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INTRA- AND INTER-REGIONAL KNOWLEDGE SPILLOVERS ACROSS EUROPEAN REGIONS

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Résumé :

The paper takes up a twofold investigation of knowledge spillovers. The first one concerns *intra-regional knowledge spillovers* among regional institutional sectors involved along the innovation process of European regions. The methodology consists in testing a simultaneous system of equations that allows for potential feedback relations between university and business R&D efforts. This approach is motivated by the consideration that the innovation process is no longer linear with scientific discovery as the only source of ideas, but rather circular, sourcing and spreading ideas and knowledge among the actors involved all along the innovation process. Complementary to the investigation of intra-regional knowledge spillovers, the second investigation concerns *inter-regional knowledge spillovers* at the European scale. This issue is tested in considering geographical and technological proximities between European regions by means of a knowledge production function framework that allows for extra regional knowledge inputs. On the basis of our results, concrete policy measures are derived aiming at upgrading the knowledge creation capacity of European regions.

Mots clés : innovation process, knowledge spillovers, geographical/technological proximities

Classification : O31, O18, R11

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INTRODUCTION

When in the 1980s empirical evidence showed that some European regions maintain continuously high growth rates and that, contrary to the expectations of conventional neo-classical growth theories, convergence has ceased at the European regional level, a renewed emphasis was put on knowledge and innovation as engines of growth[1]. While for the neo-classical model of growth, technological change is treated as exogenous, it is endogenously generated by the new growth theory (Romer, 1986, 1990; Lucas, 1988; Grossman and Helpman, 1991; Aghion and Howitt, 1992; etc). Knowledge accumulation through R&D activities constitutes the primary element of endogenous growth and is the main source of increasing returns to production factors. Romer (1986) highlights two main mechanisms to explain increasing returns, namely learning-by-doing and knowledge spillovers. A similar argument is put forward by Krugman (1991) invoking Marshall (1890) in arguing that increasing returns arise from spillovers generated by (1) a thick market for specialised skills, (2) pecuniary externalities through forward and backward linkages and (3) technological or knowledge spillovers.

An important feature of the endogenous growth literature and the so called "new" economic geography is the fact that increasing returns on knowledge and knowledge spillovers may be spatially bounded. In countries or regions where knowledge accumulation is already high, additional knowledge creation may be easier compared to countries or regions where knowledge is scarce. Inducing increasing returns on production factors, continuous knowledge creation enables continuous high growth. Given that R&D activities are largely concentrated in relatively rich regions with above European average levels of high qualification, the persistence of income disparities among European regions may be due, at least partially, to mechanisms underlying the endogenous growth theory (Tondl, 2001).

The observation that increasing returns on knowledge and knowledge spillovers tend to be spatially bounded leads to the main investigation of this paper. Rather than explicitly testing an endogenous growth model, the paper focuses on the central mechanism of endogenous growth, namely knowledge spillovers. The overall question raised and answered in this paper is as follows: To which extent do knowledge spillovers influence the knowledge creation capacity of European regions and what are the implications in terms of policy making?

In order to answer this overall question, it is useful to adopt a distinction between intra- and inter-regional knowledge spillovers. *Intra-regional knowledge spillovers* are considered to arise when actors involved in the innovation process such as universities, the business sector and the government sector tie close links leading to cross fertilisations and feedback

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[1] The foundation for modern theories of innovation go back to Schumpeter (1928, 1935, 1939, 1954) who conceives economic development as the creation of new combinations of productive means which give raise to new products, new processes but also to new markets and organisational forms.

relations[2]. *Inter-regional knowledge spillovers* occur if a given region's R&D effort does not only enhance its own knowledge creation but also contributes to the knowledge creation of other regions. Going into details, when analysing the aforementioned sources of knowledge spillovers and their respective effects on knowledge creation, is obviously impossible within the limits of a single paper. Therefore, the adopted approach is sketchy in the sense that we only give the flavour of the estimated models and concentrate more extensively on implications in terms of policy making.

The rest of the paper is organised as follows. In the next section we briefly discuss first, the concept of knowledge spillovers, second, the importance of proximities for knowledge creation and third, the standard knowledge production function framework. Section two investigates intra-regional knowledge spillovers among actors engaged in the innovation process. Section three tests for knowledge spillovers among European regions and analyses the importance of geographical and technological proximities. The final section sums up and discusses the implications of our findings in terms of policy making.

I. KNOWLEDGE SPILLOVERS, PROXIMITIES AND KNOWLEDGE PRODUCTION

The seminal contribution of Griliches (1979) identifies two major sources of externalities associated with R&D activities, namely rent spillovers and knowledge spillovers. *Rent spillovers* arise because the price of intermediate inputs is not fully adjusted for quality improvements induced by R&D investments. Rent spillovers originate from economic transaction and roughly can be classified into input-related spillovers, investment-related spillovers and patent-related spillovers. "*Working on similar things and hence benefiting from each others research*" is the way Griliches (1992, p. 29) defines *knowledge spillovers*. More explicitly knowledge spillovers occur when knowledge produced by a given actor contributes to the knowledge creation or innovation of other actors. The basic idea is that the creation of new knowledge has positive external effects. These positive effects arise because knowledge is characterised by imperfect appropriability. As opposed to rent spillovers, knowledge spillovers are generally not due to economic transactions but largely depend on face to face contacts.

Despite the fact that from a conceptual point of view the frontier between knowledge and rent spillovers appears to be clear-cut, practically, once an empirical analysis is to be implemented the frontier gets relatively ambiguous. As far as rent spillovers are concerned, Cincera and van Pottelsberghe (2001, p. 6) identify a major reason behind this difficulty namely the fact that "*rent spillovers are approximated through economic transactions which may also be associated with – or imply – some knowledge transfer"*. This paper focuses on knowledge spillovers within and between European regions and concentrates on R&D activities. Thus, since we are concentrating on R&D activities only, it might be the case that the part of knowledge transfer included in traded goods is not covered by our approach. Furthermore, it should be noted that our concept of knowledge spillovers is somewhat larger than the notion of "pure" knowledge spillovers as a pure public, non-excludable and non-rival good. Indeed, we assume that face to face contacts, and close links between actors are necessary in order permit knowledge to spill over.

[2] The extent of intra-regional knowledge spillovers or externalities also depends on the organisation or the composition of the region's underlying productive system in terms of specialisation and / or diversity (Feldman and Audretsch, 1999; Paci and Usai, 1999; Greunz 2004a, 2004b). This aspect is not considered here.

This last reflection naturally leads us to highlight the most important channels of knowledge spillovers. The related literature reflects general agreement on the fact that geographical proximity facilitates knowledge exchange in general and uncodified and tacit knowledge in particular. The channels through which knowledge can potentially flow are various and depend partly on the willingness of regions to foster them. One of these channels is the interaction of employees in social, civic, and professional organisations. Considered to be a major determinant of uncodified knowledge transmission at the intra-regional level, it may also be considered as a channel of knowledge flow between regions. There is no reason for interactions between employees to be regionally bounded. It is however true that distance and language matter. Therefore, one may expect that employee driven knowledge exchanges between regions essentially occur within the national, cultural or linguistic territory and are far less important between regions belonging to different countries. Another possible channel of knowledge spillovers is a common stock of suppliers and / or customers. Kline and Rosenberg (1987) stress the importance of interdependence and dynamic learning across various actors within a linkage and feedback model of innovation. A third channel of knowledge transmission is shown to be the knowledge embodied in traded goods (Grossman and Helpman, 1991, 1994; Coe and Helpman, 1995; Verspagen, 1997).

As far as knowledge spillovers between universities and the business sector are concerned, Varga (1998) identifies several ways of university – business knowledge transfers: formal co-operations and agreements on R&D, industry financed university research centres, faculty consulting in industry, scholarly journal publications and industrial associates programs. Most formal and informal mechanisms of technology transfer and diffusion depend on spatial proximity. This is even more the case for spillovers of tacit knowledge embodied in persons. Local labour markets of scientists and engineers promote local technology transfers since these persons are more likely to move to nearby firms when changing jobs (Bania et al., 1992) and trained graduates may look for their first jobs in an area of the university (Jaffe, 1989). Other forms of university – business sector knowledge transfers are industrial incubators and industrial parks mainly aimed at providing facilities to start-up firms as well as university spin-offs.

Beside geographical proximity, it is assumed that technological proximity favours knowledge spillovers and thus innovative activity. According to this view, at the firm level, the capacity to take productive advantage of another firms' stock of knowledge depends heavily on the extent of technological similarity. The reason for this is that each technology embodies a kind of unique language and concerns a specific set of applications. Researchers in similar technological fields are likely to publish in commonly read journals, browse a common set of web pages and operate in the same professional organisations. Since a region's productive system is nothing else than a set of firms acting in different technologies, spillovers are expected to be higher between regions with similar technological profiles.

A powerful approach to empirically model the characteristics of localised knowledge flows and their influence on regional innovation is the knowledge production function framework initiated by Griliches (1979) and first implemented at the aggregate level by Jaffe (1989). The conceptual framework of our paper is precisely the "Griliches (1979)–Jaffe (1989) knowledge production function" which has been largely investigated in recent empirical literature for the US (Jaffe, 1989; Acs et al., 1991, 2002; Anselin et al., 1997; Varga, 2000), Italy (Capello, 2001), France (Autant-Bernard, 2002), Austria (Fischer and Varga, 2001, 2003), Germany

(Fritsch, 2002), Sweden (Andersson and Ejermo, 2003) and at the European regional level (Greunz, 2002, 2003a).

According to Griliches, innovative input of a given entity *i* is best reflected by new knowledge, which is primarily embodied in R&D efforts:

$$R\&D\ output_i = f\ (R\&D\ input_i) \quad (1)$$

In essence, this knowledge production function can be modelled using a Cobb-Douglas type production function as given by equation (2). Following the above-mentioned stream of literature, we adopt a general version of the Cobb-Douglas production function, which does not impose any restriction regarding returns to scale:

$$R\&D\ output_i = a\ (R\&D\ input_i)^b\ exp^{\varepsilon} \quad (2)$$

Under this formulation, the term *a* is a constant while *b* measures the elasticity of R&D output with respect to R&D input. Taking the natural logarithm of each side of (2) leads to:

$$ln\ (R\&D\ output_i) = ln\ a + b\ ln\ (R\&D\ input_i) + \varepsilon \quad (3)$$

In this paper, innovation of region *i*, that is the output of the knowledge production function is proxied by patent applications to the European Patent Office (EPO). The data come from Eurostat which attributes the patent applications to the living places of the inventors rather than to the locations of the headquarters of applying firms. This procedure has the advantage to reflect more thoroughly the creative capacity of regions and avoids a somewhat artificially concentration of patents in metropolitan areas where headquarters are generally located. In order to account for the region's size, patent applications are expressed in terms of 1000 inhabitants[3]. Patent applications as a proxy for the output of the knowledge production function are produced by R&D efforts, namely the region's R&D expenditures per capita expressed in PPS and deflated by the GDP deflator with respect to the price level of 1990. The basic formulation (3) of the knowledge production function is adapted in the following sections in order to enable the estimation of intra-regional as well as inter-regional knowledge spillovers.

II. INTRA-REGIONAL KNOWLEDGE SPILLOVERS AMONG ACTORS INVOLVED IN THE INNOVATION PROCESS

Initially considered as national or transnational (Lundvall, 1992), the concept of the innovation system has gradually been extended to the sub-national regional level and is now recognised as having an important role to play in economic development policy (Cooke, 1998). The reason for this is that in the context of the ongoing (techno-) globalisation and the emergence of the knowledge based economy the region as a supportive environment for innovation is becoming more and more important. The concept of the regional innovation

[3] However, it should be noted that patent applications as a proxy for innovations have some shortcomings. For several reasons, not all innovations are subject to patent applications. A strategy of secrecy in order to avoid disclosure of new knowledge may be preferred. The high cost associated with patent applications may discourage especially small firms to apply. Moreover the propensity to patent differs across industrial activities and so does the economic value of patents (for a review of patent literature see Griliches, 1990). Despite these shortcomings there is a strong link between patents and innovations (Acs et al., 2002). In any case, patent applications are the only available harmonised innovation measure at the European regional level.

systems is based on the idea that innovations are hardly the outcome of isolated actions but rather the result of consciously planned market motivated R&D efforts jointly realised by a set of interrelated private and public actors. This set of actors, which can be viewed as the region's technological infrastructure, is composed of universities which develop new scientific and technological knowledge, innovative firms that transform these technologies into industrial innovation and the government which provides R&D support.

However, contrary to a conventional wisdom of the "linear model" that, for a long time, viewed innovation as a straightforward path from the laboratory directly to the marketplace, the innovative process follows a complex pattern of interaction. Schematically, university research feeds private business research. And private business research which is also fuelled by diverse types of expertise coming from customers and supplies, feeds back university research (Kline and Rosenberg, 1987).

Moreover, as has become clear by the numerous unsuccessful policy making attempts to imitate Silicon Valley's success story, technological infrastructure alone is not sufficient. The productivity and efficiency of the innovation system heavily depends on the region's characteristics in terms of the qualification level, the willingness to cooperate and the openness and degree of insertion into the world economy.

As far as university and private business sector R&D are concerned, Mansfield (1991) notes that university R&D enhances the stock of basic knowledge, generates increasing technological opportunities across a wide range of industrial fields, and increases the potential productivity of private industrial R&D. However, these opportunities and potentialities do not automatically turn into real effects. While knowledge is clearly a crucial element, in *itself* it does not contribute to economic growth. It has to be incorporated into the production of goods and services. Advances in technological and organisational knowledge have to be absorbed by firms and applied to the production process and organisation of work. Therefore the economic contribution of academic institutions depends on the effectiveness of technology transfer and diffusion to the private business sector. Besides universities and the business sector, the third actor within the innovation system is the government. Government R&D is partly realised in universities but also in national laboratories. The rationale behind government research is not only to satisfy public needs but also to counterplay marked failures in the field of R&D investment such as the problem of imperfect appropriability[4].

As previously stated, technological infrastructure alone is not sufficient. The productivity of this infrastructure heavily depends on the efficiency of technology transfer and diffusion mechanisms and on the region's absorption capacity (Capron, 2002). In order to benefit from existing knowledge sources outside and inside the region, the private business sector must be able to understand and to integrate this knowledge, which is only possible if a minimum level of R&D is performed within the firm (Cohen and Levinthal 1989). Cockburn and Henderson (1998) show that the absorption capacity is dependent on the intensity of R&D performed by the firm, the level of qualification and competence of the workforce, the remuneration of the latter and the capacity to tie close links with the public sector. These factors ensure a high quality internal research but also access to public research performed by universities and the government. Moreover, the higher the quality of human capital, the higher the productivity of internal research provided that strong links are established with public research.

[4] For an overview of the effects of different government policy instruments on private R&D see David et al. (2000).

While there exists a wide range of literature focusing on particular aspects of this innovation process[5], relatively little attempts have been undertaken to explicitly investigate the reciprocal influence of university research and business research as well as their impact on knowledge creation, especially for the European case. For the US case, Jaffe (1989) was the first to consider a simultaneous model of influence. He was also the first to use the Griliches (1979) knowledge production function framework at the aggregate level considering as output and inputs respectively corporate patents and university as well as business R&D expenditures. University R&D depends on a set of structural variables and on business R&D which in turn is a function of university R&D. Jaffe's findings suggest that both industry and university research are an important source of innovation for the business sector. Furthermore, universities induce the location of industry R&D spending nearby. However, neither for his global model nor for the different technical areas, does he find evidence of a significant impact of industrial R&D on university R&D. Inspired by the work of Jaffe (1989), Feldman and Florida (1994) investigate a very similar model but instead of corporate patents, they consider commercial product-innovation citations as a measure of innovative output. They find evidence that both, industrial and university R&D, positively and significantly influence private business innovation. University R&D fuels industrial R&D and contrary to the findings of Jaffe (1989), their estimates indicate that the reverse also occurs, private business R&D positively and significantly influences university R&D. Anselin et al. (1997) broaden the cross-section database used by the former authors and test the system for a sample of 125 MSA[6]. Although the estimated elasticities vary quite a lot according to the specifications, like Jaffe (1989) and Feldman and Florida (1994) they find a positive impact of university R&D and industrial R&D on innovative output. Moreover, university R&D significantly influences private business R&D. Like Jaffe (1989), but contrary to Feldman and Florida (1994) they find no evidence of a significant contribution of private business R&D to university research.

Inspired by the above mentioned studies, this section focuses on the knowledge production process of European regions which has never been investigated. Our analysis should enable us to highlight not only the respective contributions of university and business R&D to innovation but also whether the innovation process is characterised by feedback relations among institutional sectors. Moreover, since the knowledge creation capacity of European less favoured regions is relatively low, it is attempted to identify the leverages that should be stimulated by adequate policy measures.

The investigation is carried out by estimating the simultaneous system of equations illustrated in Figure 1. The base equation A of Figure 1 is the previously explained knowledge production function where total R&D inputs are split into university and business R&D expenditures as follows:

$$R\&D\ output_i = f\,(university\ R\&D_i,\ business\ R\&D_i,\ qualification\ level_i) \qquad \text{(A)}$$

Innovative output which is proxied by patent applications to the EPO is modelled as a function of business R&D and university R&D expenditures. Moreover we control for the qualification level of the working age population. Following Jaffe (1989), the potential

[5] Varga (1998) provides a detailed overview of the literature with regard to university research and regional innovation. Massard (2001) offers a summary of recent empirical analysis focusing on knowledge externalities and the geography of innovation.

[6] The authors also investigate the system for 43 US states in using different measures for the "geographic coincidence index" that aims at correcting for the relative inappropriateness of states for this kind of analysis.

interaction between university and business R&D is captured by extending the base equation (A) with two additional equations that allow for simultaneity between these two variables.

Business R&D$_i$ = f (university R&D$_i$, government R&D$_i$, structure of productive system$_i$, qualification level$_i$) (B)

Equation (B) explains business R&D as a function of university and government R&D, the structure of the productive system and the qualification level of the region's workforce. As far as university R&D is concerned, it has been suggested in the introductive part of this chapter that it fuels business R&D through mechanisms of technology transfer and diffusion. The structure of the productive system, proxied by the employment concentration in industry, is introduced as a control variable in the sense that innovation is believed to be mainly driven by the industrial sector[7]. Business R&D is also assumed to depend on the qualification level of the region's workforce. Both, high and moderate qualification levels are considered. The former is supposed to play an important role in the conceptualisation stage while the latter provides technical assistance at later stages in the innovation process.

University R&D$_i$ = f (business R&D$_i$, government R&D$_i$, qualification level$_i$) (C)

Finally, equation (C) states that university R&D depends on business R&D expenditures, government R&D expenditures and the qualification level of the region's workforce. Since the innovation process is characterised by manifold linkages and feedbacks (Kline and Rosenberg, 1987), private business R&D is supposed to fuel university R&D. Government R&D is another determinant of university R&D. Part of government R&D which is often associated with high risks, is realised in universities. Through this channel, universities may have access to highly promising strategic fields of research which enable them to acquire a specific expertise which in turn gives rise to further research.

The model illustrated by Figure 1 is tested[8] over the period 1991-1996 on an extended sample of 153 European regions covering the entire European Union except the new Länder of Germany and Luxembourg for which the necessary data are not available. The estimates lead to the following observations.

First, the European region's patenting activity depends on both, private business and university R&D. Since university R&D is essentially concerned with the generation of fundamental scientific knowledge its impact on patent applications is lower compared to private business R&D which is more market-oriented. More precisely, on average, a one percentage increase of business R&D investment per capita generates a 0.76 percentage increase of patent applications per 1000 inhabitants. For university R&D expenditures, the elasticity is about 0.14. This result is relatively close to the one obtained by Jaffe (1989). A

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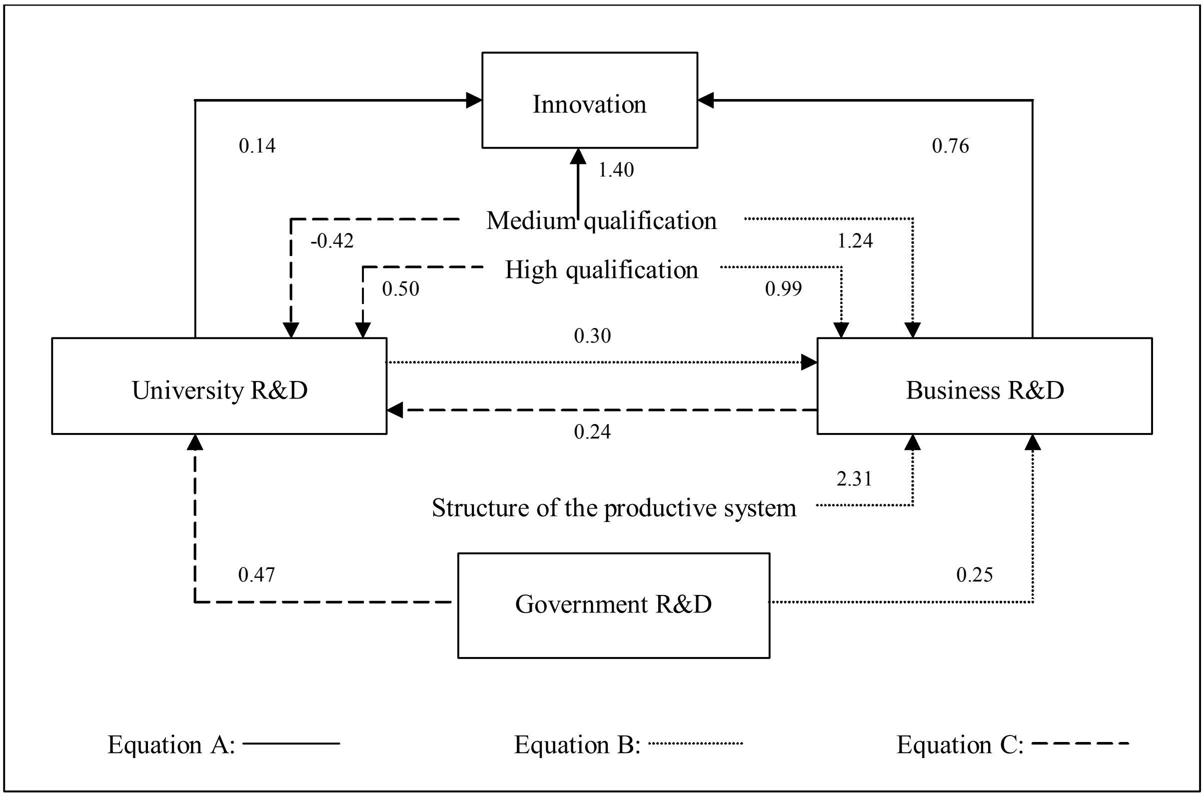
[7] Despite the fact that technological progress in recent years is increasingly generated by the service sector, industrial patenting activity is still predominant.

[8] The system of equations has been estimated by full information maximum likelihood, two stage least squares and three stage least squares. The estimated coefficients obtained by the three estimation methods are statistically similar. The model has also been estimated allowing for different time lags. It appears that patent applications (equation A) are best explained by contemporaneous business R&D expenditures together with university R&D realised three years previous to the application. As far as business R&D is concerned (equation B), contemporaneous university R&D and government R&D with a time lag of five years is the best fitting specification. Finally for the university R&D (equation C), the best fitting formulation is the one which considers as explanatory variables contemporaneous business R&D and tow years lagged government R&D expenditures. For more details see Greunz (2002, 2003b).

second, more fundamental result suggested by the estimates of the model is the cumulative effect of university and business R&D efforts. University R&D induces business R&D and conversely, business R&D fuel university R&D. On average, a one percentage increase of university R&D expenditures per capita leads to a 0.3 percentage increase of business R&D expenditures per capita. At the same time, a one percentage increase of business R&D expenditures per capita generates a 0.24 percentage increase of university R&D expenditures per capita. This result is essential from a policy making point of view and suggests that knowledge spillover mechanisms are at work among the actors involved along the innovation process. Feldman and Florida (1994) came to a similar conclusion for the US case. A third result is that business R&D activities depend on both, the region's endowment of highly and moderately qualified workforce while only high qualification positively influences university R&D. Finally, both, university R&D and business R&D are significantly and positively influenced by lagged government R&D investments.

Figure 1 : The innovation process of European regions



Note: the numbers reported in the figure correspond to the estimated elasticities which are significant at the 5 percent level and heteroskedasticity consistent. For more details see Greunz (2002, 2003b). Source of data: Eurostat.

European less favoured regions and especially the so called "objective 1" regions are characterised by extremely low levels of business and university R&D activities. Given that their innovation system is fragmented and only partially in place, their knowledge creation capacity is poor. In this context it is worth investigating the simultaneous equation model in paying special attention to "objective 1" regions. In order to do so, we adopt a dummy variable approach. A striking observation of this exercise is the *potential* high leverage effect of increased business and university R&D expenditures in "objective 1" regions. While on average a one percentage increase of business and university R&D expenditures respectively generates a 0.39 and a 0.11 percentage increase of patenting activity, the corresponding elasticities in "objective 1" regions are 0.71 and 0.33 percentage increases. The question that naturally arises is how can these potentials be realised? The estimates indicate that an increased industrial activity could substantially increase business R&D activities. In general, and compared to the European average, "objective 1" regions are characterised by a relatively high employment concentration in agriculture. Since for the agricultural sector market and technological opportunities are weak, the growth potential of these regions is relatively low. Although this is not a new discovery, the result confirms that the industrial base of "objective 1" regions is insufficient. As far as university R&D activities are concerned, the government has an important role to play. The impact of government R&D activities in "objective 1" regions on university R&D is about twice as important as the one we estimate for the overall sample. According to our estimates, a one percentage increase of government R&D expenditures generates on average a 0.39 percentage increase of university R&D expenditures. In "objective 1" regions the corresponding elasticity is a 0.87 percentage increase. A major distinctive feature of the innovation process of "objective 1" regions is the finding that an increase of business R&D does not positively influence university R&D while it is clearly an important determinant for the overall sample. As previously stated, in European less favoured regions, the entire innovation process is not yet in place and this appears to be particularly true for the feedback relations between the private business sector and university R&D.

Before investigating inter-regional knowledge spillovers, it is useful to sum up the main findings of this section. In a nutshell, the patenting activity of European regions depends, on both, business and university R&D. The relation between university R&D and business R&D is characterised by feedback relations. While business R&D depends on the availability of highly and moderately qualified workforce, only high qualification positively influences university R&D. For European less favoured regions the impact of an increase of university and business R&D on knowledge creation is potentially higher than for a European "average" region. These potentials could be realised first, by a strengthening of the region's underlying industrial bases, second, by an increase of government R&D activities and third, by an upgrading of human capital.

3. INTER-REGIONAL KNOWLEDGE SPILLOVERS ACROSS EUROPEAN REGIONS

While in the previous section evidence was found for intra-regional knowledge spillovers, this section analyses the issue of inter-regional knowledge spillovers. In other words we wish to investigate whether an R&D effort realised in a given region contributes to the knowledge creation of geographically and / or technologically close regions.

The fact that geographical proximity matters for knowledge spillovers is largely supported by the recent empirical literature. Using US patent citation statistics, Jaffe et al. (1993) found that intra-national and intra-state citations occur more often than one may expect from the distribution of patenting activity. To put it differently, patents are more often cited when the citing and the cited patents belong to the same geographical entity. Jaffe and Trajtenberg (1996) obtained comparable results. An investigation for the Swedish case (Sjöholm, 1996, 1997) indicates that citations to patents originating from more distant countries are less frequent than citations to patents from neighbouring countries. Maurseth and Verspagen (1999) examined whether these findings apply to Europe as a whole and found evidence that there are some regions or clusters of regions that can be characterised as "high-tech" and others as "low-tech".

Besides geographical proximity it is assumed that technological proximity between regions influences innovative activity. Jaffe (1986) can be considered as a forerunner in the field of empirical investigations of technological proximity spillovers. He used firm patent data to compute the distribution of patenting across technology classes in order to evaluate technological similarities between firms. Controlling for industry specific technological opportunities, the author found evidence for technological dependent spillovers. Firms active in research intensive technology groups enjoy higher returns to R&D. Goto and Suzuki (1989) took up Jaffe's approach in order to study technological spillovers for Japanese industrial sectors but used the distribution of R&D investment instead of patents. An alternative method to proxy technological neighbourhood consists in using some kind of input-output tables. The rationale behind this approach is that industries or firms using similar inputs "borrow" similar technologies (Wolff and Nadiri, 1993; Wolff, 1997; Vuori, 1997; Verspagen, 1997).

Although, the related literature reflects a general agreement on the importance of knowledge spillovers due to geographical and / or technological proximity within or between sectors of activity or within a given country or region, few attempts have been undertaken to explicitly test inter-regional spillovers at the European level in a knowledge production function framework. To the authors' knowledge, only Bottazzi and Peri (2003) attempted an empirical investigation in this field. They consider a model in the spirit of the endogenous growth literature and allow knowledge spillovers across a sample of 86 sub-national European regions. Using the average number of patents over the period 1977-1995 and the average total R&D employment / expenditure for the same period, they focused on the estimation of a spatial diffusion pattern and found evidence for knowledge spillovers to occur within a circle of 300 km. Autant-Bernard (2002) investigates the case of French departments and concludes that the innovative activity of a given department is positively influenced by the intensity of research efforts in neighbouring departments as well as the degree of technological proximity shared with the latter.

The aim of this section is to contribute to the aforementioned stream of literature in estimating the impacts of geographical and technological proximities on the European region's innovative activities. Moreover in distinguishing between university R&D, business R&D and government R&D expenditures we intend to identify the institutional sector which contributes most to inter-regional knowledge spillovers.

The analytical framework is the knowledge production function previously explained for which we allow for extra regional innovative inputs. More precisely, when investigating knowledge spillovers in the geographical space the estimated relation may be expressed in the following way:

"home" R&D output$_i$ = f ("home" R&D input$_i$, R&D input of geographical neighbours$_j$) (4)

As in the previous section, R&D output is proxied by patent applications to the EPO which are attributed to the living place of the inventor and which are expressed in terms of 1000 inhabitants. Innovative inputs are not only "home" R&D expenditures per capita but also R&D expenditures realised by geographical neighbours j, $i \neq j$. Since the intensity of interaction is supposed to decline with increasing distance, the latter are weighted by row standardised squared inverse distances[9].

When investigating knowledge spillovers in the technological space, “home” innovative output is a function of “home” R&D efforts but also of R&D efforts realised in technologically close regions. This leads to relation (5).

“home” R&D output$_i$ = f (“home” R&D input$_i$, R&D input of technological neighbours$_r$) (5)

Technological neighbours r, $i \neq r$ are identified by a measure of technological distance developed by Jaffe (1986) which is calculated by means of patent application data to the EPO desaggregated into 118 IPC classes[10]. Since technological neighbours may be geographically very distant, we investigate the distance weighted technological space by applying the row standardised squared inverse distances (w_{ir}) to R&D expenditures of technological close regions.

The simultaneous investigation of the geographical and technological spaces by means of relation (6) enables to highlight how knowledge spillovers behave in the two dimensional space. Relation (6) is a combination of relation (4) and (5).

“home” R&D output$_i$ = f (“home” R&D input$_i$, R&D input of geographical neighbours$_j$, R&D input of technological neighbours$_r$) (6)

The models are tested for the period 1989-1996 using the same cross section time series sample of section 2. As previously we control for the qualification level of the working age population as well as the structure of the region’s productive system[11]. Finally it should be noted that we assume a lag structure of three periods, given that it takes time for research to turn into innovation. In order to determine the best fitting lag between patent applications and R&D investment, several estimates have been performed and the one yielding the highest t-statistic has been retained.

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[9] Formally the weight attributed to the R&D expenditure of region j when investigating patenting activity of region i is given by $w_{ij} = \frac{d_{ij}^{-2}}{\sum_j d_{ij}^{-2}}$ where d is the distance that separates region i and j. The choice of the applied distance decay parameter is somewhat subjective. A larger decay parameter would lead to a sharper distance decay and possibly to a more restricted set of neighbours with appreciable weight. However, similar empirical outcomes were obtained for different decay parameters.

[10] The measure is defined in the following way: $p_{ir} = \frac{\sum_{k=1}^{118} f_{ik} f_{rk}}{\sqrt{\left(\sum_{k=1}^{118} f_{ik}^2 \sum_{k=1}^{118} f_{rk}^2\right)}}$ where p_{ir} is the measure of technological closeness and f_{ik} is the share of a particular patent class k in the total of patents of region i. If the technological profiles of region i and r are similar, p_{ir} is close to one. Conversely, the more the regions are technologically different, the closer p_{ir} is to zero.

[11] Econometric estimations are performed by means of a panel data estimation method that allows for random effects. Given that that we wish to control for the qualification level of the working age population for which information is only available since 1997 the fixed effect panel data method is not appropriate. In order to determine whether the common or the random effect model should be applied, the Lagrange multiplier test derived by Breusch and Pagan (1980) has been performed which is in favour of the random effect model.

Figure 2 illustrates the estimation results for knowledge spillovers in the geographical space (relation 4). Not surprisingly, as in the previous section we notice a strong impact of R&D expenditures on the patenting activity at the infra-regional level. A one percentage increase of total R&D expenditures realised in the "home region" generates a 0.43 percentage increase of its patenting activity. More fundamentally, R&D activities realised by 1st-order[12], 2nd-order[13] and 3rd-order neighbourhoods[14] also significantly contribute to the knowledge creation in the "home" region. However, the extent of knowledge spillovers decreases with increasing distance. While the elasticity of "home" patenting activity with respect to R&D expenditures realised by the 1st- and 2nd-order geographical neighbours is respectively 0.22, it is limited to 0.17 for R&D expenditures performed by 3rd-order geographical neighbours. Thus, the impact of 3rd-order geographical neighbourhood's R&D on the home patenting activity is much lower but also less significant than the ones generated by 1st- and 2nd- order geographical neighbours. R&D efforts realised by 4th-order geographical neighbours has no impact any more.

Figure 2: Knowledge spillovers in the geographical space

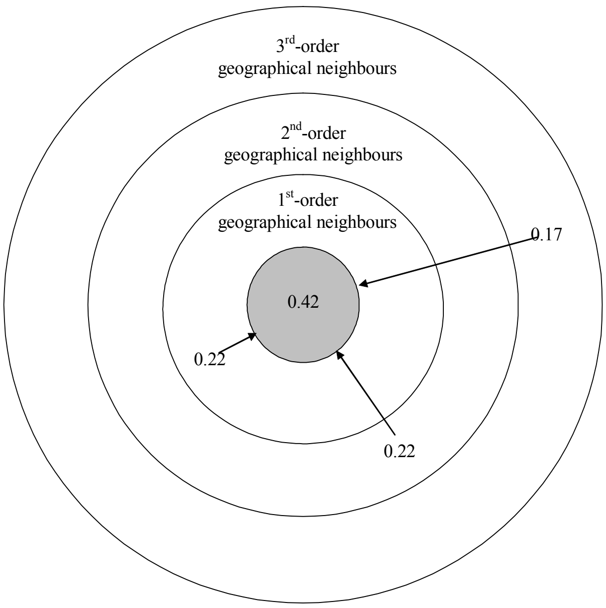
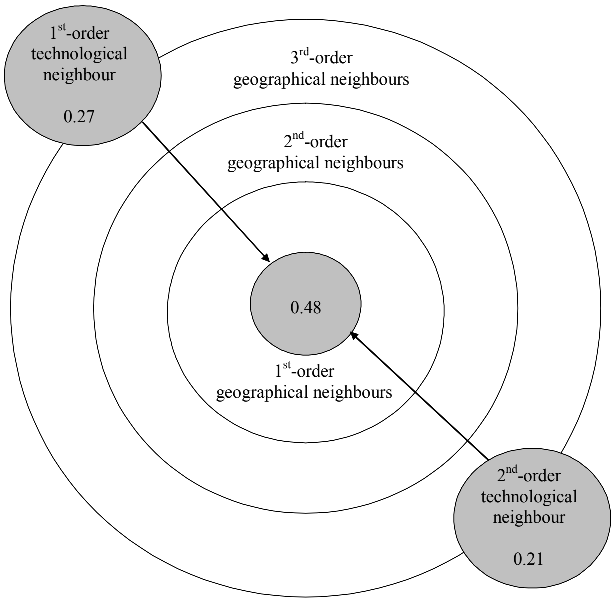


Figure 3: Knowledge spillovers in the distance weighted technological space



Note: the numbers reported in the figures correspond to the estimated elasticities which are significant at the 5 percent level and heteroskedasticity consistent. For more details see Greunz (2003a, 2003b). Source of data: Eurostat.

Despite different modelling approaches and variables it is interesting that the distance within knowledge is found to spill over is not too different from the one estimated by Bottazzi and

[12] 1st-order geographical neighbours are the set of regions with which the "home" region shares a common border. The median distance separating 1st-order geographical neighbours from the "home" region is about 147km.

[13] 2nd-order geographical neighbours are the set of regions which are direct neighbours of the "home" region's 1st-order geographical neighbours. The median distance separating 2nd -order geographical neighbours from the "home" region is about 284 km.

[14] 3rd–order geographical neighbours are the set of regions which are direct neighbours of the "home" region's 2nd-order geographical neighbours. The median distance separating 3rd-order geographical neighbours from the "home" region is about 400 km.

Peri (2003) who found evidence for knowledge spillovers within a circle of 300 km. According to our estimates knowledge spillovers may occur within a distance of 400 km[15].

As previously stated, not only geographical but also technological proximity may induce knowledge spillovers across regions. Figure 3 illustrates the estimation results for knowledge spillovers in the distance weighted technological space (relation 5). A comparison between the knowledge spillovers generated by 1st- and 2nd-order geographical neighbours (Figure 2) and the knowledge spillovers generated by the 1st- and 2nd-order technological neighbours (Figure 3) indicates relatively similar elasticities. Thus, ceteris paribus, this result suggests that technological proximity is as important as geographical proximity for the generation of new knowledge.

Figure 4: Knowledge spillovers in the geographical and distance weighted technological space

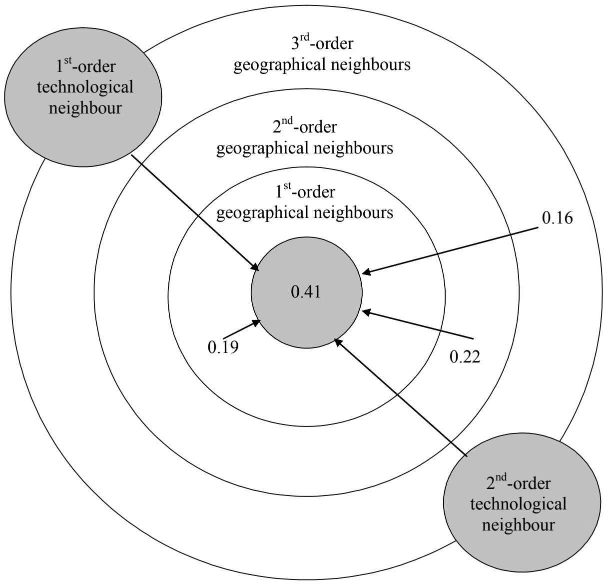
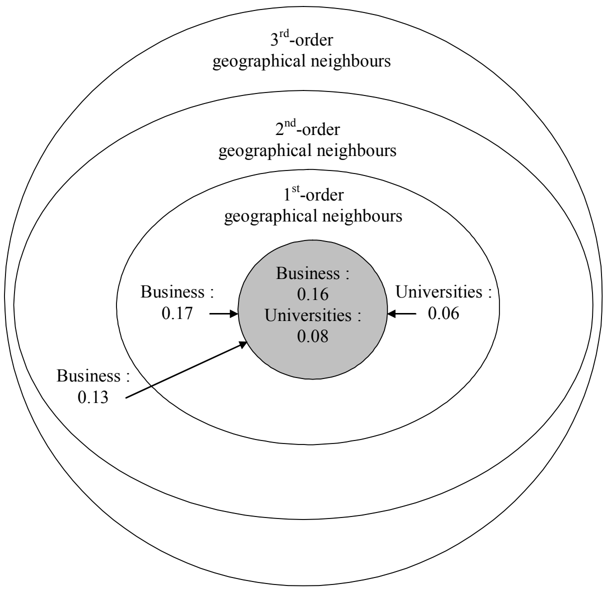


Figure 5: Knowledge spillovers in the in the geographical space generated by different institutional sectors



Note: the numbers reported in the figures correspond to the estimated elasticities which are significant at the 5 percent level and heteroskedasticity consistent. For more details see Greunz (2003a, 2003b). Source of data: Eurostat.

Since geographical and technological spaces are not separated in real world, a more accurate appreciation of the respective relevance of geographically and technologically mediated knowledge spillovers is achieved in simultaneously investigating the two dimensional space. Figure 4 illustrates the estimation results of relation 6 when R&D expenses of technologically close regions are weighted by distance. No significant spillover effect from technological neighbours can be observed anymore. However geographical proximity remains an important input to the patenting activity of the “home” region. What does this mean? In order to interpret this result, let us consider the case of the *purely* technological space which does not account for the distance that separates technological neighbours from the “home” region (not illustrated). In this case, and contrary to the *distance weighted technological space*, 2nd-order

[15] A pertinent question that naturally arises when considering that knowledge spillovers occur within a distance of 400 km concerns the underlying mechanisms. Despite the fact that this distance seems relatively important, it is likely that the mechanism is still face to face interaction. Indeed, in the European core where innovative activity is most developed, the transport system is sufficiently well developed to manage a 400 km round-trip within one day. This assumption can be formally tested using travel time distances between regions instead of geographical ones and will be tackled in future research.

technological neighbours have no significant influence on the home patenting activity. When applying a distance decay function to the 2nd-order technological neighbour's R&D expenditures (Figure 3), the impact becomes significant. Since a distance decay function rises the importance of geographical proximity relative to remoteness, we can deduce that 2nd-order technological neighbours are geographically close to the "home" region. A similar reasoning prevails for the 1st-order technological neighbourhood. For the latter, the elasticity rises and gains significance when R&D expenditures realised by 1st-order technological neighbours are weighted by distance. This indicates, once again, that the geographical distance separating 1st-order technological neighbours from the "home" region is smaller than the average distance between all regions contained in the sample[16]. Now if this is the case, it is not surprising that the estimated coefficients for R&D expenditures of 1st- and 2nd-order technological neighbours in Figure 4 turn out to be no longer significant, meaning that on average geographically close regions are also technologically close in the sense that they exploit on average similar technologies. Despite this observation, the finding does not necessarily mean that geographical close regions specialise in the same types of industries and no inference should be made regarding Marshall (1890)-Arrow (1962)-Romer (1986) (MAR) externalities[17].

Having assessed the existence of inter-regional knowledge spillovers it is worth assessing the main knowledge generating sources. In order to do so, the extent of knowledge spillovers of different institutional sectors is investigated. Given that in section two it has already been shown that the innovation process of European regions is characterised by feedback relations among the institutional sectors involved along the innovation process, we restrict the investigation of inter-regional knowledge spillovers to a more static approach in the sense that we are not modelling a system of equations involving "home" and geographical neighbours' institutional sectors. More precisely, the estimates are based on relation 4 where "home" and geographical neighbours' total R&D expenditures are respectively split up into R&D expenditures realised by universities, the business sector and the government sector. As previously, we control for the qualification level of the working age population as well as for the structure of the productive system.

Figure 5 illustrates the estimation results which indicate that "home" business and university R&D efforts significantly determine the "home" patenting activity while no significant impact can be observed for government R&D. It should be clear from section two that government R&D mainly aims at satisfying public needs and supporting business enterprises' R&D activities. For this reason, the absence of a significant impact of government R&D on the region's patenting activity does not mean that it has no impact at all. As far as the geographical neighbourhood is concerned, R&D expenditures of the business sector located in the 1st- and 2nd-order neighbourhoods significantly contribute to the "home" patenting activity. To a much lower and less significant extent, this is also the case for university R&D realised in the 1st-order geographical neighbourhood. University R&D efforts in higher order

[16] This reflection is strongly confirmed when computing for each individual region the geographical distance with its 1st- and 2nd-order technological neighbours. While the average geographical distance for each pair of regions contained in the sample is 1242 km, the average distance that separates 1st- and 2nd-order technological neighbours from the "home" economy is respectively 895 and 817 km.

[17] MAR externalities arise when firms active in a same industry cluster geographically. In opposite to Jacobs (1969) externalities, it is assumed that only firms active in a same industry are able to internalise these externalities. However, our measure of technological proximity does not allow inferring on this issue since a given technology can be exploited by quite different industrial sectors. Theoretically it is even possible that two regions exhibit a similar technological profile but are specialised in very different industries.

neighbourhoods do not significantly contribute to "home" knowledge creation. No inter-regional knowledge spillovers are generated by government R&D[18].

When relating our results to the findings of Anselin et al. (1997) for the US case, we observe that we obtain the opposite geographical pattern of knowledge spillovers from university and private business research. While Anselin et al. (1997) found no evidence for spillovers from private business sector R&D but only from university R&D, our results clearly indicate that inter-regional knowledge spillovers are essentially generated by the private business sector. It can be shown that the most important reason for these differences is the strong assumption adopted by the authors that R&D efforts instantaneously turn into innovations[19]. This assumption is relaxed in our study since we adopt a lag structure of three periods.

Before discussing the implications suggested by our analysis in terms of policy making, it is useful to briefly sum up the findings of this section. A first result is that knowledge spills over among European regions. R&D expenditures realised by 1st-, 2nd- and 3rd-order geographical neighbours significantly and positively contributes to the knowledge creation at "home". Second, technological neighbours coincide to a certain extent with geographical neighbours. Finally, knowledge spillovers are mainly driven by R&D activities realised by the business sector.

SUMMARY, POLICY IMPLICATIONS AND OPEN QUESTIONS

This paper takes up a twofold investigation of knowledge spillovers. The first one concerns *intra-regional knowledge spillovers* among regional institutional sectors involved along the innovation process of European regions. The methodology consisted in testing a simultaneous system of equations that allows for potential feedback relations between university and business R&D efforts. This approach is motivated by the consideration that the innovation process is no longer linear with scientific discovery as the only source of ideas, but rather circular, sourcing and spreading ideas and knowledge among the actors involved all along the innovation process. By means of dummy variables, the special cases of European "objective 1" regions are examined in more detail.

Complementary to the investigation of intra-regional knowledge spillovers the second investigation concerns *inter-regional knowledge spillovers*. This issue is tested in considering geographical and technological proximities between European regions by means of a knowledge production function framework that allows for extra regional knowledge inputs. The latter are proxied by R&D expenditures realised by geographical as well as technological neighbourhoods of different orders. Splitting up total R&D expenditure in its different components enabled to identify the main inter-regional knowledge spillover generating actors.

[18] Compared to the previously estimated elasticities relative to total R&D for the geographical space (Figure 2), the effects obtained when splitting up total R&D may appear to be relatively limited. As shown in section two, the innovation process is neither linear nor additive but characterised by feedback relations among institutional sectors. Since in this section, feedback relations between "home" and neighbourhood's university, business and government R&D efforts are not explicitly modelled by means of a simultaneous equations framework, it is quite logical that the estimated elasticities of institutional sector's inter-regional knowledge spillovers turn out to be lower.

[19] When we estimate our model assuming that R&D efforts instantaneously turn into innovations, our results are remarkably similar to the ones obtained by Anselin et al. (1997) for their "full" model (p. 436, Table 2). University R&D expenditures realised in the 1st-order geographical neighbourhood significantly contribute to the "home" knowledge creation but business R&D expenditures realised by the 1st- and the 2nd-order geographical neighbourhoods do not influence "home" patenting activity.

A first, not too surprising result regarding intra-regional knowledge spillovers suggests that, on average, the patenting activity of European regions proxied by patent applications to the EPO is heavily influenced by business R&D expenditures and to a lesser extent by university R&D. Since university R&D is mainly concerned with the creation of fundamental scientific knowledge, it is quite logical that the impact on patent applications is lower and takes more time compared to business R&D which is mainly market oriented. A second more fundamental result is that business R&D and university R&D fuel each other, suggesting the existence of intra-regional knowledge spillovers among the actors involved along the innovation process. Moreover, government R&D feeds both, business R&D and especially university R&D. Regarding the role of qualification within the process of knowledge creation, both moderately and highly qualified human capital positively influences private business R&D while only the latter contributes positively to university R&D. Despite the fact that in recent years the innovative activity of the service sector has gained in importance, it appears, on average, that industry is still "the engine of growth".

For "objective 1" regions, potentially high leverage effects on knowledge creation could be achieved by higher business and university R&D expenditures. Both, university and business R&D would benefit from an increase of highly qualified human capital. However, the most important effects on knowledge creation could be realised by a strengthening of the industrial base which appears in most "objective 1" regions to be weak and insufficiently oriented towards high value adding activities. Finally, in "objective 1" regions, government R&D has an important role to play, not only in order to strengthen university and business R&D, but also to develop sufficient absorption and transfer capacities.

As far as the investigation of inter-regional knowledge spillovers is concerned, a fundamental result is that knowledge spills over among European regions. Not only "home" R&D expenditures determine the region's patenting activity but also R&D expenditures realised by the 1st-, 2nd- and 3rd-order geographical neighbourhoods. The 4th-order neighbourhood no longer has any significant influence. Our results also indicate that, on average, geographically close regions share similar technologies. Inter-regional knowledge spillovers are shown to be mainly driven by the business sector. Business R&D expenditures realised in the 1st- and 2nd-order geographical neighbourhoods generate significant inputs to the "home" patenting activity. Despite the fact that university R&D of the 1st-order geographical neighbourhood also matters, the corresponding elasticity is relatively limited and less significant.

From a policy making point of view, the findings lead to the several recommendations. Our conceptualisation of the innovation process suggests that linkages between sources of knowledge are critical and argues favourably for increased interaction between the latter. Therefore, in regions where a sufficient technological infrastructure is in place, policy efforts should be increasingly oriented towards the development of bridging social capital and the constitution and consolidation of an institutional framework that promotes private-private, private-public co-operations. The development of strong bridging social capital is likely to enhance the efficiency of the region's innovation process through a more strategic approach regarding the valorisation of the region's knowledge sources and the region's identity in the context of the global economy.

When all types of knowledge sources are present, the innovation process is likely to be more successful. For European less favoured regions, business R&D especially is still extremely low. However, from the reduced form parameters of the model illustrated in Figure 1, it can be deduced that a direct increase of business R&D expenditures (e.g. through public funding) has little effects on knowledge creation in less favoured regions, a finding that confirms the so-called innovation paradox (Ougthon, Landabaso and Morgan, 2002). The latter refers to the observation that despite greater needs to invest in innovation, less favoured regions experience difficulties to absorb public funds. While relatively poor institutional and organisational capacities may provide an explanation for that, our estimates indicate that a major reason is an insufficient industrial base. Public policy should therefore indirectly act in order to enhance business R&D activities. A strengthening of the industrial base and an increase of the qualification level should be the favourite fields of intervention. From the above consideration, it becomes clear that S&T policies alone may fail to hit the target. Instead, the latter should be integrated into a global, structural policy aimed at building up and reinforcing absorption and transfer capacities by adopting a systemic approach.

Government R&D is justified regarding the public good nature of knowledge and, as has been shown, its important contribution to strengthen business and university R&D. In less favoured European regions, absorption capacity is mainly embodied in government and university R&D. In order to diffuse knowledge within the productive system, public policy should concentrate on the development of tangible and intangible transfer facilities.

The investigation of the apparently abstract concepts of technologically and geographically mediated knowledge spillovers among European regions leads to the following reflections. The existence of inter-regional knowledge spillovers should not be confounded with free lunch. Absorption capacity is a necessary condition for a region to capture knowledge created elsewhere and to benefit from knowledge spillovers. In this sense, public policy should mainly focus on the underlying conditions of absorption capacity such as the development of highly qualified human capital, the promotion of life-long learning, the stimulation of entrepreneurial and community spirit etc, especially in less favoured regions. For the latter, a sufficient level of absorption capacity is a precondition to reach a level of technological assimilation that enables them to understand, to integrate and to exploit technologies developed elsewhere.

Since an important channel of knowledge spillovers is face to face interaction, the stimulation of increased mobility of human capital may contribute to foster inter-regional knowledge spillovers. These policy efforts should not only concentrate on “world-class researchers” which are relatively mobile anyway but entail all actors involved in the innovation process. However, increased attention should be paid to the problem of brain drain especially in the case of less favoured regions.

Inter-regional knowledge spillovers generated by universities have been shown to be relatively limited compared to the ones generated by the business sector. At the same time we have shown that university R&D is an important input to business R&D. In other words and from the perspective of knowledge spillovers, the region’s innovation system is relatively “dependent” on the local / regional universities. Given this observation, universities are more and more considered as - and asked to be - local actors contributing to local development. In order to allow them to increasingly take on regional development as an institutional mission, the question arises, at least for some regions, whether the financial resources assigned to universities are sufficient to permit them effectively to act as “entrepreneurial, pro-active universities”.

Although this paper provides close insight into the mechanisms driving the innovation process of European regions in highlighting the feedback relations between university and business R&D and the impact of inter-regional knowledge spillovers, all facets influencing the innovation process could not be covered. Geographical, organisational, relational and technological proximities among actors are assumed to be the main explanations for the territorially anchored character of the innovation process. While the available data enabled to assess geographical and technological proximities between regions, it is not possible to evaluate the latter at the intra-regional scale. But even more "basic" indicators such as the region's endowment of venture capital, its cross border collaborations or the degree of intra-regional competition could not be constructed with the data available. The constitution of a harmonised European regional data base in these fields would be greatly beneficial not only for research, but above all for the implementation of "regionally tailored" development policies.

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