On Specifying Heterogeneity in Knowledge Production Function

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Abstract

Motivations for the use of spatial econometric methods for the estimation of the patent equation at the regional level are usually data-driven. Theoretical arguments for the spatial concentration of innovative activities rely on the tacit character of knowledge, according to which some knowledge can be exchanged only through face-to-face contacts and hence within short distances. However, factors other than knowledge spillovers might influence the spatial clustering of innovative activities as well. Accordingly, the omission of these factors from the patent equation, may lead to wrong conclusion, qualifying as spillovers what actually is the effect of other, omitted, information. A Generalized Additive Model, in which a non-linear spatial trend is added to the standard patent equation, is here estimated. Once spatial heterogeneity, captured by the spatial trend, is accounted for, evidences of spillovers disappear.

1 Introduction

The Griliches-Jaffe [Jaffe, 1989] formulation of the Knowledge Production Function (KPF) has become a leading approach to analyze

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the extent to which knowledge externalities are geographically localized at the regional level and the increasing popularity of spatial econometric methods has undoubtedly contributed to this. At the empirical level, the choice of spatial econometric models in a cross-regional framework is usually, strongly motivated by the detection of spatial autocorrelation in data. On the other hand, at the theoretical level, a spatial extension of the KPF is justified by the presence of Localized Knowledge Spillovers (LKS) [Audretsch and Feldman, 2004].

The KPF framework can be summarized in a linear relationship between regional patent applications, the output of innovative activity, and R&D expenditures by private firms and universities, both in the region and in the neighbors. In this paper it is argued that the evidences of LKS arising within such a framework might be misleading, as a consequence of endogeneity and omitted variable bias problems in the specification. In more detail, results are biased on the one hand, by the omission of information on market potential, which, being highly correlated with both R&D and patenting activity, causes R&D endogeneity and, on the other hand, by the omission of spatial heterogeneity.

Interpretation of the role of spatial heterogeneity is straightforward: innovative activity at the regional level is not only the result of specific investments, bu also and even depends on characteristics which impact R&D investments productivity at the regional level. Being these characteristics linked with past history of the region, with the technological path, with the level of social capital and other unobservable variables, they are usually omitted causing wrong inference about LKS. Furthermore in this paper it is used a different indicator for university knowledge in order to disentangle the real contribution of academic knowledge to the production of new innovations.

Using data on the high-tech patenting activity of 232 NUTS II regions in 2005-2006, a patent equation is estimated using a negative binomial model. Spatial heterogeneity is further introduced adding to the specification a non-linear smooth trend, function of geographical coordinates, resulting in a semi-parametric specification. Results clearly show that the semi-parametric Generalized Additive Model fits better than the parametric Generalized Linear Model and evidences of LKS disappear once heterogeneity is introduced. Moreover, the market potential proves to be an important determinant of regional concentration of innovative activities.

In the remaining of the work specification issues are first discussed from both a theoretical and an empirical viewpoint in section 2. The empirical model is discussed in section 3. Results are summarized in section 4. Conclusion follows.

2 Space, heterogeneity and LKS

Within the Geography of Innovation literature [Audretsch and Feldman, 2004], special attention is payed to knowledge spillovers in an attempt to explain the determinants of geographical clustering of innovative activities. The existence of positive externalities generated by the knowledge transfer between organizations and/or institutions explains the willingness of innovative firms to co-locate in places from which knowledge can be easily accessed. This, in turn, determines regional differences in innovative activity [Jaffe et al., 1993] and, eventually, in economic performances, raising the issues of what are to be considered relevant knowledge sources and to what extent knowledge spillovers are localized. In considering the first issue, it is acknowledged that firms are the main investors in research, and thus a primary source of knowledge, accompanied by universities [Jaffe, 1989]. Concerning the geographical scope of knowledge spillovers, arguments in favor of localized knowledge refer to its character of "stickiness" [von Hippel, 1994]. Although the revolution of communication technologies has depressed the cost of transmitting knowledge, any part of it is transmitted only through face-to-face contact and frequent interactions. Admittedly, low distance is however not a sufficient condition for knowledge transfer as institutional and organizational barriers [Boschma, 2005] may also prevent knowledge flows.

The Jaffe's [1989] formulation of the knowledge production function (KPF) has thus become a landmark in this literature because, while suggesting a shift to areal unit of observation to capture inter-firms spillovers and extending the original Griliches' [1979] formulation to include third-parties research, easily allows to be modeled with spatial econometric methods in order to capture interregional externalities [see for example Greunz, 2003, Moreno et al., 2005]. Empirical evidences using such a framework [Anselin et al., 2000, Barrio-Castro and García-Quevedo, 2005, Fritsch and Slavtchev, 2007, Piergiovanni and Santarelli, 2001] seem to confirm the theoretical hypothesis. The described approach has been subject to criticisms, however, on both the theoretical and empirical perspectives.

At a broader theoretical and conceptual level Breschi and Lissoni [2001], elaborating on Geroski's argument [Geroski, 1995] that standard methods do not allow to distinguish pure externalities from knowledge flows mediated by market, denote how knowledge tacitness is far from being the only explanation to the concentration of innovative activities. According to authors, alternative explanations for spatial clustering of innovative firms may ground on the presence of a local market for technologies as well as of specialized suppliers of technology. A developed market for technology, matching demand and supply of technologies, is likely in fact to increase the market value of a patent, making it more convenient for innovative firms to locate within short distances from that market. The development of these markets however requires the coordination of activities of different actors at different institutional levels, as well as characterizing skills and expertise. For both it is necessary time: on the one hand to bridge institutional distances between agents with different purposes and objectives and, on the other hand, for the development of such capabilities [Lamoreaux and Sokoloff, 1999]. Also the presence of specialized suppliers of technologies is expected to encourage co-location of innovative firms, as a consequence of the reduced complexity of the innovative processes. New technologies may in fact easily be acquired into the market rather than produced internally, which usually requires more time and efforts. This critique inevitably questions the role of universities in the process of knowledge spillovers. Although recognizing the valuable source of knowledge universities actually represent, not necessarily the knowledge produced by universities freely spills over the borders of the institutions. Mansfield [1995] documented how firms mostly demand applied research, interacting with universities by mean of market transactions rather than occasional face-to-face contacts in which knowledge spills over. Accordingly, the motivations for the uneven spatial distribution of innovative activities should be traced back in the past history and in differences between technological development paths at the local level more than in the tacitness of part of knowledge.

At the empirical level, it has been argued that coefficient estimates of the patent-research relationship are biased because of the omission of relevant variables strongly related to both research investments and patenting activity [Bottazzi and Peri, 2003]. Examples of these variables are the market potential of a region and generic factors influencing R&D productivity. The market potential, meaning with this a measure of the market share which can be accessed by within the region, is expected to be positively correlated with patents, simply because innovative firms might be willing to locate near the market in which to sell their innovations. But a positive correlation is also expected between the market potential and investments in research, as long as higher levels of production are associated with higher propensities to invest in research. More important, patents and research investments at the regional level are both positively correlated with the productivity of research investments. On the one hand because higher productivity of inputs means higher levels of outputs and, on the other hand, because higher productivity further attracts investments in research.

Furthermore, the omission of relevant variables causes misleading inference not only relative to the so-called “internal effects” coefficient but also with respect to “external effects”, always qualified as interregional spillovers. Inference on external effects is normally based on additional parameters of the spatial model, arguing that the magnitude of parameters determines the degree of spatial interaction of regions and, therefore, the relevance of external spillovers. The reason why this way of doing inference on interregional spillovers is misleading is that spatial interactions between regions is only one of the causes of spatial autocorrelation in data, together with the unobserved spatial heterogeneity and the omission of relevant variables [LeSage and Pace, 2009, pp 27-30]. Nevertheless spatial models estimates do not allow to distinguish between autocorrelation due to unobserved spatial heterogeneity from that caused by spatial interactions and, consequently, there is a possibility that we qualify as interregional knowledge spillovers what actually is the effect of unobserved spatial heterogeneity[1].

Interpretation of the linkage between the conceptual weakness and the specification problems is straightforward. In Jaffe’s empirical formulation of the patent equation it is not possible to distinguish knowledge spillovers from other factors which are likely to influence the spatial concentration of innovative activities, with the risk of identifying as knowledge spillovers from other firms and/or universities effects mostly related to market forces and, more generally, to location-specific characteristics. And is exactly the omission of these characteristics, usually unobservable at the local level, which biases the coefficient estimates on the base of which it is made inference concerning the existence of regional and interregional spillovers.

3 Econometric strategy

The input-output relationship is empirically specified using data on patent applications to European Patents Office at regional NUTS II level, for which a count model described in 1 seems to be more appropriate than the usual linear specification. The dependent variable y_i is the count of applications registered in high-tech industries, while X_i is a matrix of covariates, among which the inputs of the KPF. Population is added as additional covariate with the coefficient constrained to unity (offset). The output measure is obtained as the

[1]To some extent the notions of unobserved heterogeneity and omitted variables overlap here in the broader definition of unobserved spatial heterogeneity, as long as most of the unobserved variables refer to location characteristics which are also source of heterogeneity.

average number of applications in years 2005-2006, while all the covariates has been chosen for a previous period in order to avoid simultaneity bias.

$$\begin{aligned} y_i &\sim Poisson\,(\mu_i) \\ \mu_i &= \exp\,(\alpha + X_i\beta + WX_i\gamma + \varepsilon_i) \end{aligned} \tag{1}$$

Covariates are included for both the i^{th} region and its neighbors and neighboring relationships are, as usual, described by a row-standardized contiguity matrix constructed using great circle distance as method to define contiguity relationships. The intensity of neighboring relationships is modeled as an inverse function of squared physical distance between neighbors (d_{ij}), such that the generic element of W is defined as in 2.

$$w_{ij} = \frac{d_{ij}^{-2}}{\sum_j d_{ij}^{-2}} \tag{2}$$

As well known, the limit of Poisson distribution is the characterizing mean-variance equality, a condition which might not hold also in our special case. For this reason a Negative Binomial model is employed, admitting a variance different from the mean thanks to the introduction of the overdispersion parameter θ. Within the full sample of 232 NUTS II regions in the database, only 8 of them show a value of patent applications equal zero, excluding the application of econometric procedures to control for the abundance of zeroes.

Among the regressors, the primary focus is on the variables identifying research expenditures by firms $(REDE)$ and universities $(REDU)$, as well as on their spatial lag. In order to overcome the previously described limits of this ordinary specification, the patent equation is extended controlling for market size, a different measure of university knowledge and unobserved spatial heterogeneity.

The proxy for the market size is the multimodal potential accessibility developed by ESPON[2] (MP), which has been preferred to per-capita income, given the potential endogeneity of the latter. Following the ESPON definition, potential accessibility is in fact *"a measure for the potential for activities and enterprises in the region to reach markets and activities in other regions"*. Accordingly it is exogenous, as it is calculated on the base of the distance separating the origin region by other potential accessible regions and is, at the same time, appropriate because Gross Domestic Product is used as a

[2] http://www.espon.eu.

weight for distances, hence accommodating a scale of the potential market for (not only) innovative firms.

A more careful attention is deserved to the issue of university knowledge. Admittedly most of the knowledge produced by universities by mean of direct investments in research might spillover in case of joint projects between universities and firms as well as in cases of university spin-offs. By using the total amount of research expenditure carried out by universities it is not possible, however, to distinguish involuntary knowledge transfers, like in case of spillovers, from market transactions. The consequent lack of confidence in results questions the validity of spillovers from universities. For this reason an adequate measure of academic knowledge should be such that the hypothesis that knowledge is transferred by market transactions is ruled out. The measure employed in this paper $(RANK)$ is based on the ranking of universities in the Academic Ranking of World Universities[3] index. The index is constructed in order to reflect the quality of research, primarily measured with publications and relative citations. The fact that the output of the research is published makes unnecessary any market transaction oriented to its acquisition. Notwithstanding, only the ultimate results of the research is published, while a conspicuous part of knowledge remain embedded in the institution and, possibly, spills over.

The issue of unobserved spatial heterogeneity is certainly the more demanding one. Not only because the lack of data at the regional level impedes to observe aspects affecting patenting activity of firms, but specially because most of these aspects are not observable and even measurable, as in the case of the local market for technologies. Insofar as these characteristics are not randomly distributed across the geographical space, it would be possible to capture their contribution by including geographical variables. The case of geographical dummy variables is the simplest and, to some extent, most intuitive solution. Nonetheless it requires an ex ante definition of the geographical space assuming an existing knowledge of the spatial distribution of these characteristics. The method employed in this work, on the contrary, avoids such strict assumptions and lets the geographical distribution of patent counts be explained by the data. Fur this purpose a spatial trend is included as a generic function of geographical coordinates, with the aim of detecting spatial heterogeneity unspecified in the model. Among the several possible choices for the function, a nonlinear one seems to be preferred, allowing the trend to be smoothed across the geographical space.

The model to be estimated can be represented as a Generalized Ad-

[3] http://www.arwu.org/.

ditive Model[4] 3 in which a penalized thin plate spline term $s(x, y)$ is added to a linear parametric specification of the mean function, and is estimated with semi-parametric methods described in Bivand et al. [2008, pp. 297-300]

$$
\begin{aligned}
y_i &\sim NB(\mu_i, \theta) \\
\ln(\mu_i) &= \alpha + \beta_1 rede_i + \beta_2 redu_i + \beta_3 rank_i + \beta_4 mp_i \\
&+ \gamma_1 Wrede_i + \gamma_2 Wredu_i + \gamma_3 Wrank_i + \gamma_4 Wmp_i \\
&+ s(x, y) + \varepsilon_i \qquad (3)
\end{aligned}
$$

The non-linear component $s(x, y)$ describes the trend surface in the geographical space determined by the value of X and Y coordinates and is expected to capture the unobserved spatial heterogeneity.

4 Results

The empirical analysis starts by specifying the patent equation with and without university ranking indicator (first two columns in table 1) and adding, only in a second step, the spatial trend (last two columns). In the very simplified version, the effect of R&D is, in accordance to theory and to previous empirical literature, positive and significant for both private enterprises and university expenditures. Among the spatially lagged values of research expenditures only the one relative to private enterprises is significant. According to the traditional interpretation of results it would be possible to conclude in favor of the existence of positive knowledge spillovers, notably localized in the case of university knowledge and less spatially bounded in case of private firms.

The coefficients for market potential and its spatially lagged value are of the expected sign, although only the latter is significant. The result should not surprise as far as the spatial lag is a measure of size of the markets accessible not only from the region but also from neighbors and hence better embodies the idea of location advantages for innovative firms. Results slightly change after the introduction of university ranking indicator. Both coefficients for R&D expenditures fall down, from 1.051 to 0.709 in the case of private enterprises and from 0.0012 to 0.007 in the case of universities with, in addition, a decrease of the significance level in the latter case. The new coefficient for university knowledge is correctly

[4] Lower cases of variables indicate logarithms as a result of the choice to use logarithm as link function for the mean specification of the negative binomial model.

sloped and strongly significant. This result points the validity of different ideas on the role of universities for innovation, especially reinforcing the argument in favor of localized knowledge spillovers. University knowledge spillovers are however limited within regional borders, as indicated by the significance of the coefficient relative to the spatial lag. On the opposite, research expenditures produce cross-border externalities, positive only in the case of private enterprises research. The coefficient for lagged university research is negative but only marginally significant.

Overall, results suggest that common evidences emerged in previous literature are confirmed also in this study, except for the negative coefficient for lagged university research. Market potential apparently shows as an important factors influencing regional innovative activities, pointing to the relevance of market dynamics in the development of new ideas. Moreover the use of university ranking indicator improves the understanding of the role of university knowledge spillovers, differentiating the latter from generic benefits attributed to the presence of university research. Finally, despite the inclusion of spatial lags of covariates to account for spatial relations, it is worth to note that residuals of both models show significant spatial autocorrelation, detected by the Moran's I, making necessary a further modeling of spatial heterogeneity.

Results discussed until now prove to be robust only in part, with respect to the introduction of the spatial trend. On the one side, the evidence on the effect of private enterprises research remain almost unchanged, noticing the expected decrease in the magnitude of coefficient after the introduction of the trend. On the other side, university research turns to be insignificant and the significance of the spatial lag of private research decreases substantially. The inclusion of the trend does not affect the results on the market potential, which continue to show a positive and significant coefficient in the spatial lag.

The further introduction of university ranking, jointly with the spatial trend, corroborates results above. Evidences of spillovers from university research, as well as of interregional spillovers, disappear once spatial heterogeneity is taken into account in the model specification. Evidences of pure academic knowledge spillovers, on the contrary, remain robust to the modeling of spatial heterogeneity. Furthermore, the spatial lag of the ranking indicator turns now to be significant, although at a very low confidence level. Also notice that, contrary to the GLM case, the coefficient of the spatially lagged ranking is higher than the coefficient for ranking itself, contradicting the hypothesis of localized academic knowledge spillovers.

Estimation results confirm the validity of the research hypothesis

Table 1: Negative Binomial Model Estimates of The Patent Equation in High Tech Industries

	GLM		**GAM**	
Intercept	-1.58500***	-1.98700***	-13.23000***	-13.63000***
	(0.18620)	(0.17960)	(0.31960)	(0.33660)
REDE	1.05100***	0.70920***	0.78790***	0.62390***
	(0.08367)	(0.07476)	(0.06349)	(0.06165)
REDU	0.00116***	0.00073**	0.00030	0.00007
	(0.00037)	(0.00033)	(0.00029)	(0.00028)
RANK		0.46100***		0.24590***
		(0.04457)		(0.03603)
MP	0.00000	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
WREDE	0.38940**	0.48660***	0.45090*	0.30580
	(0.18450)	(0.18840)	(0.27180)	(0.24890)
WREDU	-0.00175	-0.00179*	-0.00098	-0.00112
	(0.00118)	(0.00103)	(0.00129)	(0.00119)
WRANK		0.19010		0.38710*
		(0.18230)		(0.20120)
WMP	0.00005***	0.00002*	0.00003***	0.00003***
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
s(X,Y)			78.83***	78.37***
logLik	-889.98	-853.69	-797.89	-784.77
AIC	1795.96	1727.37	1655.77	1628.81
I	0.07149***	0.09993***	0.00585	-0.00134

Notes to table 1

SE in parenthesis

***, * and * denote significance at 1%, 5% and 10% confidence levels

Spatial trend's significance evaluated through a LR statistic

Moran's I significance obtained from a two-sided test under randomization

Table 2: Robustness check of results to the specification of the contiguity matrix

	d=300 km	d=400 km	d=500 km
Intercept	-12.92000***	-13.18000***	-13.34000***
	(0.21000)	(0.23680)	(0.28160)
REDE	0.61990***	0.61610***	0.62030***
	(0.06200)	(0.06148)	(0.06226)
REDU	0.00013	0.00011	0.00009
	(0.00028)	(0.00028)	(0.00028)
RANK	0.24410***	0.23750***	0.23970***
	(0.03643)	(0.03616)	(0.03610)
MP	0.00000	0.00000	0.00000
	(0.00000)	(0.00000)	(0.00000)
WREDE	0.06847	0.19170	0.27230
	(0.17230)	(0.18130)	(0.19970)
WREDU	0.00010	-0.00017	-0.00058
	(0.00092)	(0.00103)	(0.00112)
WRANK	0.11590	0.16750	0.21430
	(0.11620)	(0.14290)	(0.17020)
WMP	0.00002**	0.00003***	0.00003***
	(0.00001)	(0.00001)	(0.00001)
s(X,Y)	115.00***	89.00***	83.65***
logLik	-785.29	-784.62	-784.65
AIC	1633.71	1629.11	1630.09
I	0.00781***	0.00971***	-0.00281***

Notes to table 1 also hold for table 2

formulated in the introduction. Of course most of the evidences of knowledge spillovers in research activities result from incorrect specification of the patent equation, especially from the omission of spatial heterogeneity. This main conclusion remain unchanged, notwithstanding the different specifications of the contiguity matrices in table 2. Here, several cut-off distances, namely 300 km, 400 km and 500 km, have been used to reproduce the result in last column of table 1, in which the 736 km distance has been used. At least based on the value of the AIC, the 736 km specification seem to be the best choices.

5 Conclusion

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