Knowledge Spillovers and Local Innovation Systems: A Critical Survey

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This paper re-examines critically the growing literature on localized knowledge spillovers (LKSs), and finds the econometric evidence on the subject still lacking a firm theoretical background, especially in relation to the more recent developments in the economics of knowledge. LKSs as externalities are too narrow a concept to embrace the wide variety of knowledge transmission mechanisms that may, or may not, spread ideas and expertise while keeping the diffusion process bounded in space.

1. *Introduction*

This paper provides a critical assessment of the recent fortunes met by the concept of 'localized knowledge spillovers' (LKS), and its role in the debate on the spatial boundaries of spillovers from both private and public (including academic) R&D laboratories.

Going back at least to Nelson (1959) and Arrow (1962), economists have been busy discussing to what extent knowledge can be seen as a non-rival production asset, and have portrayed 'knowledge spillovers' as a prototypical externality, by which one or a few agents investing in research or technology development will end up facilitating other agents' innovation efforts (either unintentionally, as it happens when inventions are imitated, or intentionally, as it may happen when scientists divulge the results of their research).

Following this tradition, LKSs could be first and foremost defined as 'knowledge externalities bounded in space', which allow companies operating nearby important knowledge sources to introduce innovations at a faster rate than rival firms located elsewhere. As such, they are the key object of enquiry of a fast-growing stream of econometric studies, which deal with the impact of academic and industrial R&D on the location of firms' innovative activities

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(see references in Baptista, 1998). These studies exploit the increasing availability of large data-sets on the innovation inputs and outputs of firms and regions, whether measured by R&D, patents, innovation counts or questionnaire results, and frequently invoke the existence of LKSs to comment upon their findings. Although originally proposed as an extension of previous research on the relationship between public and private R&D, innovation and productivity growth (Mohnen, 1996), these studies have become increasingly popular within economic geography, as witnessed by some common referencing and cross-referencing within Krugman (1991, 1995), Martin (1999) and Feldman (1999).[1]

This same popularity, however, has somehow broadened the meaning of the LKS-buzzword, which in a number of econometric studies and a few geographical case studies has been recently used as if it could encompass any kind of 'localized knowledge flows', no matter whether such flows are the outcome of economic transactions, free sharing agreements or some agents' failure to appropriate the outcome of their own innovation efforts.[2]

We will argue that the concept of LKS is no more than a 'black box', whose contents remain ambiguous. On the one hand, its frequent citation serves well an evocative purpose, i.e. it helps to signal a strong interest in coupling 'geography' and 'innovation' as research themes. On the other, by contrast, it provides the researcher with an escape route to avoid studying the specific mechanisms through which the two phenomena are linked.

The main reason for our dissatisfaction with the quantitative literature on LKS is the suspicion that its increasing popularity may:

1. distract too much research energy from the study, both theoretical and empirical, of the role of geographical distance in the economics of knowledge transmission, which is still rather controversial (Rallet and Torre, 2000);

[1] In particular, many of the econometric studies we will survey in this paper quote extensively a few influential case studies on high-tech clusters in the US (above all, Saxenian, 1994), which in turn owe a lot to the European literature on industrial districts, learning regions and 'milieux innovateurs' (Camagni, 1991, 1995; Cossentino *et al.*, 1996; see also Phelps, 1992, for a critical survey). As a feedback effect, a few authors from both the US and European traditions have resorted to the LKS metaphor, and quote therelated quantitative studies. For a few observations on the causes and consequences of such cross-fertilization (and mutual legitimization) see Breschi and Lissoni (2001).

At the same time, LKSs are frequently questioned as a meaningful or useful research category by the so-called 'New Economic Geography', started by Paul Krugman's authoritative reassessment of location theory and soon developed into a research field of its own (Krugman, 1991, 1995, 1998, 1999; Ottaviano and Thisse, 2000; see also David, 1999).

Finally, LKSs play an important role also in some recent developments of trade theory. For a recent survey, see Barba Navaretti and Tarr (2000).

[2] For a survey of all these (often contradictory) meanings, see again Breschi and Lissoni (2001).

2. lead to naïve policy implications, which recall many not-so-distant and unfortunate experiences with science parks, growth poles and the likes (Massey *et al.*, 1992).

The first risk is revealed by the far too ready acceptance of the concept of *knowledge spillover* (which we suggest ought to keep its original meaning of 'knowledge externality') as an unequivocal summary variable for a number of knowledge flows, each of them bearing, on closer inspection, a different relationship to both markets and hierarchies. Too little attention has been paid to the origins of the LKS concept, which is a by-product of a 'production function' view of innovation processes (which is strictly functional to neo-classical growth theory), and not the outcome of a specific enquiry into the circumstances under which scientific and technical knowledge may (or may not) take on some 'public good' features. Things are made even worse when the LKS concept is supported by calling in an even fuzzier conceptual category, namely that of 'tacitness', to be intended as an intrinsic property of scientific and/or technical knowledge, which is said to require physical proximity for the latter to be exchanged. Indeed, the concepts of 'spillover' and 'tacitness' form an odd couple, which we will show are ill-equipped to help us highlight, and possibly solve, the conceptual problems that stand in the way of a full understanding of the role of geographical distance in knowledge transmission.

The second risk derives from the potentially self-reinforcing view of LKSs as a 'stylized fact', i.e. as a quasi-automatic consequence of a sufficiently high stock of geographically concentrated R&D activity. This in turn may lead to:

1. a return of innovation policies mainly designed to overcome market failures due to 'information externalities' of some kind, possibly by means of incentives, subsidies or contract R&D;
2. the erroneous belief that social returns from policies of that kind are necessarily localized, i.e. that they will be retained by the same communities that took their burden.

Suggestions like that of Jaffe (1989, p. 968) that '... a state that improves its university research system will increase local innovation both by attracting industrial R&D and augmenting its productivity' sound too daring if confronted with the conceptual fuzziness of LKSs.

Space constraints force us to limit the scope of our review, so we will concentrate our efforts on illustrating only the first of the two risks mentioned above. In particular, in Sections 2–5 we will show that the existence of LKSs is far from being a 'stylized fact', i.e. a non-controversial starting point for research. We will suggest that innovators' spatial proximity, when found to be significant, may not depend upon any intrinsic feature of knowledge, such as its degree of 'tacitness', but on a much more complex interplay between the economics of knowledge codification, the labour market for scientists and technologists, and the innovators' appropriation strategies.

Then, in Section 6, we will make a few steps towards opening up the LKS black box. In particular, we will examine a few recent studies on the geography of innovation that do not start from any 'knowledge production function', some of which go to the extreme of questioning the link between knowledge diffusion and spatial proximity. Above all, these studies show how many different knowledge flows link together universities, public laboratories, private companies and individuals, each of them serving different purposes and, as a consequence, being affected in different ways by physical distance.

In Section 7 we will conclude by offering some research questions which build upon the literature we have reviewed, and which may help to stop the indiscriminate hunting of LKSs.

2. *Three Critiques to the LKS Story*

The past 15 years have witnessed the growth of a new breed of empirical literature on the 'geography of innovation', which tries to asses whether knowledge spillovers exist and are bounded in space, and to what extent they are better described as 'Marshallian' rather than 'urbanization' externalities.

Marshallian externalities refer to intra-industry economies of localization, and are most commonly listed (e.g. Krugman, 1991) as:

1. *Economies of specialization.* A localized industry can support a greater number of specialized local suppliers of industry-specific intermediate inputs and services, thus obtaining a greater variety at a lower cost.
2. *Labour market economies.* Localized industries attract and create pools of workers with similar skills, smoothing the effects of business cycle (both on unemployment and wage) through the effects of large numbers.
3. *Knowledge spillovers.* Information about novelties flows more easily among agents located within the same area, thanks to social bonds that foster reciprocal trust and frequent face-to-face contacts. Therefore, geographical clusters offer more *innovation opportunities* than scattered locations. Innovation diffusion is also faster.[3]

Urbanization externalities occur whenever job or innovation opportunities are enhanced by exchanges and cross-fertilization among technologies and sectors, i.e. inter-industry externalities, which are most likely to appear within large urban centres.[4]

Entries (1) and (2) in the list above are often referred to as 'pecuniary' or 'rent' externalities, as opposed to (3), and its homologues in urbanization theories, which more clearly represent 'technological' externalities (Scitovsky, 1954).[5] Rent externalities allow co-localized firms to access traded inputs and labour at a lower price than rivals located elsewhere; as such, they occur through market interactions. Technological externalities, on the contrary, materialize through non-market interactions and, in principle, are accessible to all members of the local community.

However, when it comes to empirical studies, the distinction between pecuniary and technological externalities becomes blurred. In particular, econometric studies on R&D productivity may underestimate the former, and overestimate the latter, because of measurement errors (Griliches, 1992). The typical example is that of the influence of business R&D on sectoral productivity: we know the latter to be positive, but we find it hard to say why. It may be the case that a few firms' successful R&D projects bring about new or improved inputs, which increase the marginal productivity of a number of other firms in the same industry. But it may also be the case that the overall R&D effort of the industry contributes to the increase of a common pool of knowledge, which enhances the innovation opportunities for all the firms contributing to it. Although we can distinguish the two effects on the theoretical ground (as well as in terms of policy implications), we find it hard to do the same empirically.

Despite this, all the best-known studies on LKSs (as surveyed by Feldman, 1999) seem to be unanimous in concluding that knowledge spillovers, either intra-industry or inter-industry, are important and strongly bounded in space.

The (unverified) story that is usually told assumes that the employees and managers of firms near to universities (where leading-edge research is carried out), as well as close to a number of other innovative firms, will be the first to be acquainted with the results of important discoveries, or to obtain the

[3] Some authors add to this list the provision of public infrastructure, which local or national authorities are forced/convinced to provide if and only if they recognize the importance of a specific industry to the welfare of local communities (Henderson, 1986).

[4] Common synonyms for Marshallian vs. urbanization externalities are respectively 'MAR' and 'Jacobs' externalities, where the former stands for 'Marshall–Arrow–Romer'. As observed by one referee, when itcomes to empirical studies, the 'intra-industry' vs. 'inter-industry' contrast may be fuzzy, as long as externalities between vertically related sectors, such as those we listed as of the Marshallian (i.e. intra-industry) kind, can be seen by others as occurring at the inter-industry level. However, if it helps clarify our standing, in the example we have just made, we would stick to the Marshallian label.

[5] In a number of studies, Jacobs externalities of a pecuniary kind are also examined (Henderson, 1999).

accessory knowledge that is necessary to exploit those discoveries commercially, thus gaining an innovative edge over distant rivals. More precisely, this story can be broken down into a *three-step logical chain*:

1. knowledge generated within innovative firms and/or universities is somehow transmitted to other firms;
2. knowledge that spills over is a (pure) public good, i.e. it is freely available to those wishing to invest in searching for it (non-excludability), and may be exploited by more than a few users at the same time (non-rivalry);
3. despite this, knowledge that spills over is mainly 'tacit', i.e. highly contextual and difficult to codify, and is therefore more easily transmitted through face-to-face contacts and personal relationships, which require spatial proximity; in other words, it is a public good, but a local one.

One can level three critiques at such a logical chain.

First, it might be that what standard methodologies (such as the production function), data sets (patents and innovation counts) and concepts ('tacit knowledge' vs. 'freely available information') suggest to be pure externalities will turn out to be, on more careful scrutiny, knowledge flows that are mediated by market mechanisms (Geroski, 1995). These mechanisms influence local firms' innovation opportunities indirectly, i.e. via *pecuniary*, rather than *knowledge*, externalities. In Section 3 we show how the prevailing interpretation of the quantitative evidence on LKS has either mentioned many of these market mechanisms as *examples* of localized externalities (with little regard for the logical twists behind this claim), or simply ignored them, hiding behind the (supposedly) comprehensive label of LKS.

In Section 4 we level a second, deeper criticism against this three-step logical chain, which addresses the prevailing conceptualization of 'tacitness' as an intrinsic property of some scientific or technical fields' knowledge base. We suggest that tacitness, when referring to knowledge flows rather than stocks, is a key *exclusionary* mean, which can be wilfully manipulated to prevent a number of actors (even local ones) from understanding the content of scientific and technical messages. At the same time, tacit messages can be sent long distances either through written (even public) media or telephone conversations, thus allowing knowledge to be shared within physically dispersed 'epistemic communities', as a common property or a club good.

The third criticism refers to a common 'modified version' of the logical chain, wherein step (3) is substituted/complemented by the suggestion that LKSs are not (just) the result of inter-firm, or university-to-firm, communication, but also of localized inter-firm mobility (see again Feldman, 1999). In this case tacitness is invoked to assume that knowledge is embodied in a few people, who carry it with them across firms when changing jobs, with changes always occurring within a pool of local employers. In Section 5 we outline a number of contradictions between this assumption and the treatment of knowledge as a local public good.

3. *Interpreting LKS Studies: Logical Traps and Open Questions*

In this section we discuss the prevailing LKS-based interpretation of the leading quantitative studies on the issue of innovation and geographical clustering. For the sake of reviewing, we focus on a selected number of papers, and group them into two broad categories. A first, most influential category comprises all the econometric studies based upon the 'production function' approach, which addresses the impact of external R&D (especially public and/or academic) on private firms' innovation capabilities, sometimes with explicit references to the debate between different schools of economic geography (Section 3.1).[6]

A second category includes a much narrower and more mixed set of recent attempts to quantify, in a direct way, the existence and importance of LKSs. These studies come from a more heterogeneous group of innovation, urban or regional economists, and can be quite creative with respect of the data sets and methodology they employ (Section 3.2).

3.1 LKSs and the Knowledge Production Function

The starting point of recent econometric studies on LKSs is the observation that innovative activities are strongly concentrated geographically, both in the US and in Europe, and that firms located in certain areas are systematically more productive than firms located elsewhere. As a way of explaining these patterns, it is then argued that firms located in regions with high flows (or

[6] More generally, the production function approach to the theme of knowledge externalities can be seen as following three different lines of enquiry: (i) the large, well-established body of research on the social rate of return to R&D; (ii) the evaluation studies on the effectiveness of specific public R&D projects and/or R&D incentive schemes; (iii) the narrower, but more focused stream of research we survey in this paper, which has more openly dealt with the issue of LKSs. Type (i) econometric research has been surveyed effectively and extensively by Mohnen (1996) and David *et al.* (1999), while selected pieces of work dealing with (ii) are discussed by Klette *et al.* (1999).

Research on (i) deals with R&D as a production input, thus using it as an explanatory variable for the growth of output or total factor productivity for the observation unit, while research on (ii) and (iii) make extensive use of modified versions of Griliches's (1979) *knowledge production function*, thus relating R&D to *innovation* output measures, such as patents or innovation counts.

stocks) of both private and public R&D and academic research (as well as other innovative inputs) are more likely to be innovative than firms located elsewhere, since they benefit from knowledge 'leaking out' from these sources. In turn, the reason why 'distance' matters in determining the beneficiaries of knowledge spillovers is found in the distinction between 'tacit' knowledge and information, the latter being often taken as a synonym for 'codified' knowledge. As Audretsch (1998, p. 23) puts it:

> The theory of knowledge spillovers, derived from the knowledge production function, suggests that the propensity for innovative activity to cluster spatially will be the greatest in industries where tacit knowledge plays an important role. ... it is tacit knowledge, as opposed to information, which can only be transmitted informally, and typically demands direct and repeated contacts.

As the above quotation makes clear, this approach combines the 'tacit' vs.'codified knowledge' distinction with the use of a *knowledge production function*, i.e. it relates R&D (and other innovative inputs) to *innovation* output measures, such as patents or innovation counts. As a result, it becomes usual to distinguish between local and distant external innovation inputs, i.e. between inputs coming from outside the observation unit, but within its geographical area (or in a nearby one), and those inputs originating not just outside the observation unit, but also far away from it. Significant differences between the estimated parameters of the two kinds of R&D are then interpreted as evidence in favour of the existence *and* the localization of R&D spillovers.

Taking a quasi-chronological perspective, the first breakthrough in this field, apart from Thompson's (1962) pioneering effort, is due to Jaffe (1989). Aiming to assess the *real effects of academic research*, Jaffe first reclassified patents into a restricted number of technological areas, and then showed that the number of patents of each US state for each technological area is a positive function of the R&D performed by local universities (after controlling for both private inputs and state size, as measured by population). The relationship between patents and university R&D is then interpreted as a sign of the existence of some localized 'technological spillovers' from the academic institutions into the local business realm.

A more careful examination of Jaffe's data reveals two key drawbacks, which we can find, more or less unaltered, in many other econometric studies.

First, state boundaries are a very poor proxy for the geographical units within which knowledge ought to circulate. US states are simply too large as units of analysis to allow us to assume that inventors, entrepreneurs and managers living in one state will have more chances of having face-to-face contact with each other than with people living elsewhere. Similarly, there is no reason to presume the existence of a common cultural background, or a close set of parental or friendship ties, which ought to make mutual understanding and trust easier, and reduce transaction costs.

Second, Jaffe's technological areas are far too broad to let us presume any serious matching between firms' technological competencies, corporate R&D objectives, and university research or expertise. Indeed, technological and scientific distances *within* product areas as broad as 'electronics, optics, and nuclear technology' or 'mechanical arts' (to name just two of Jaffe's six areas) are far too great to let us presume that people active in the specific disciplines within such areas will be more likely to share or combine their knowledge than people active in disciplines belonging to different fields. That is, arguments militating in favour of localization of knowledge spillovers, such as the highly specific and tacit nature of technical and scientific knowledge, are at odds with the most easily available econometric proxies.

Of course, Jaffe was well aware of these problems and tried to provide some remedy. In particular, he corrected for the inadequacies of the state as a unit of observation by calculating an index of co-localization, within each state, of corporate and university R&D laboratories active in the same area. This index, multiplied by the level of university R&D, is then included in the knowledge production function, as a measure of the distinctive input provided by the 'geographical coincidence' of university research and patent output. However, its significance is admittedly poor.[7]

Acs *et al.* (1992) build upon this last point and replicate Jaffe's (1989) exercise by substituting patents with innovation counts, derived from the Small Business Innovation Data Base (SBDIB).[8] The authors' aim is to show that innovation counts, which they consider a better proxy of innovation output, may capture the effect of 'geographical coincidence' that eluded patents. However, their exercise refers only to two technological areas ('electronics'

[7] More recently, Anselin *et al.* (1997) have proposed to solve these problems by including explicitly in the model a *spatially lagged variable*, namely the university R&D expenditures carried out within varying distances from the recipient firm, and by adopting SMSAs (Standard Metropolitan Statistical Areas) as the spatial units of observation, which are much smaller than the states. Their results show that spillovers of university research have a positive impact on regional rates of innovation and that they extend over a range of 75 miles from the innovative region. In addition to that, they also applied spatial econometric techniques to take into account the possible effects of *spatial autocorrelation* either in the dependent variable or in the error term. This is quite a serious problem, which many other studies are apparently unaware.

[8] See Feldman and Florida (1994, p. 212 and footnote 1) for a detailed description of this data set.

and 'mechanics'), both possibly defined even more widely than those in Jaffe (1989). In addition, there is no control for the size of the state.

Above all, innovation counts for one single year (1982) are related to R&D undertaken by industry laboratories and by universities just a few years before, with the same lag for both kinds of R&D. Although we can believe that industrial R&D may turn into 'innovations' in a few years time, this is not the case for academic R&D, which is usually of a much more basic kind. And even if we concede that, nowadays, academic R&D is more readily exploitable than 20 or 30 years ago, then we must be consequential and presume that (large) business companies will be readier than before to finance it. If it is so, academic R&D results may not 'spill over' at all, since they could be sold via standard commercial transactions to business companies, or distributed to a selected number of sponsors via *club* arrangements, as we discuss in Section 5.

Acs *et al.* (1994), however, insist on the 'spillover interpretation' and propose two different innovation production functions, one for large firms, the other for small ones. They find that 'geographical coincidence' is significant only for small firms, and suggest that this is so because university R&D substitutes for firms' internal R&D, which is too costly for small firms. However, we observe that this result does not prove the existence of direct externalities. It may rather suggest that *innovative* small firms may be readier than larger ones to subcontract their research projects to academic institutions simply because they cannot afford to integrate vertically. Besides, they are possibly *forced* to refer to local institutions, due to their difficulties in getting in touch or paying for the services of distant (and possibly more efficient) universities. Finally, nothing is said about how many *non-innovative* small firms in the same geographical area do not benefit at all from the research activities of local universities, i.e. are not touched by any externality whatsoever.

Audretsch and Feldman (1996) improve upon their previous work (see also Feldman, 1994) both by trying to test more directly the role of university R&D inputs in the production of localized innovations, and by making use of less aggregated technological areas (proxied by four-digit SIC sectors). In particular, their cross-section exercise shows that the geographical concentration of the innovation output is positively related to the R&D intensity of the industry (after controlling for the spatial concentration of production). This result reveals the 'propensity for innovative activity to cluster spatially', but the authors rush to relate it to what they call the 'considerable evidence supporting the existence of knowledge spillovers' (where such evidence is mainly to be intended as their own and Jaffe's previous work). That is, they do not prove, but rather assume, the existence of knowledge externalities (on the basis of the same empirical evidence whose reliability and interpretation we question) and then recall it as the only reasonable explanation for their results.

Similarly, Feldman and Audretsch (1999) again make use of the innovation production function (by city *s* and four-digit SIC industry *i*) to test the role of specialization vs. diversity, i.e. Marshallian vs. Jacobian LKSs. More precisely, they test whether the number of innovations from sector *i*, in state *s*, owes more to the city specialization in sector *i*, or to the presence, within the state, of other industries whose science base is related to that of industry *i*. They reach the conclusion that diversity matters more than specialization (for some evidence pointing at the opposite direction, see Henderson, 1999) and, above all, interpret this as evidence that knowledge spills over *across* sectors rather than *within* them, although they have provided no evidence whatsoever for the existence of knowledge spillovers as such.

This tendency to force an interpretation on the data is even stronger in Feldman and Florida (1994). They again employ the innovation production function for 13 three-digit industries, in each US state. They also include, among other explanatory variables, the value added coming from firms that, within each state, belong to the two-digit industry that encompasses the three-digit one under consideration. That is, they test the existence of some (very generic) agglomeration effects. However, they insist upon calling this 'the network effect', and patently mix up what are very different kinds of externalities:

> Concentrations or agglomerations of firms in related industries provide a pool of technical knowledge and expertise and a potential base of suppliers and users of innovations. These networks play an especially important role when technological knowledge is informal or tacit in nature.... Concentrations of these firms foster important synergies in the innovation process, as for example when innovations in semiconductors spill over into electrical, consumer electronics, and computers industries. (Feldman and Florida, 1994, p. 220)

Notice that the 'pool' of technical knowledge could easily be interpreted as a pool of specialized workforce, i.e. a Marshallian externality of the second kind,[9] while network effects can be either defined as the outcome of non-market relationships among firms or as a Marshallian externality of the second type, i.e. one mediated by specialized suppliers. Above all, it is hard to believe

[9] For a list of different kinds of Marshallian externalities, see Section 2.

that tacit knowledge, which requires mutual understanding of working practices, can be exchanged across three-digit industries by means of informal contacts.

Such a bold conclusion contrasts heavily with Jaffe's (1989) caution in judging his own exercise as a first step towards a more careful test of the 'localized knowledge spillover hypothesis', to be conducted at a finer level for both the geographical and the technological areas. Jaffe's main reason for going on to study the role of academic R&D was the high estimated elasticity of patent 'output' with respect to academic R&D 'input'. Above all, Jaffe was quite clear in stating that, whatever association he could find between local R&D and innovation output, nothing in his estimates could explain the reasons for such association.

> It is important to emphasise that spillover *mechanisms* have not been modelled. Despite the attempt to control for unobserved 'quality' of universities, one cannot really interpret these results structurally, in the sense of predicting the resulting change in patents if research spending were exogenously increased. (Jaffe, 1989, p. 968, original italics)[10]

3.2 Other Statistical Tests on LKSs

Despite being most influential, at least within mainstream economics, the production function approach is not the only methodology for testing the existence and exploring the nature of LKSs. A number of alternatives have been recently proposed, which make use of large data sets and incorporate quite creative statistical tests.

One of the most influential approaches has been proposed by Jaffe *et al.* (1993). Using patent citations, these authors manage to track direct knowledge flows from academic research into corporate R&D. They find that innovative firms are more likely to quote research from a co-localized university that conducts relevant research, than from similar universities located elsewhere.[11] Almeida and Kogut (1997) conduct an analogous exercise for

[10] It is worth noting that this conclusion did not differ much from Thompson's (1962), albeit coming 27 years later. It is also quite curious to read similar observations in Audretsch (1998): 'While a new literature has emerged identifying the important role that knowledge spillovers within a given geographical location plays in stimulating innovative activity, there is little consensus as to how and why this occurs. The contribution of the new wave of studies... was *simply* to shift the unit of observation away from firms to a geographic region' (Audretsch, 1998, p. 24, italics added).

[11] Once again, the spatial unit of observation is no longer the state, but the SMSA. Further work on patent citations as indicators of spillovers is reported by Jaffe *et al.* (2000), who have surveyed a number of inventors. They establish that citations and spillovers are certainly correlated, but with a lot of noise.

semiconductor-related patent citations, and reach similar conclusions. Once again, the result is interpreted (and has been popularized) as satisfactory evidence that knowledge spillovers from university research to firms are highly localized.

A variant on this approach has been also proposed by Maurseth and Verspagen (1999), and Verspagen and Schoenmakers (2000). Their exercise is based upon counting the number of patent citations between pairs of regions, and then estimating a model where these counts are related to the geographical distance between pairs of regions. Their estimates show that the number of cross-citations drops significantly as the distance increases. Finally, Brouwer *et al.* (1999) found that firms located in agglomerated Dutch regions tend to produce a higher number of new products than firms located in more peripheral regions. They explicitly argue that this result adds to the literature on regional knowledge spillovers.

A further attempt to quantify the importance of LKSs has been carried out by Kelly and Hageman (1999), who make use of US patent counts at the state level, classified by two-digit SIC sectors. Using a quality ladder model, they show that patenting activity exhibits strong spatial clustering independently of the distribution of employment, and that 'knowledge spillovers' (as measured by the stock of patents in a given state in all other sectors) are important determinants of a state's innovative performance.

All of these studies certainly strengthen the case for the existence of important localization effects in innovation activities, but do not prove, despite their authors' claims, the existence of LKSs. For example, there is no reason to believe that knowing about the local university's research results does not come from contractual arrangements with the latter (or with individual researchers therein), as indeed is suggested by many of the case studies we shall review in Section 6.

A further set of empirical literature on LKS has to do with two specific issues within urban economics, namely the attempts:

- to estimate the relative importance of natural resource endowments *vis-à-vis* knowledge externalities in affecting the location of industries;
- to distinguish between Marshallian externalities and more specific 'urbanization' externalities.

Only a fraction of all the citations one can find on each patent document were known to the inventors contributing to that patent, since many of them were added directly by patent attorneys and examiners. And most inventors suggested they came across the cited documents they know about only *after* having filed their patent application, that is only after having completed their invention. Similar evidence had already been anticipated by Jaffe *et al.* (1998) for inventions originating from research at NASA laboratories.

Key contributions in this field have come from Glaeser *et al.* (1992), Ellison and Glaeser (1997, 1999), Head *et al.* (1995), Henderson (1999) and Black and Henderson (1999). Once again, however, the evidence on LKSs is by and large of an indirect kind (sometimes bringing back the production function tool, as in Henderson, 1999), and cannot be taken as definitive. For example, Glaeser *et al.* (1992, p. 1151) conclude their paper by admitting that:

> ... our evidence on externalities is indirect, and many of our findings can be explained by a neoclassical model in which industries grow where labor is cheap and demand is high.

Once again, the econometric evidence does not necessarily suggest the existence of properly defined 'spillovers', i.e. *pure* knowledge externalities. As we will see in Sections 5 and 6, we will build on these inadequacies and argue that, once one enters the black box, not much remains of the LKS.

4. *'Tacitness' Reconsidered, and the Property Regime of Knowledge*

The distinction between tacit and codified knowledge plays a central role in much of the literature we have reviewed so far, but conflicts with a few basic tenets in the economics of knowledge.

The latter point out that technical knowledge, and even more scientific knowledge, may be considered as 'tacit' not because it cannot be articulated (as, for example, the craftsman's knowledge) but because it is highly specific. Far from being transmitted only by practical examples and hands-on apprenticeship, it is usually reported orally or by means of written words.

Following Cowan *et al.* (2000), we interpret this by saying that technical and scientific knowledge can be (and most often are) codified by developing an appropriate vocabulary, which may or may not be stored in a dictionary or codebook, but in any case retains well-defined meanings. At the same time, though, the *messages* that transport that knowledge can be tacit, in the sense that only a small portion of the relevant codebook is usually referred to *explicitly*, with much else left to the understanding or the intuition of the addressees, whose capability of disclosure varies according to their expertise in the field.

The language used for exchanging technical or scientific messages is not the same as the language of the broader local community which hosts the firms (or the academic laboratories) that produce those messages. Rather, it is the language of a much closer and more restricted community, an 'epistemic' one, whose members learn how to communicate by developing their vocabulary through prolonged studies and, possibly, a few common experiences (Steinmueller, 2000).[12]

As long as the members of the epistemic community do not disclose their common codebook, the latter may act as a powerful exclusionary device, even for local actors who live and work side by side with the community members, but cannot understand the messages (openly) exchanged by the latter. At the same time, since tacitness (in this new definition) and codification are mutually compatible, tacit messages can be sent over even long distances by means of a variety of communication media (both written and oral).

It follows that it is up to the epistemic community members to follow some rules for sharing (and possibly diffusing) the benefits of the discoveries they make by using/developing their language. As long as they do so, they have nothing to fear from communicating openly, or even from publishing papers and articles. These publications may convey (to whatever distance) tacit messages concerning the authors' knowledge assets, in order to arouse the interest of potential research partners, wherever they are located (Hicks, 1995). The ensuing contract research agreements (or informal knowledge sharing deals; see below) will then provide, if necessary, for co-location or visiting arrangements. In this case, it is physical proximity that follows epistemic proximity, and not vice versa.

These observations are consistent with up-to-date definitions of the concept of 'externality', which see the latter as the outcome of specific institutional arrangements, rather than the consequences of some natural properties of specific goods or services. As Cornes and Sandler (1996) observe:

> The literature often treats certain types of physical goods or services as inherently possessing rivalry or nonrivalry, excludability or nonexcludability. However, this can sometimes be dangerous. For one thing, the economically relevant characteristics of a good or service derive from the structure of incentives provided for its production and/or consumption. A loaf of bread typically may be thought of as a private good, but a collective enterprise that bakes loaves and distributes its output equally among it workers creates an incentive structure that is similar to that encountered in the context of public good provision.... In many contexts there are

[12] Steinmueller also observes that technical knowledge, far from being static, is highly dynamic. Incremental technical change takes place in all sectors of activity, and brings about new codes of communications as well as new artefacts, which change the practitioners' vocabulary incessantly: outsiders, however close, may learn nothing of it.

> *alternative ways of providing and distributing consumption services to individuals {with} varying degrees of excludability and... nonrivalry*. (Cornes and Sandler, 1996, pp. 9–10, italics added)

That is, the sharing rules of the epistemic community may encompass a large number of intermediate cases between the two extremes of pure private and pure public goods, such as price-excludable public goods, common property and club goods.[13] Knowledge property regimes are not exhausted by the dichotomic couple 'private' vs. '(local) public good'.[14]

Bearing this variety in mind, one can go back and re-examine the increasingly rich literature on sharing arrangements among scientists or engineers (von Hippel, 1987; Kreiner and Schultz, 1990; and all the studies quoted by Cowan and Jonard, 2000). In most cases knowledge is shared 'on request', i.e. members of the community are bound to help other members to solve well-defined technical problems, even if those other members work for rival firms. It follows that the members of the community are bound by reciprocity obligations, which complement the codebook disclosure rules as a powerful exclusionary device, and may be or may be not coupled with other similar devices based upon physical distance.[15] Therefore, even when distance matters, reciprocity obligations may exclude many neighbours from the externality flow. At the same time, such obligations may force the community members to refuse contacts outside their inner circle, and forgo their chances to access externalities generated outside it, even if at a short distance.

In summary, when tacitness is no longer considered an intrinsic property of knowledge, but rather as a property of the messages exchanged within an epistemic community, as well as the result of a system of incentives, one is

[13] Price-excludable public goods occur when the producer can sell simultaneously to many consumers, and it is possible for individual consumers to consume any amount up to the total provision, and also for different consumers to face different prices. With common property goods, access to the good itself is typically restricted to members of a certain community. In addition there are restrictions on individual members' input levels and implications for the way in which total output is to be shared among the members. For example, in the case of fishing, instead of each taking home his or her own catch, there may be a strongly established tradition whereby the day's aggregate catch is divided up equally among the fishers. Club goods generalize the public good concept to situations in which the community size is endogenous. Any additional member of the club generates benefits to fellow members by reducing the per capita cost of a given quantity of public good, but contributes to a congestion phenomenon, which in the end places bounds on the desirable size of the club. All these definition summarize those provided by Cornes and Sandler (1996).

[14] Local public goods share with club goods the characteristic of endogenous community size, due to the existence of congestion effects. However, physical distance is the only exclusionary mechanism: all the people in the same area have access to the public good, but individuals are free to move around and finally choose the local community, or country, in which to contribute and consume public goods.

[15] For recent study on a sharing arrangement totally independent from physical distance, see Lakhani and von Hippel (2000).

forced to recognize that physical proximity may play a far more complex role than that of a necessary enabling condition for benefiting from knowledge externalities.

It is possible to object that, although physical proximity *per se* does not imply any epistemic proximity, the former may be needed to create the latter, i.e. to create the language and codebooks whose sharing will then define the boundaries of the epistemic community. In fact, during the early stages of some research projects, or the pioneering phase of some technology, much of the relevant knowledge still has to be codified, so that it can only be transmitted by continuous interaction, practical demonstrations and so forth.

However, epistemic communities may well survive the end of co-localization among their members. Even when dispersed in space, the latter will share more jargon and trust among each other than with any outsider within their present local communities. And even when meetings are required, their frequency will not necessarily be as high as to impose co-localization as a necessary requirement for belonging to the epistemic community. Besides, the extent and speed of the codification process will depend, once again, on economic calculus: codification costs entail some fixed costs, but help saving upon relocation and travel costs, by enabling some long-distance communications (von Hippel, 1994). As a consequence, even the length of time during which the community members will be co-located (or the time spent by a new member at close contact with some fellow ones) is not entirely dependent upon some exogenous characteristics of the knowledge base.

5. *Localized Mobility of Skilled Workers as Carriers of Knowledge*

An alternative (or, sometimes, complementary) knowledge diffusion mechanism that is often invoked by LKS supporters consists in the *localized mobility* of individual (skilled) workers.

However, labour mobility generates 'pure knowledge spillover' if and only if, as workers move from one firm to another, they help in creating a common pool of knowledge from which *all* their previous employers are capable of drawing. That is, labour mobility must be supposed to help in spreading of knowledge (in particular frontier knowledge that is immediately relevant for enhancing innovation opportunities), instead of merely shifting it from one place to another.

Unfortunately, such a knowledge-diffusing function of labour mobility is not entirely compatible with the depiction of knowledge as 'tacit' because it is 'embodied' in human capital. If the latter were true, workers who move across firms may take away their knowledge with them, unless they have shared it with their colleagues or bosses. This may require, once again, some codification effort and the definition of a proper incentive system to induce sharing.

On the contrary, if tacitness is intended here not as a property of the individual's knowledge, but of the organizational knowledge, i.e. as knowledge embodied in firms' organizational routines (as in Nelson and Winter, 1982), the departure of an employee may represent more of a loss for the former employer than a positive externality for the future one. Firm-specifity, in this case, would in fact hinder the possibility of generating a positive externality.

It follows that interpreting the evidence on the self-reinforcing mechanisms set in motion by labour mobility, especially in high-tech complexes, with the very rough guide of the 'public good' vs. 'private good' dichotomy, is very dangerous, since it may suggest the existence of LKSs where in fact there is none (compare the studies we quote below with their interpretation by Feldman, 1999, section 2C).

This line of interpretation is supported by recent contributions by Zucker *et al.* (1998a,b). They argue that the standard notion of LKS (according to which 'social' ties and meetings between local firms' employees and university scientists are the main vehicles for knowledge exchange) does not seem to apply to the biotechnology industry, at least in the phase of its emergence. Rather, they argue that discoveries in this field are characterized by high degrees of *natural excludability*, since the *techniques* for their replication are not widely known. Anyone wishing to build upon recently generated knowledge must gain access to the research teams and laboratory environments that generated that knowledge. Under these circumstances, the scientists who make key discoveries ('superstars') tend to enter into contractual arrangements with some existing firms or start up their own firm, in order to extract the supra-normal returns from the fruits of their intellectual capital. Quite naturally, when doing so, those scientists tend to prefer jobs or start-up locations within commuting distance of their home or university (where they tend to retain affiliation, both for the purposes of their reputation and as a source of young assistants), thus creating localized effects of university research. Such localization, however, is not the necessary consequence of any intrinsic characteristic of knowledge.

In the same vein, a very interesting piece of research has been recently produced by Almeida and Kogut (1999). Using a sample of highly cited, semiconductor-related patents, these authors replicate the exercise carried out by Jaffe *et al.* (1993). In addition, they focus upon the mobility patterns of individual patent-holders (engineers) in a number of industry clusters, and find them to be high and highly localized, but only in Silicon Valley, which is also the only cluster wherein such mobility affects positively the innovation rate of local firms.

Again, these results raise more than one suspicion about the 'LKS interpretation' of the econometric and statistical findings we reviewed in Section 3.

First of all, workers that embody relevant knowledge may tend to move 'locally', for a number of reasons (above all risk aversion, localization sunk costs and existing social ties) which have nothing to do with their need to tap their colleagues in universities or rival companies for information and help (long-distance communications and regular meetings may do the trick especially if face-to-face contacts are needed only during the early stages of innovation processes).

This is not to deny the importance of the institutional and social context. Quite the contrary. In order to work smoothly, this kind of inter-firm worker mobility must be supported by a local industrial culture, like the one that prevails in Silicon Valley, in which the allegiance of engineers and scientists is not so much to any individual firm, but to the production complex as a whole (Angel, 1991). The point is rather that this collaborative atmosphere may serve only the purpose of reducing the costs associated with search and screening procedures, as prescribed by the definition of Marshallian externality of the second kind.

In other words, the so-often cited face-to-face contacts may serve only to ease the access to *information* about *who knows what and where is employed*, which is the only local public good.[16] Embodied scientific and technical knowledge remains a private good, unless sharing agreements of the kind we mentioned in Section 4 turn it into common property or a club good.

Secondly, we observe that localized labour mobility, while producing positive effects through knowledge diffusion, may also generate tensions and contradictions, i.e. congestion effects that, once again, are a characteristic of local public goods. After all, the loss of experienced workers to the advantage of competitors can have damaging effects for those firms engaged in ambitious innovation projects. In these circumstances, firms may attempt to keep proprietary control over new technologies and manufacturing experience by reaching some agreement with other local companies, which prevents the participants from starting competitive bids for the local technical/scientific

[16] Or possibly a club good, with co-location as a requirement to enter the club.

superstars, thus limiting skilled labour mobility.[17] If this is true, labour mobility is never localized, but always cross-border.

6. *Further Explorations of the LKS Black Box*

The major limitation of the empirical literature we have reviewed in Section 3 is that virtually no contribution has explored the ways in which knowledge is actually transferred among people located in the same geographic area. Besides working more on the issue of labour mobility (see Section 5; we will also return to this point in the Conclusions), we need to explore the price and non-price mechanisms through which knowledge may be traded between universities and firms (or individuals therein), as well as between firms.

First and foremost, we observe that much of knowledge transmitted from universities to firms has nothing to do with the public results of basic science, but consists of consultancy services to firms. Rather than providing *innovation opportunities*, such knowledge transfer may enhance the customer firms' *appropriation capabilities* (Section 6.1). Digging further into the issue of appropriability, we recognize that even the most open among firms and academic institutions may wish to exert some control over their knowledge outflows. This may be done by attaching some property rights or exclusionary arrangement to those outflows, thus turning them into a private good, to be exchanged via market transactions, or a club good, to be shared freely, but only within the borders of a well-defined network of relationships (Section 6.2).

Finally, we suggest that rigorous research ought to consider not only locational advantages in accessing the results of academic or other firms' research, but also some diseconomies, as well as the relationship between the time dimension and the geographical dimension of spillovers (Section 6.3).

6.1 What Do Local Universities Provide to Firms? Innovation Opportunities vs. Appropriation Means

The impact of academic R&D on firms' innovative performance is often cited as clear evidence of LKSs. The relevant question is: does the estimated impact of university R&D on local firms' innovation output (via knowledge production function or patent citation approaches) represent convincing evidence that academic knowledge may be dealt with as a local public good?

[17] See interviews with textile machine designers in northern Italy by Lissoni (2000); see also Saxenian's (1994) remarks about the labour market in Route 128.

The fashionable answer is certainly 'yes'. However, a careful reading of some recent literature on the role of universities in the innovative activities of local firms suggests otherwise.

In the first place, one observes that local academic institutions and public research institutes may provide critical inputs for firms' innovative activities, such as *training* and *consultancy*, even if their current research is not *directly* relevant to those activities. Universities whose reputation has increased thanks to brilliant research records may attract brilliant students, thus providing a big push for the creation of a localized market for highly skilled labour, which will be possibly reinforced by increasing returns. The same kind of university (or individual researchers therein) may also be the only one capable of providing key specialized intermediate inputs, such as consultancies and testing at critical stages of product development. Notice that current research may be far from relevant to these externalities: brilliant students and key inputs can be produced just by knowing about and teaching consolidated results in one's own specialized field, as many scientists actually do. More importantly, by producing graduates and offering services (or tolerating their staff doing so), even universities with a lower research standing may help enhance local firms' capabilities *of appropriating* the results of their own research efforts, even if they do not give them any *opportunity* to innovate. In both cases, no direct knowledge externality arises, as knowledge is diffused in the local context via the labour market and the market for specialized inputs.

Secondly, even those academic *research* activities that have a direct relevance to the current innovation projects of local firms may have little to do with innovation opportunities (as stressed repeatedly by the LKS story), and much more to do with enhancing the appropriation capabilities of the beneficiary companies, once again via market mechanisms.

To understand this, one should first observe that local firms may end up quoting local universities' research projects simply because they were directly involved in those projects, either as service customers or research sponsors. A survey conducted by Mansfield (1995) supports this view. Corporate R&D managers were asked to mention any academic researcher who had played some role in the development of their companies' new products and processes. In the large majority of cases, the most frequently mentioned names were of those who had received higher-than-average private research funds, had entertained continuing consulting relationships, and had tutored students who later on took up jobs within the industry. None of these links can be claimed to be a pure knowledge spillover.

The work by Zucker and Darby we mentioned in the previous section is extremely important also from this, more methodological, perspective. In fact, it represents a key attempt to study the knowledge transfer mechanisms between university scientists and business companies. In particular, the authors show that the innovative performance of biotechnology firms is positively associated with the *total* number of articles by local university 'star' scientists. However, when a distinction is made between the articles written by the star scientists in collaboration with *firm* scientists ('linked') and those co-authored only by other *academic* scientists ('untied'), the explanatory power of the latter nearly vanishes. Previous evidence on the existence of indiscriminate localized knowledge spillovers seems therefore to have resulted from a specification error, i.e. the inability to control for the contract arrangements linking *individual scientists* to *local firms*.[18]

6.2 Markets for Technology

While reading the literature on LKSs one is struck by the fact that almost no reference is made to the now vast body of research on the sources of knowledge and the means of appropriation (see references in Geroski, 1995). Therefore, one more question arises: is the LKS interpretation consistent withwhat we know about the ways firms acquire new knowledge and the strategies they follow to protect it from imitation?

First, we observe that problems of appropriation are clearly evident in a wide variety of sectors, and the effectiveness of the solutions differ from one sector to another, so that one cannot rule out, in principle, the relevance of knowledge spillovers. However, there is no evidence to support the view that these spillovers are necessarily 'localized'. In the first place, many mechanisms by which firms can learn the 'secrets' of competitors are not sensitive to geographical distance: reverse engineering, patent disclosures, trade journals and fairs. In the second, some studies have demonstrated that the time needed

[18] After these remarks, it does not surprise us to learn from Audretsch (1999) that, in such a highly academic R&D-related field as biotechnology, many young scientists set up new technology-based firms within the same area as the university they are working for. Nor that they do so because they are willing to go on working within their university department, in order to build up both their knowledge base and their reputation. What we can hardly understand is why the author classifies these young scientists' knowledge contributions to their own start-ups as university R&D spillovers. They look like being fully appropriated, either by the researchers or by the universities that employ them (since they possibly pay them low wages, in exchange for allowing them to exploit some of their research results). In addition, there is no proof that the start-ups translate ongoing research results into viable products as such: young researchers may do very different jobs when dealing with basic science inside their university (in order to publish and build up their academic reputation), and when working on product development inside their own start-ups (which may exploit established ideas). And if they quit their university department and work full time for their own firm, they may decide not to leave the local area simply because they want to be ready to go back to their department should their business fail.

to imitate a rival's innovation is between 6 and 12 months (Levin *et al.*, 1987) and that rivals generally learned about decisions to develop major new products or processes 12–18 months after the decision had been made (Mansfield, 1985). Unless any direct proof is produced to show that the quickest imitators are located nearby the source of knowledge, such short lags cast doubt on the assumption that *distance* affects imitation speed.

Second, Levin *et al.* (1987) showed that independent R&D was rated, by R&D managers, as the most effective means of learning about rivals' technology. This raises two points. On the one hand, to the extent that investing in R&D is necessary to develop one firm's ability to 'assimilate and exploit' external knowledge and that a considerable number of firms do not invest in informal R&D, spillovers may benefit just a few firms in each industry. On the other hand, co-localization of innovation inputs (i.e. R&D) and outputs (i.e. patents) might be simply the coincidental development of similar answers to commonly perceived problems, which a group of co-localized competitors reach simultaneously by drawing on a pool of common (but well-established) scientific knowledge. In other words, what are apparently localized knowledge spillovers are no more than simultaneous independent findings (Geroski, 1995).

The third point we wish to raise digs further in this direction. In our view, any testing of the LKS hypothesis should compare the latter with non LKS-based explanations for the clustering of innovative firms. A very interesting explanation of this kind has been provided by Lamoreaux and Sokoloff (1997, 1999). Using historical patent data for the US, the two authors tracked the career patterns of a number of inventors, in order to relate the production of inventions to regional manufacturing activities. The main results emerging from their analysis are as follows:

1. Although there was some clustering in both production and patenting activities, the geographic patterns were quite different. Some production centres did not have any inventive activity, while areas with very little production had very high rates of innovation.
2. Firms in clusters of production were using obsolete technologies and their locational choices reflected the search for cheap material inputs. Firms using newer technologies were thus more spatially dispersed than those using older methods.
3. Patenting activity tended to be higher in regions where patenting rates *had long been high* and where a *market for technology* (as measured by thesales of patents) had evolved more fully, irrespective of the share of industry production. In regions with such well-developed markets, inventors

tended to be more specialized, numerous and productive in terms of the number of patents per inventor.

Despite it being hard to generalize from these results, one is tempted to speculate about them and to suggest that concentration of firms and production in a given area is not *per se* a necessary and sufficient condition to determine high rates of innovative activity. Industries may move across regional and national borders without a corresponding relocation of inventive activity, as long as 'soft' institutions (such as trust, norms and codes of communication) may be substituted by 'hard' institutions (such as property rights legislation and enforcement, and financial markets) that help building market mechanisms to mediate relations among inventors, suppliers of capital and entrepreneurs.

6.3 The Time Dimension of Spillovers, and a Few Implications for Firms' Localization

Looking back to the previous discussion, we recognize that there is hardly any doubt that innovation networks are often localized. However, the rationale for co-localization may have less to do with knowledge spillovers mediated by physical proximity, than with the need to access a pool of skilled workers and to establish transaction-intensive relationships with suppliers and customers.

Going back to the fundamentals of the economics of innovation, one can recall Nelson's (1959) classical observation about the huge time gaps that often separate a scientific discovery from its first industrial applications. Therefore, we suspect that the long time interval between scientific discoveries and industrial applications will suffice to transmit knowledge far away from the university or firm that produced it. That is, the results of *current research* may not spill over from universities to *local* firms, simply because the time they take before being fully understood (or coupled with the complementary innovations necessary for exploitation) is so long that they manage to reach over long distances.

On the other hand, Mansfield (1995) convincingly shows that only a few top universities are up to the task of serving business companies by producing basic rather than applied research. This explains why the evidence he provides on the role of geographical proximity is mixed: companies that need basic research may go far to buy it, but will do so only occasionally and, although they need face-to-face contacts with the university researchers, those contacts will not be sufficiently frequent as to require co-localization. However, companies buying applied R&D services will need almost daily contact, which can be provided only by local universities, which in turn do not have resources and competencies for producing the most fundamental, or basic research.

If this is so, one should recognize that LKSs, although being a possible explanation for co-localization, may be offset by the need establish close links with suppliers of new technologies or new customers, which may be located far away from the original network participants (Lyons, 1995; Echeverri-Carroll and Brennan, 1999). Particularly for firms located in regions and cities with a relatively small accumulation of knowledge, the development of relationships with universities and other firms (suppliers and customers) located in higher-order urban centres is a key factor in determining success in the development of new products and processes. The most dynamic and innovative firms look for knowledge embodied in engineers and scientists *wherever* they are available, and are not necessarily constrained by geographical barriers. Moreover, these firms establish network relationships (alliances, joint ventures, collaborative research, etc.) with customers and suppliers from all over their country, if not the world.

Even more than that, a few studies have shown that *not* locating in a cluster may actually hold some advantages, by allowing firms to safeguard their privacy and to introduce new products earlier than their competitors (Oakey and Cooper, 1989; Suarez-Villa and Walrod, 1997). In particular, Suarez-Villa and Walrod found that non-clustered electronic establishments spent on average 3.6 times more on R&D and employed 2.5 times more R&D personnel than clustered ones. Despite all the conventional assumptions, spatial clustering in and of itself is not as supportive of innovation as has been so far assumed. In particular, the evidence shows that non-clustered establishments achieved greater economies from the adoption of just-in-time methods and outsourcing and were more able to allocate these resource savings to support R&D, thanks to the greater physical isolation from other producers and the more limited obligations that weaker relational ties entailed. Notably, these results open the way to the hypothesis that *sectoral clustering* and broader (non-localized) linkages are more important than has been so far assumed.

7. *Conclusions*

This paper has provided a critical reassessment of the recent literature on localized knowledge spillovers (LKSs). The central point we have stressed is that the notion of LKSs has been largely abused, thereby generating great conceptual confusion.

We have not denied that knowledge flows may be an extremely important agglomeration force. What we have questioned is the strategy of putting *all* of these flows under the common heading of LKSs, as a necessary step towards (re-)discovering regions as the right unit of observation. The problem is not only one of terminology.

In fact, as soon as one tries to open the black box of LKSs, it becomes quite clear that:

1. What might appear, at first, as 'pure' knowledge externalities are actually pecuniary externalities, which are mediated by economic (market and non-market) mechanisms, such as the labour market, the market for technologies, and club or network agreements.
2. What might appear as involuntary knowledge spillovers are actually well-regulated knowledge flows between academic institutions (or individuals therein) and firms, or across firms, which are managed with deliberate appropriation purposes.
3. A large amount of the knowledge flowing in this way has much more to do with enhancing the innovation appropriation strategies of local companies (by speeding up the development phases of new products and processes) rather their innovation opportunities (by providing them with new ideas).

These observations set a tight research agenda for those who want to understand why geography really matters to firms' innovative activities.

The first entry in the agenda is the labour market, which we examined in Section 5. A crucial mechanism through which knowledge diffuses locally is the mobility of technologists and scientists, either across firms, and between firms and academic institutions. However, this is not necessarily true for all localities and all industries. Besides, it remains to be seen to what extent technologists and scientists, by moving across firms, contribute to the creation of a common pool of knowledge, or manage to retain control over their intellectual assets, either personally or along with selected members of the relevant epistemic community. Studying more in depth the career paths of a few key professional figures is therefore an extremely interesting avenue of research.

A second line of research should deal with assessing more carefully the impact of local universities and public research institutes on firms' innovative activities. Our opinion is that the 'spillover' perspective has obscured the wide set of mechanisms through which those actors actually contribute to local and non-local firms' research efforts. These mechanisms ought to be explored by overcoming the far too easy, but obscuring, metaphor of the 'local community', and by studying in some depth the knowledge-based services that academic and public institutions (or individual scientists therein) sell to, or share with, local and non-local businesses. When doing so, more attention should be paid to the large number of club or common property arrangements that situate knowledge flows in between the two extremes of private vs. public goods. This, in turn, would require a big effort to establish an explicit link between the geographical dimension of those knowledge flows and the disclosure rules foreseen in the related arrangements.

In both lines of research, the existing data-sets on R&D, patents and innovation counts will still play a prominent role, according to the new fashion of exploiting them as indicators of knowledge exchange links among individuals and/or organizations, or of knowledge stocks whose accessibility varies with distance (and not just as mere innovation output/input indicators, as was the case with traditional studies on R&D productivity). However, we will need to couple those indicators with additional evidence on the identity and the activities of individual firms and inventors, in order to track the latter's movements in space, as well as their mutual relationships.

In any case, the urge to carry out more, and richer, quantitative analysis must not lead us to avoid the most urgent task, which is that of reassessing our conceptual framework, in order to introduce more sophisticated categories to describe both the content and the property regimes of knowledge flows. Devoting time to such a reassessment will possibly prevent us from running regressions for a while, but it will help to keep at bay the temptation to abuse, once more, the LKS metaphor.

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