), Economies of Scope in Intermediate Goods and a System of Cities, *Regional Science and Urban Economics*, 24, 497-524.

Abdel-Rahman H.M. (1996), When do Cities Specialize in Production?, *Regional Science and Urban Economics*, 26, 1-22.

Acs Z.J., D.B. Audretsch and M.P. Feldman (1991), Real Effects of Academic Research: Comment, *The American Economic Review*, 82, 1, 363-367.

Anselin L., A Varga and Z. Acs (1997), Local geographic spillovers between University Research and High Technology Innovations, *Journal of Urban Economics*, 42, 422-448.

Audretsch D.B. and M.P. Feldman (1996), R&D Spillovers and the Geography of Innovation and Production, *The American Economic Review*, 86, 3.

Audretsch D.B. and P.E. Stephan (1996), Company-Scientist Location Links: The case of Biotechnology, *The American Economic Review*, 86, 3, 641-652

Baumont C., H. Beguin and J.M. Huriot (1998), An Economic Definition of the City, in: D.A. Griffith, C.G. Amrhein and J.M. Huriot, *Econometric Advances in Spatial Modelling and Methodology: Essays in Honour of Jean Paelinck*. Dordrecht: Kluwer Academic Publishers, 15-31.

Baumont C. and J.M. Huriot (1997), Economic Geography and Growth, Working Paper n° 9715, Dijon: LATEC.

Beyers D. (1989), The Producer services and Economic Development in the United States: the Last Decade, US Department of Commerce, Washington: Economic Development Administration.

Carrincazeaux C. (1999), L’organisation spatiale de la recherche industrielle. Proximité et coordination des activités de R&D des firmes, Ph.D. in economics, Bordeaux: Université Montesquieu-Bordeaux IV.

Carrincazeaux C., Y. Lung and A. Rallet (1997), De la localisation à l’organisation spatiale des activités de recherche-développement des entreprises. Hypothèses théoriques et résultats empiriques dans le cas de la France, paper prepared for the XLVIth Congress of the AFSE, Paris.

Castells M. (1989), *The Informational City: Information Technology, Economic Restructuring, and the Urban-Regional Process*, London: Blackwell.

Castells M. (1996), *The Rise of the Network Society*, Oxford: Blackwell.

Coffey W.J. (1996), Employment Growth and Change in the Canadian Urban System: 1971-1994, Ottawa: CPRN.

Cornish S.L. (1997), Product Innovation and the Spatial Dynamics of Market Intelligence: Does Proximity to Market Matter? *Economic Geography*, 73, 2, 143-165.

Englmann F.C. and U. Walz (1995), Industrial Centers and Regional Growth in the Presence of Local Inputs, *Journal of Regional Science*, 35, 1, 3-27.

Feldman M. (1994), *The Geography on Innovation*, Dordrecht: Kluwer.

Feldman M. and D.B. Audretsch (1998), Innovation in Cities: Science-Based Diversity, Specialization and Localized Competition, Discussion Paper Series of AEPR

Feldman M. and R. Florida (1994), The Geographic Sources of Innovation: Technological Infrastructure and Product Innovation in the United States, *Annals of the Association of American Geographers*, 84, 2, 210-229.

Florax R. and H. Folmer (1992), Knowledge Impacts of Universities on Industries: an Aggegate Simultaneous Investment Model, *Journal of Regional Science*, 32, 4, 437-466.

Foray D. and B.A. Lundvall (1996), The Knowledge-Based Economy - From the Economics of Knowledge to the Learning Economy, in: *Employment and Growth in the Knowledge-Based Economy*. Paris: OCDE Documents, 11-34.

Fujita M. (1990), Spatial Interactions and Agglomeration in Urban Economics, *in* Chatterji M. and Kunne R.E., eds, *New Frontiers in Regional Science*, London: Macmillan, 184-221.

Fujita M. and P. Krugman (1995), When is Economy Monocentric? Von Thünen and Chamberlin Unified, *Regional Science and Urban Economics*, 25, 505-528.

Fujita M. and P. Krugman (1999), A monopolistic Competition Model of Urban Systems and Trade, in J.-M. Huriot and J.-F. Thisse, *Economics of Cities*, Cambridge, Mass.: Cambridge University Press.

Fujita M., P. Krugman and T. Mori (1994), On the Evolution of Hierarchical Systems, Paper prepared for the 41st North American Meeting of Regional Science International, Niagara Falls, Canada.

Fujita M. and T. Mori (1994), Structural Stability of Urban Systems Evolving Economic Geography, Paper presented at the International Conference on Decentralization and the Economic Organization of Space, EHESS, Marseilles, 16-17 june, mimeo.

Fujita M. and H. Ogawa (1982), Multiple Equilibria and Structural Transition of Non-Monocentric Urban Configurations, *Regional Science and Urban Economics*, 12, 161-196.

Fujita M. and J.F. Thisse (1999), Economics of Agglomeration, in J.M. Huriot and J.F. Thisse, eds, *Economices of Cities*, Cambridge, Mass.: Cambridge University Press.

Garreau J. (1991), *Edge City: Life on the New Frontier*, New York: Anchor Books, Doubleday.

Gaspar J. and E.L. Glaeser (1996), Information Technology and the Future of Cities, Working Paper 5562, Cambridge, Mass.: National Bureau of Economic Research, INC.

Gehrig T. (1999), Cities and the Geography of Financial Centers, in J.M. Huriot and J.F Thisse, *Economics of Cities*, Cambridge, Mass.: Cambridge University Press.

Gehrig T., K. Stahl and X. Vives (1994), Competing Exchanges, in: *The Location of Economic Activities: New Theories and Evidence*, Vigo: CEPR Conference Volume, 549-581.

Glaeser E., H. Kallal, J. Scheinkman and A Shleifer (1992), Growth in Cities, *Journal of Political Economy*, 100, 1126-1152.

Griliches Z. (1979), Issues in Assessing the Contribution of R&D to Productivity Growth, *Bell Journal of Economics*, 10, 92-116.

Griliches Z. (1990), Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature*, XXVIII, 1661-1707.

Guillain R. and J.M. Huriot (1998), Informational Interactions and the Future of Cities, Working Paper n°9810, Dijon: LATEC.

Hägerstrand T. (1953), *Innovation Diffusion as a Spatial Process*, Chicago: University of Chcago Press.

Hägerstrand T. (1965), Aspects of the Spatial Structure of Social Communication and the Diffusion of Information, *Papers of the Regional Science Association*, 16, 27-42.

Henderson V, A Kuncoro and M. Turner (1995), Industrial Development in Cities, *Journal of Politicval Economy*, 103, 5, 1067-1095.

Hoover E.M. (1937), *Location Theory and the Shoe and Leather Industries*, Cambridge, Mass: Harvard University Press.

Howells J.R.L. (1984), The Location of Research and Development: Some Observations and Evidence from Britain, *Regional Studies*, 18, 1, 13-29.

Isard W. (1956), *Location and Space Economy*, New York: John Wiley and Sons.

Jaffe A.B. (1989), Real Effects of Academic Research, *The American Economic Review*, vol 79, n°5, 957-970.

Jaffe A.B., M. Trajtenberg and R. Henderson (1993), Geographic Localisation of Knowledge Spillovers as Evidenced by Patent Citations, *Quarterly Journal of Economics*, 63, 577-598.

Krugman P. (1991), *Geography and Trade*, Cambridge, Mass: MIT Press.

Léo P.Y. and J. Philippe (1998), Tertiarisation des métropoles et centralité, *Revue d'Economie Régionale et Urbaine*, 1, 63-84.

Lucas R. (1988), On the Mechanisms of Economic Development, *Journal of Monetary Economics*, 22, 3-42.

Lundvall B.A. (1992), User-Producer Relationships, National Systems of Innovation and Internationalization, in B.A. Lundvall, ed, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter, 45-67.

Malecky E.J. and S.L. Bradburry (1992), R&D Facilities and Professional Labour: Labour Force Dynamics in High Technology, *Regional Studies*, 26, 2, 123-136.

Moss M.L. (1987), Telecommunications, World Cities, and Urban Policy, *Urban Studies*, 24, 534-546.

Ota M. and M. Fujita (1993), Communication Technologies and Spatial Organisation of Multi-Unit Firms in Metropolitan Areas, *Regional Science and Urban Economics*, 23, 695-729.

Ottaviano G.I.P. (1998), Dynamic and Strategic Considerations in International and Interregional Trade, Ph.D. Dissertation, Louvain-la-Neuve: CORE.

Polanyi M. (1966), *The Tacit Dimension*, London: Routledge.

Romer P. (1990), Endogenous Technological Change, *Journal of Political Economy*, 98, 5, S71-S102.

Sivitanidou R. and P. Sivitanides (1995), The Intrametropolitan Distribution of R&D activities: Theory and Empirical Evidence, *Journal of Regional Science*, 35, 3, 391-415.

Saint-Julien T. and L.M. Sabatier (1996), La diffusion des services aux entreprises dans le réseau des villes françaises, *Economie et Statistique*, 294/295, 153-163.

Sassen S. (1991), *The Global City*, Princeton: Princeton University Press.

Saxenian A. (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, Mass.: Harward University Press.

Stanback R. (1997), The dynamics of production systems, territories and cities, in F. Moulaert and A. Scott (eds), *Cities, Enterprises and Society on the Eve of the XXIst Century*, London, Pinter.

Walz U. (1996), Transport Costs, Intermediate Goods and Localized Growth, *Regional Science and Urban Economics*, 26, 671-695.