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Science and knowledge flows: evidence from the French case

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Abstract

Public research is often considered as essential in the technological change process. Yet, few studies have been undertaken to measure its real impact on innovation. The objective of this study is therefore to evaluate the presence of public technological externalities. From the results, it appears that public research produces positive effects both directly in increasing innovation level and indirectly in favoring private research. However, these externalities are not widespread. They are geographically localized. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Knowledge is often considered as a public good (Arrow, 1962).[1] Incentives to research are then reduced, particularly concerning the upstream phases (fundamental research). Despite the patent and license systems which aim at giving back an attractive feature — for the private sector — to the production of new knowledge, the outputs stemming from innovations are but partially appropriable (Romer, 1991).

As a consequence, public sector has a role to play in the production of new knowledge. The objective is then to produce externalities, especially towards the private sector. If this objective is widely acknowledged, few studies however enable to evaluate its achievement. The first objective of this study will be therefore to analyze to what extent public research produces externalities favoring innovation.

Besides, the technological policies implemented are often based on the idea of a local dimension concerning the effects stemming from public research. The creation of technological poles — grouping together in the same place private innovative activities and public research laboratories — stands in this perspective. Close by location would favor transfers of technology from the public to the private sector. Some empirical studies confirm this idea.[2] However, the development of new information and communication technologies tends to blur the notion of geographic distance. A recent study by Beise and Stahl about the German situation throws back into question the hypothesis of an impact due to the geographic distance on the science-industry relations (Beise and Stahl,

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[1] See also Stephan (1996) for a general presentation on this question.

[2] Most of these studies concern the American case (Mansfield (1995); Mansfield and Lee (1996); Acs et al. (1991); Feldman (1994); Rosenberg and Nelson (1994); Zucker et al. (1994); Jaffe and Trajtenberg (1996); Anselin et al. (1997) and to a lesser extent Jaffe (1989)) but we can also find some studies on a European level (Antonelli (1994); Audretsch and Vivarelli (1994); Blind and Grupp (1999); Beise and Stahl (1999); Carrincazeaux (1999)) or about Japan (Kenney and Florida (1994)).

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1999).[3] We can thus wonder whether, in the French case, the externalities stemming from public research are geographically limited or whether other types of proximity, especially sector-based ones, are more important.

The objective of this paper is therefore twofold. It is a matter of both evaluating to which extent public research activities produce externalities and testing the characteristics, either localized or not, of these externalities.

The remainder of the paper is organized into three parts. Sections 2 and 3 indicate the methodological framework, showing how the public externalities as well as their local dimension are modelized, and describe the data. The results are discussed in Section 4. They underscore the following points. First, public research produces overflowing effects on innovation. Then, the local dimension acts differently depending on whether the externalities are captured by the private or the public sector. Public externalities favoring the private sector are geographically limited: private research benefits above all from public research conducted in the same geographic area. On the other hand, concerning the externalities proper to the public sector, the local dimension is not geographic but scientific: externalities occur when research domains are relatively similar and not between neighboring geographic areas. Some brief concluding comments are given in Section 5.

2. The model

The model draws its inspiration from Jaffe's 1989 paper. Public research externalities are measured in the same way, as an external stock of knowledge.[4] Yet, the geographic dimension is tackled differently and an indicator of the role of scientific proximity is integrated to the analysis.

[3] See also Audrestch and Stephan (1996).

[4] An alternative measuring method of knowledge externalities is used by Jaffe et al. (1993). It consists in studying patents citations. Despite its interest, this spillovers measuring method does not seem to be the most suited to the study of public externalities in research in the sense that a whole part of public activity in research does not result in the registration of a patent.

2.1. The public externalities and their local dimension: the basic equation

Public research spillovers[5] are modelized through the means of a knowledge production function (e.g. Griliches, 1979).

$$\log(I_g) = \alpha_1 + \beta_1 \log(\mathrm{RD}_g) + \beta_2 \log(\mathrm{PUB}_g) + \beta_3 \log(\mathrm{PUB}_{v(g)}) + \beta_4 \log(\mathrm{PUB}_{v'(g)}) + \beta_5 \log(\mathrm{PUB}_{S(g)}) + u_1 \quad (1)$$

I is an indicator of the level of innovation. The variable RD measures the private effort of R&D and PUB represents public research. α_1 is a constant term and u_1 a term of random error. Public externalities are therefore modelized, as in Jaffe's study, by introducing in the production of innovation function a stock of knowledge stemming from public research.[6] Yet this model differs from Jaffe's approach in the way of measuring spatial dimension. Indeed, the indicator of geographic coincidence proposed by Jaffe does not seem to be completely satisfactory. It consists in establishing a measure of the geographic concentration of public and private research within American states. We can therefore notice that innovation is more important in the states in which private and public research are geographically concentrated. But it does not show that we are dealing with externalities.[7] By measuring separately the presence of externalities and their geographic dimension, Jaffe's method does not enable to know if private innovation is more affected by the neighboring public research than by public research conducted at the far end of the state, or even outside the state. But to really test the presence of localized public technological externalities, we must prove that

[5] The term "spillover" is used here as a synonym of the term externality. Even if this terminological correspondence is common in knowledge externalities literature, some give sometimes to these two expressions slightly different meanings. Cf. Mohnen (1991) and Cheynet and Fadairo (1998) for more details about it.

[6] This externalities modelization method is traditional just as well in theoretical as in empirical works. You can find it again in the endogenous growth models (cf. Verspagen review of the literature (1992)) as well as in the econometric studies about technological spillovers (cf. the literature review of Feldman's (1998) or Autant-Bernard and Massard (1999)). See also Mohnen (1991) and Cheynet and Fadairo (1998) for a presentation of the different modelization modes of technological externalities.

[7] Cf. Autant-Bernard and Massard (1999).

private innovation benefits more from public research carried out nearby than from public research carried out at a distance.[8]

An alternative method is therefore suggested here. It consists in comparing different geographic levels. The local characteristic of externalities is studied by taking into account not only public research conducted within a geographic area (PUB_g) but also public research carried out nearby ($PUB_{v(g)}$) and finally public research conducted in a more distant neighborhood ($PUB_{v'(g)}$). If public activities in research are geographically limited, then the level of local innovation must be even more affected by neighboring public research than by research carried out at a distance. We can consequently really test the local dimension of externalities.

Besides, this method enables not to be confined to an analysis of the impact of the geographic dimension of externalities. It enables to take into account the possible externalities stemming from public research activities achieved in distant geographic areas but which stand in similar scientific fields ($PUB_{S(g)}$). It entitles then an analysis of the local dimension of externalities both geographically and technologically.

2.2. The endogenous feature of private and public research

The relation modelized by the Eq. (1) underlies the relations between private and public research. Public research can indeed act upstream upon private research. So, a discovery in the public sector can generate new private research expenditure so as to adapt the invention to the activity of the firm and to consumers' needs. Conversely, the public effort in research in a given geographic area can be linked to the level of private research. A certain amount of science-industry relations can result in externalities from the private to the public sector (private grants for public scientists, contracts between firms and public research centers, etc.).

To give an account of these relations, a simultaneous system of equations must be calculated. Private research is analyzed according to public research:

$$\begin{aligned}\log(RD_g) = \alpha_2 &+ \beta_6 \log(PUB_g) + \beta_7 \log(PUB_{v(g)}) \\ &+ \beta_8 \log(PUB_{v'(g)}) + \beta_9 \log(PUB_{S(g)}) \\ &+ \beta_{10} \log(SIZE_g) \\ &+ \beta_{11} \log(KH_g) + u_2 \qquad (2)\end{aligned}$$

The method adopted here to measure the geographic dimension enables to take into account the local dimension of public externalities in research as an explanatory variable of the private research expenditure. Therefore, the variables $PUB_{v(g)}$ and ($PUB_{v'(g)}$) are too included in the Eq. (2). The same applies to $PUB_{S(g)}$. Besides, some variables, specific to the geographic area and likely to influence R&D expenditure are taken into account. The first one is an indicator of the economic weight of the considered geographic area (VA). It is the added value of the area in relation to the French GDP. A human capital (KH) variable is also introduced; it is a ratio between the number of scientists and the total research staff. We can think that research expenditure is all the higher since the number of scientists in proportion to the whole employed staff in research is important. The paid wages must therefore be higher if there are many researchers, which has repercussions on the total expenditure of R&D.

Symmetrically, public research is made dependent on private research:

$$\begin{aligned}\log(PUB_g) = \alpha_3 &+ \beta_{12} \log(RD_g) + \beta_{13} \log(PUB_{v(g)}) \\ &+\beta_{14} \log(PUB_{v'(g)}) + \beta_{15} \log(PUB_{S(g)}) \\ &+\beta_{16} \log(SIZE_g) \\ &+\beta_{17} \log(UNIV_g) + u_3 \qquad (3)\end{aligned}$$

Here again public research activities in geographically or scientifically neighboring areas are introduced as explanatory variables. We also add some variables internal to the geographic area and which enable to explain the level of public research. One of them gives an account of the economic weight of the area (SIZE),[9] the other is a dummy variable which indicates whether there is or not a university (UNIV) within the area.

[8] This method is also used in C. Autant-Bernard (2001) to study geographic and technological spillovers from private R&D.

[9] The variable SIZE is also inserted into the Eq. (1) in order to take into account a possible effect exclusively linked to the size of the geographic area and to avoid much too high residues variability.

3. The data

3.1. Innovation output

The retained indicator is nothing else than patents.[10] This indicator of innovation, even if often used, raises questions. We can, without aspiring to exhaustiveness, pick out two main difficulties. On the one hand, there is a gap between patents and innovations: all innovations do not lead to the registration of a patent[11] and conversely all patents do not result in an innovation.[12] On the other hand, the value of a patent is not always identical but we have to consider that a patent is equivalent to an innovation unit.

Despite these deficiencies, patents present a certain amount of features, which make of them a good innovation indicator. First of all there is a close link between patents and inventions.[13] Next, patents are submitted to an administrative procedure, which guarantees an exhaustive database on the one hand and limits the risks of statistical errors on the other hand. In other respects, Duguet notices that: "Patents and licenses are part of the principal determinants of radical innovations, which are themselves the only significant determinants of the increase of the global productivity of factors" (Duguet, 1999, p. 51). Thus, patents give an account of the essential of innovation in the sense that they are representative of innovations which are the sources of productivity gains.

3.2. Private R&D and public research

Private effort in research is measured by the internal expenditure of R&D.[14] The patents being observed for the year 1996, R&D expenditure effected in 1993 is therefore retained in the model. Patent data are smoothed for three years (1996 patents are an average of patents registered during three years). So, the 1994–1996 innovations are explained by the 1993 R&D level. This assumes a lag structure between the moment when R&D takes place and the moment it leads to an invention. We can indeed consider that an investment in research needs time to materialize through the registration of a patent.

Public activity in research is also measured for 1993. However, it infers a slightly different hypothesis as for the lag structure, since publication data are also smoothed for 3 years. Therefore, the hypothesis of a temporal gap a little longer for public research than for private research is made. Moreover, public research is not evaluated through the means of public expenditure. It is indeed impossible to know with precision the public expenditure in research at a local level. The amount of credits granted by each different administrative level (state, region, and department) is known but it is impossible to know how it is precisely divided up on the local level. It is, therefore, necessary to use another indicator of public effort in research. Scientific publications listed by the OST are being used here.

The publications are without doubt the most significant production of public research. Written communication, whatever the way (written text, computer...) represents indeed one of the typical products of a research activity.[15] Besides, even more than public expenditure, publications represent a knowledge diffusion channel and therefore a preferential indicator of technological externalities.

Yet, this indicator is only an approximation of public effort in research. As for patents, the question of the value of these publications can be raised. Moreover, the activity of public scientists does not only amount to written and codified communication in pub-

[10] Source: OST, 1994, 1996, 1998 (Observatoire des Sciences et des Techniques).

[11] The innovation survey of the SESSI (Ministry of Industry) estimates at 30% only the part of innovation covered by the registration of a patent.

[12] These patents would represent, according to scientific studies as well as according to the common knowledge of the people in the profession (INPI, OEB...), almost 50% of the total of patents. Thus, only half of the patents would really reflect an innovation (Guellec and van Pottelsberghe, (1999)). We will have to remain aware of this gap between patents and innovation in the interpretation of the results.

[13] In the course of the last two centuries, all major inventions have resulted in the registration of a patent. The steam engine, the telephone, all these major inventions have been patented. Besides, we can think that patents definitely represent innovation in the sense that they entail a cost. So firms accept this cost if they envisage an application which must bring profits covering the costs.

[14] Source: R&D survey conducted by the Ministry of National Education of Higher Education and of Research and Technology (1993), Arghibugi (1992).

[15] Cf. the OST Report (OST, 1998).

lications form. Training, assessments are other important dimensions. Besides, the bibliometric statistics has got limits. The selection of the type and sources of documents as well as the counting methods have a significant influence on the data (see footnote 14). Furthermore, private sector can, itself, be at the origin of publications. The data we have at our disposal does not enable to achieve such a distinction. The OST indicates nonetheless that only 5% of the publications come from the private sector. We can consequently consider that publications constitute a good approximation of public research. A table showing the means and standard deviations of the variables is given in Appendix A and B.

3.3. The geographic unit

The geographic area g is the department,[16] $v(g)$ represents the bordering departments of g and $v'(g)$ the bordering departments of v. $\mathrm{PUB}_{v(g)}$ is constructed by multiplying the publications data by a binary matrix composed of 1 (when it concerns bordering departments) and 0 (when they are not bordering departments). In the same way, a matrix of the bordering of the border departments is used to calculate $\mathrm{PUB}_{v'(g)}$.

It then comes down to observing the relation between the production of innovations of a department and the public research effort carried out locally and on the periphery by defining concentric areas around the department. Externalities are studied by testing the possible effect of local research and of neighboring departments' research on the innovation output of the department. It is nonetheless uncertain that this geographic level is the most relevant to give an account of local externalities. If some local technological consequences exist, it is likely that, concerning a certain number of cases at least, they do not occur between departments but at a subtler level. Nevertheless, departments constitute an acceptable geographic level. It is the smallest administrative division for which the whole data is available. It is besides a relatively coherent level in the sense that departments represent essentially a large town and its urban agglomeration. This scale presents therefore a certain homogeneity.

3.4. The scientific coincidence

Externalities do not necessarily pass in transit through a geographic proximity. We can even think that it is above all the fact of being in the same technological field that matters. That is, this very dimension which is taken into account by the variable $\mathrm{PUB}_{S(g)}$. It represents the number of publications of the nearest scientific neighbor of g. A matrix of scientific proximity is built on the basis of an indicator of "similarity" between departments. The profile of each department's public research is determined. Vectors of departments' scientific position are created thanks to the publications carried out in the different scientific fields. A measure of the correlation of these vectors[17] enables then to determinate which is, for each department, the nearest neighbor in the scientific area.[18] We can thus measure the impact, on the innovation of area g, of public research carried out at a distance but in the same scientific field.

4. The results

4.1. Few comment on the estimation method

Limited dependent variable models are frequently used when the explained variable is measured by patents. It is due to the fact that, often, a high number of observations comprises zero value. The data used here is nonetheless aggregated (no sector-based decomposition and data smoothed for 3 years as for patents and publications) in such a way that this problem does not occur.[19] According to the rank condition, each equation of the model is perfectly identified (cf. Maddala, 1992). On the other hand, we

[16] Departments are French administrative units. All in all, the study concerns the entire French departments, with the exception of overseas regions and Corsica for which the notion of geographic distance is critical and can not be tackled with the method chosen here; that is to say a population of 94 departments.

[17] If we note S_1 the scientific position vector of the area 1 and S_2 the scientific position vector of the area 2, the scientific similarity between the two areas is given by: $[S_1S_2]^2/([S_1S_1][S_2S_2])^{1/2}$.

[18] Jaffe (1986) builds up a similar indicator for private research thanks to patents registered in different technological fields.

[19] Besides, it is not obvious that, even in the presence of an important amount of null observations, resorting to a tobit model is appropriate. Cf. Johnston and Dinardo (1997) for a discussion on this question.

are confronted with a simultaneity bias. Then, it is impossible to effectuate ordinary least squares[20] unless we do suppose that the endogenous variables are independent from terms of error, that is to say that the term of error u_1, u_2 and u_3 are not correlated between each other. To avoid such a restrictive hypothesis, three stages least squares are implemented.[21] Results from ordinary least squares are given for information.

4.2. Public research influence on innovation

Table 1 gives the results obtained for the equation of patents. Non surprisingly, the number of patents is significantly linked to the level of private R&D as well as to the size of the geographic area.

As for public research externalities, we can make three remarks. We can first notice that coefficients decrease according to distance. Public research modifies local innovation especially since it is carried out nearby. Only PUB_g has a significant influence on I_g, whereas $PUB_{v(g)}$ and $PUB_{v'(g)}$ are non-significant. So, it appears clearly that public research produces some geographically localized spillovers. On the other hand, $PUB_{S(g)}$ has no significant effect. Thus, we cannot find any evidence of spillovers from public research conducted at a distance, but in the same scientific field. Scientific proximity would not compensate for the lack of geographic proximity.

However, the results obtained here as regards externalities must be cautiously interpreted. Indeed, the patents, used as a measure of innovation, include both private and public patents. We cannot distinguish the patents registered by the private sector from the patents registered by the public sector. Therefore, the significant value of the parameter of PUB_g does not necessarily reflect the presence of externalities. We can not precisely know to which extent public research in a given geographic area modifies the private innovation of the same geographic area. This problem is solved thanks to the examination of Eq. (2). Besides, the absence of significativity of the variables $PUB_{v(g)}$ and $PUB_{v'(g)}$ can express two distinct phenomena: either neighboring public research does not produce any spillover, or, its effect is taken into account more upstream, through its relations with private research. This uncertainty is cleared up in Eq. (3).

Table 1
Level of innovation according to private and public research[a]

Dependent variable: patents logarithm	OLS adjusted-R^2: 0.889	3SLS adjusted-R^2: 0.683
Constant	−9.22 (1.018)***	−3.843 (1.056)***
RD_g	0.342 (0.048)***	0.476 (0.097)***
PUB_g	0.063 (0.043)	0.200 (0.098)**
$PUB_{v(g)}$	0.033 (0.035)	0.050 (0.061)
$PUB_{v'(g)}$	0.028 (0.040)	0.016 (0.068)
$PUB_{S(g)}$	−0.027 (0.027)	−0.047 (0.053)
$SIZE_g$	0.696 (0.122)***	0.106 (0.094)

[a] The standard deviations are given by the figures in brackets.
** Significant to the threshold 5%.
*** Significant to the threshold 1%.

4.3. Public research effect on industrial R&D

Table 2 summarizes the results obtained for the second equation. The variable KH_g has a negative influence on RD_g. The idea that research expenditure is all the more important because the level of human capital is high is not validated. It is quite surprising since the majority of R&D expenditure is for personnel.

Table 2
Level of R&D according to internal and external public research[a]

Dependent variable: logarithm of R&D private expenditure	OLS adjusted-R^2: 0.757	3SLS adjusted-R^2: 0.643
Constant	0.644 (2.350)	14.131 (1.747)***
PUB_g	0.252 (0.086)***	0.630 (0.113)***
$PUB_{v(g)}$	0.098 (0.069)	0.205 (0.080)**
$PUB_{v'(g)}$	0.190 (0.079)**	0.222 (0.092)**
$PUB_{S(g)}$	−0.045 (0.055)	−0.049 (0.074)
$SIZE_g$	1.388 (0.205)***	0.205 (0.130)
KH_g	−1.658 (0.367)***	−1.867 (0.435)***

[a] The standard deviations are given by the figures in brackets.
** Significant to the threshold 5%.
*** Significant to the threshold 1%.

[20] It would be possible in the case of a recursive system, which is not the case here.

[21] More precisely, two kinds of estimation were implemented. Firstly, three stages least squares were only made on Eqs. (2) and (3). Indeed, only Eqs. (2) and (3) require 3SLS. The predicted values are then inserted in Eq. (1). But doing so, the estimated standard errors are not the right ones. For this reason, estimations were also made applying 3SLS on the whole system. As we can expect, the results are quite similar. The 3SLS results given in Tables 1–3 are those obtained with the first method.

This result may be due to the special construction of the variable KH_g. In several small areas, the research staff is composed of only one scientist. Then, human capital ratio is very high (100% of research staff are scientists), whereas R&D expenditure are low. This could explain the negative correlation between RD_g and KH_g.

Furthermore, there is strong evidence of the presence of public externalities. Private research is positively and significantly correlated to public research within the same geographic area. Likewise, the geographic dimension appears again. The coefficient of PUB_g is higher than the coefficients of $PUB_{v(g)}$ and $PUB_{v'(g)}$. Moreover, private research is not affected by the public research conducted at a distance even if the research fields are alike. However, contrary to the Eq. (1), public research conducted in the periphery has a significant influence. The decreasing effect with distance seems then to be less distinct than in Eq. (1). The role of distance seems to depend on the place where we are situated in the innovation process. Upstream, in the research phase (Eq. (2)), geography plays a less important role than downstream, at the time of innovation (Eq. (1)). Externalities would be more localized at the time of innovation while, during the research phase, externalities would be captured more easily, even at a distance. We can acknowledge here the results obtained by Mansfield (1995). He notices indeed that geographic proximity is more important for applied research than for fundamental research. The firm and university staff would interact more for applied research, hence, the necessity of being localized nearby.

So, public research produces localized externalities on innovation, both directly as Eq. (1) shows and indirectly through its effect on private research (Eq. (2)). Thus, in the first regression, we underestimate the role of public research. Not only does it directly influence local innovation but also, it produces effects on private research, which enables indirectly to increase innovation. This indirect effect occurs as well thanks externalities proper to public research, despite quite different mechanisms.

4.4. Research externalities specific to the public sector

The results obtained for private research can not be found again when public research is being studied (cf. Table 3). Private innovation benefits from local public research but the opposite is not true. There would be no private sector externalities towards public research. This absence of repercussions from private to public research is opposite to the results obtained in the American case. Most American studies (Jaffe, 1989, Acs et al., 1991 and above all Feldman, 1994) conclude that there is a self-reinforcement dynamic. Private research is localized close to universities and conversely, public research is localized where the level of private research is high. Such a behavior does not appear in the French case. Besides the difference in method, we can think that it results from the differences in the national systems of innovation. In the US, university research is financed for a noticeable part by capital stemming from industry. Moreover, firms tend to favor the financing of neighboring universities (Jaffe, 1989). This explains the link between the location of private research activities and the location of universities. On the other hand, in France, private financing of public research remains unusual. Public research is above all situated upstream whereas the US has an applied research tradition (Rosenberg and Nelson, 1994). Now, externalities are by definition more numerous from fundamental research towards applied research than the other way. It is, therefore, not surprising to notice the absence of influence of private research on public research in the French case.[22]

Table 3
Level of public research according to private research and external public research[a]

Dependent variable: logarithm of scientific publications	OLS adjusted-R^2: 0.822	3SLS adjusted-R^2: 0.782
Constant	−8.719 (2.057)***	1.604 (2.242)
RD_g	0.260 (0.102)**	0.028 (0.225)
$PUB_{v(g)}$	−0.107 (0.075)	−0.053 (0.088)
$PUB_{v'(g)}$	−0.106 (0.085)	−0.093 (0.094)
$PUB_{S(g)}$	0.169 (0.057)***	0.189 (0.062)***
$SIZE_g$	0.812 (0.258)***	0.511 (0.139)***
$UNIV_g$	1.674 (0.316)***	2.481 (0.422)***

[a] The standard deviations are given by the figures in brackets.
** Significant to the threshold 5%.
*** Significant to the threshold 1%.

[22] This confirms Grupp's results (1996), according to which European countries would have less strong relations between firms and science than the US or Japan.

An urban effect appears through the variable SIZE. Public research is positively linked to the economic importance of the area. It is also correlated to the presence of universities within the area. This result square with the expectations, considering in particular the public research indicator used. Publications are indeed the reflection of a public research, which usually gets through university works. We can, therefore, think that the presence of a university is crucial to have a high level of publications.

If we study now public research external to the department, we learn a great deal from the results obtained. The presence, nearby, of an intense public research is not positive for the local public research. The coefficients of $PUB_{v(g)}$ and $PUB_{v'(g)}$ are not significant. Their negative sign would suggest that neighboring public research is harmful. It would reflect the focused distribution of public activities in research. When there is a public research concentration nearby, few means are granted to the department itself.

Yet, some externalities proper to public research also exist. If local public research seems not affected by neighboring public research, it is on the other hand sensitive to the public research conducted in the same scientific disciplines. $PUB_{S(g)}$ exerts a positive and significant influence on PUB_g. So, public research would not only produce consequences for the private sector. Positive externalities occur within public research. We find evidence that those spillovers are associated to scientific proximity and not to geographic proximity. However, the significant effect of $PUB_{S(g)}$ must be interpreted carefully. This could merely be telling us that regions that perform research in expensive technological areas spend more on research.

5. Conclusion

This study confirms the presence of technological externalities stemming from public research activities and highlights their positive impact on innovation. These externalities occur both directly and indirectly. Public research affects innovation directly in the sense that this latter is significantly correlated to the external stock of public knowledge. But public research also produces more indirect consequences on innovation. It favors private research on the one hand and public research on the other. Private effort in research is indeed stimulated by the presence of an important public research activity. But, public research externalities can also be picked up by the public sector itself, which favors the development of public research and so, indirectly innovation.

So, public research produces positive externalities on innovation. Yet, these latter are not widespread. They are limited either in the geographic space or in the scientific space. The geographic location of public spillovers can be observed as much on innovation as on private R&D. On the other hand, for the externalities specific to public sector, what matters is not neighboring research but research carried out in close scientific fields.

However, this last result needs to be deepened. The measuring method of the sector-based dimension is not completely satisfactory. It does give an account of the spillovers proper to public research, but it is not very well adapted to the study of externalities towards the private sector. It is indeed unlikely that public research acts in a totally diffuse way on innovation or private research. On the contrary, we can think that externalities are specific to a sector. It is, therefore, surprising not to observe a sector-based effect when the consequences of public research towards private sector are being studied. A real analysis by scientific fields would therefore be necessary to test precisely the sector-based dimension of public technological externalities. This would besides enable to identify the sector-based characteristics of science-industry relation.[23]

Finally, if this study shows the existence of public research local spillovers, it does not explain why local dimension matters. So far, few are the studies dealing with this question. The results obtained by Almeida and Kogut (1997) and by Zucker et al. (1994) indicate that inter-individual relations are essential vectors of localized knowledge externalities. It is necessary to develop the analysis in this sense in testing the role of interactions between private and public research on the one hand and in trying to determine the nature of these interactions on the other hand. It would enable at the same time a better understanding of the mechanisms of knowledge transfer and beyond, more efficient technological policies, based on the complementarities between public and private research.

[23] Cf. Grupp (1996) and Mansfield (1991,1998).

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Appendix A. Data construction

1. For patents, the database relies on the publications of European patents requests (EPAT) which are collected in a file constituted by the National Institute for Intellectual Property. The Science and Technology Office (OST) adds to this database the requests for patents linked to the Patent Corporate Treaty procedure. In order to lessen sporadic effects, the counting method is an average on 3 years. For each of these patent requests, the location of inventors and depositors is mentioned. The patent is assigned to the inventor's address, which is the most coherent to measure the location of innovation. Indeed, taking into account the address of the depositor would bias the location in favor of Paris area where numerous head offices are situated. Finally, when patents result from the research of many inventors localized in different areas, there is a fractional counting according to the number of inventors.
2. R&D expenditure stems from the R&D survey carried out by the Ministry of Research. It concerns the internal expenditure of research, that is to say R&D executed by the firm itself. Contrary to the innovation survey of the Ministry of Industry used in some studies dealing with econometrics of innovation (Duguet, 1999), it is not conducted for a firm sample. It focuses on all the firms (having more than 20 employees) which carry out some R&D and employ at least one full time researcher. The location (region and department) is subjected to a systematic coding. This database is then appropriate to deal with the question of local dimension of technological externalities and enables a comprehensive analysis of the French case.
3. The variable called "human capital" is also constructed on the database of the R&D survey. It relates the number of researchers to the total staff employed in research. In other words, it measures, for each geographical area, the proportion of scientists relatively to the whole research staff (scientists, technicians, administrative staff, etc.).
4. The scientific publications are listed by the Science and Technology Office (OST) which have got a simplified version of the Integrated Citation File (ICF). They are filed into eight scientific fields and, as for patents, an average on 3 years is calculated. For each publication, the location of each author is known. However, there can be many authors, not necessarily localized in the same department. In that case, as for patents, a fractional counting is used, depending on the number of co-authors.

Appendix B. Data description

Variable	Mean	Standard deviation	Minimum	Maximum	Cases
I_g	3.198	1.332	−0.404	6.365	94
RD_g	12.552	1.810	6.867	16.939	94
KH_g	3.566	0.264	2.875	4.409	94
PUB_g	3.414	2.274	−1.096	8.576	94
$\text{PUB}_{v(g)}$	6.286	1.452	2.354	9.122	94
$\text{PUB}_{v'(g)}$	7.146	1.231	3.059	9.355	94
$\text{PUB}_{S(g)}$	3.566	2.266	0.277	8.576	94
PT_{vg}	0.668	0.171	0.139	0.949	94
SIZE_g	10.905	0.857	8.878	13.595	94
UNIV_g	0.500	0.503	0.000	1.000	94

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