Strategic interactions in public R&D across European countries: A spatial econometric analysis

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Abstract:

The paper adds to the existing literature on the determinants of government spending in Research and Development (R&D) by considering the role of strategic interactions among countries as one of the possible competing explanations, within a spatial econometric framework. We account for several factors affecting national levels of public R&D spending, including (i) the international context – i.e. Lisbon strategy; (ii) country characteristics – level of private R&D, GDP, trade openness and the National System of Innovation; (iii) countries' similarities in relation to (a) trade and economic size and (b) sectoral specialization. The analysis is carried out on 14 European countries. First, we find that factors traditionally affecting the level of public R&D expenditure, such as the scale of the national economy, trade openness, sectoral specialization and private R&D, significantly influence the level of public R&D in European countries between 1994 and 2006. Interestingly, the introduction of the Lisbon strategy does not seem to have affected changes in the levels of public R&D spending. Second, by using different weight matrices, we confirm the existence of strategic interactions in relation to R&D spending among European countries with similar economic, international trade and sectoral structure characteristics.

Keywords: Public R&D expenditures; Strategic interactions in public spending; National Systems of Innovation; private R&D; EU countries; spatial dynamic panel data.

JEL codes: H5; 03

1. Introduction

The existing literature on tax competition almost unanimously concludes that countries strategically compete on public expenditure to attract (or avoid the migration of) firms or multinational corporations that are seeking a favourable environment to locate their activities (Case et al., 1993; Figlio et al., 1999; Baicker, 2005; Redoano, 2003, 2007). However, although firms often claim that public R&D is an important factor affecting their decision to locate in a particular area, there is, to our knowledge, no empirical contribution that tests the strategic interactions in government spending among countries as one of the several possible determinants of public R&D spending.

We find this gap in the public choice literature somewhat puzzling, given the European Commission's (EU, 2004) emphasis on the Lisbon Strategy and the debate over the so-called 'European Paradox' (Dosi et al., 2006). The Lisbon strategy sets goals for innovation performance by EU countries based explicitly on public spending on R&D. There is a large body of empirical evidence showing that the higher the expenditure on R&D, the higher the competitive advantage due to innovation, and the higher are national growth rates. Public R&D is therefore likely to be used by government as a strategic tool to improve the competitiveness of countries and to attract mobile tax bases within their boundaries.

However, public R&D expenditure is a very specific item of public spending policy that is likely to be linked to a more complex set of factors than only competition among countries. The aim of this paper is to contribute to the existing literature on public choice by testing –within the same framework- the effect of traditional factors related to public R&D spending and the relevance of competing explanations such as the existence of strategic interactions among the EU-15 countries.

To this purpose, we first review a selection of the existing literature on factors that drive policy makers' choices related to R&D expenditure, and might explain strategic interactions in such choices. Part of the rationale of the Lisbon strategy is the desirability of a certain level of convergence among countries' public R&D spending on the basis of the evidence referred to above. From a reaction function perspective, a neighbor with higher levels of R&D expenditure might be in a more favorable position to attract firms or foreign direct investment (FDI). On the other hand, a neighbor with weaker R&D intensity might impede possible R&D spillovers that would benefit both countries. In either case, it is important to investigate the determinants of different countries' behaviors and expected outcomes in terms of convergence/divergence in public R&D spending decisions. We believe it is important to examine these issues from both a reaction function and a system of innovation perspective.

This paper combines work on spatial and strategic interaction in public choices with contributions that focus on the motivations for and debate around public expenditure on R&D, to test whether there are strategic interactions in decisions related to the amount of EU countries' R&D expenditure. Our conjecture is that, in addition to factors traditionally affecting public expenditure, such as the scale of the national economy and trade competitive advantage, public expenditure on R&D is the result of specific national characteristics identified in the literature as the National Innovation System (NIS). One of the elements of the NIS is the similarity of countries' sectoral structure. While NIS and sectoral specialization arguments are common in the innovation literature, their application to a spatial interaction framework is less well explored. We provide evidence on the extent to which similar sectoral and technology structures and private R&D expenditure determine similar trends in public R&D spending decisions.

We test the existence of spatial interactions related to public R&D expenditures for 14 European countries using panel data for the period 1994-2006. We employ a maximum likelihood technique on a balanced panel dataset and use different spatial matrix specifications, which account for the specificity of public R&D expenditure. First, we find that factors traditionally affecting public expenditure, such as scale of the national economy, trade openness, sectoral specialization and private R&D significantly affect the level of public R&D spending by European countries between 1994 and 2006. However, we do not find any significant impact of the Lisbon strategy, nor of the level of public R&D in the US and Japan. Second, we show that the proximity of European countries from an economic and commercial perspective tends to be associated to similar trends in public R&D expenditure. Third, the estimation results confirm the presence of strategic interactions in public R&D spending, among European countries with the same sectoral and technological innovation structures, supporting evidence on complementarity and spillovers between public and private R&D expenditures across similarly specialized countries. In contrast to most of the spatial econometric literature, we find that geographic proximity does not matter for public spending on R&D by European countries.

The paper is organized as follows. Section 2 reviews the relevant literature and justifies the empirical strategy. Section 3 presents the empirical model and the econometric issues arising from its implementation. Section 4 summarizes and discusses the estimation results. Section 5 concludes.

2. Background literature

2.1 Strategic interactions in public policy

A number of empirical studies show the relevance of the theoretical literature on strategic interactions related to fiscal or public expenditure decisions (for an empirical survey, see, e.g. Brueckner, 2003). Generally, observed public fiscal decisions in one region positively depend on public fiscal choices in neighboring or competing regions, leading to the conclusion that public choices are strategic complements. These empirical results emerge from data for the US states and Canadian provinces (e.g. Brett and Pinske, 2000 for Canada, and Brueckner and Saavedra, 2001 for the US) and European subnational government datasets (e.g., Heyndels and Vuchelen, 1998, for Belgium; Buettner, 2001, for Germany; Feld and Reulier, 2005, for Switzerland; Bordignon et al., 2002, for Italy; Sole Olle, 2003, for Spain, and Charlot and Paty, 2007, for France). A few contributions estimate reaction functions for taxes using OECD country datasets (see Besley et al. , 2001; Devereux et al. , 2002; Altshuler and Goodspeed, 2002).

A series of factors might explain interactions among governments: these include tax competition (see Wilson, 1999 for a survey); spillover benefits (see e.g. Wilson, 1996); welfare competition (Brueckner, 2000) and yardstick competition (Besley and Case, 1995ab). Public choices are confined within national boundaries, though partly depend on what neighbouring states decide over time. Reaction functions have been estimated mainly for taxes, although an increasing number of contributions deal with reaction functions for public expenditures, in some cases, within a spatial econometric framework (Brueckner, 2003). Case et al. (1993), Figlio et al. (1999), Baicker (2005) and Redoano (2003, 2007) explicitly focus on public expenditure. However, most of this work is based on US data. For instance, Case et al. (1993) estimate the effect of a state's spending on that of its neighbors using a spatial lag model. They find that a state's per capita expenditure is positively and significantly correlated with neighbor

states' spending. These results are confirmed by Figlio et al. (1999), who check the existence of spillovers in welfare spending. Baicker (2001) finds that each dollar of national spending leads spending in neighboring states to increase by between 37 and 88 cents. Redoano (2003) estimates reaction functions for (aggregated and disaggregated) taxes and public expenditure using data on EU countries for the period 1985-1995. She finds that governments behave strategically with respect to spending items that are more directly comparable, such as education: an increase of 1 dollar in the amount spent on education by neighbors increases expenditure on the same item in the focal country by more than 40 cents.

Interdependency in public policies might also be due to yardstick competition. To avoid alienating voters and risks of not being reelected, incumbents imitate each other. Again, it is difficult to define a priori with whom voters compare their incumbents. As information on politics' decisions taken in geographically close countries is likely to be more easily accessible, interactions are likely to happen among neighboring countries. However, voters may also compare other relevant neighbors, i.e. countries that are "close" in terms of economic environment.

To our knowledge, the literature on strategic interactions reviewed above does not deal with public R&D expenditure. R&D spending decisions are part of long-term, structural public policy at the intersection between science, innovation, industrial and competition policies. Within the tax competition literature framework, it might be that countries compete on R&D expenditure in order to attract (or avoid the migration of) firms or multinational corporations that are seeking a favorable and knowledge-intensive environment to locate their activities. However, as Ladd (1992) and Case et al. (1993) argue, policy-makers are not necessarily influenced by geographic neighbours in making public decisions but are likely to interact with countries that are similar from an economic perspective. Thus, the existence of "spatial" interactions should be investigated in a broad sense using alternative definitions of proximity based on geography, economics, international trade and sectoral structure[1]. Considering that investors are likely to compare countries in terms of their economic environment to locate their activities, policy-makers may imitate those specific countries to avoid capital and firms' migration. All in all, R&D is a very specific item of public spending policy that is likely to be affected by a more complex set of factors than only competition. We address this issue in the next section.

2.2 Science policy in the EU: framing the debate

Public decisions on R&D spending are part of the broader national science policy. As a way of framing the debate around science policy in the EU and identify the relevant factors affecting governments' decisions on public R&D spending, we first revert to the so-called 'European Paradox', and the features of the EU-wide science and technology policy vis-a-vis that of the US and Japan (2.2.1). We then look at the empirical evidence on the determinants of public R&D spending from a National Innovation System (NIS) perspective (2.2.2). Among other factors, we focus on the sectoral structure of national economies, which may be linked to the demand for public support for innovation (i.e. a country with a revealed specialization in high-tech sectors– ceteris paribus – will spend more on R&D, which in turn will create political pressure for more public support for basic and applied research). This raises the crucial issue (addressed in section 2.2.3) of whether private and public R&D are complements or substitutes, which is relevant to inform science policy.

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[1] As a consequence, the effect of alternative interaction matrices should be empirically tested to provide the relevant definition of neighbors.

2.2.1 The logic of basic scientific research and the 'European Paradox'

The Lisbon strategy (EU, 2004) is well established but continues to provoke debate among science and technology policy scholars and practitioners, and has been the subject of numerous empirical studies since it was first announced (see among others, Nelson, 2006; Dosi et al., 2006).

Public R&D and 'basic research' increase the stock of scientific and technological knowledge that in turn foster countries' competitiveness. However, as put forward by Nelson (2004)[2] and Dosi et al., (2006), not only scientific and technological knowledge resulting from public R&D are public goods, subject to uncertainty and serendipity, but are likely to interact in a self-reinforcing way with their technological and industrial applications and be affected by the behavior of private enterprises (Pavitt, 1987, 2001; Freeman, 1982, 1994; Nelson, 2004, 2006).

Scholars who recognize the presence of a 'European Paradox' depict the European Science and Technology System (STS) – compared to the ones in the US and Japan - as excellent in terms of basic research, spurred mainly by public R&D spending and other public support for business R&D (e.g. tax credit, public infrastructure), although weaker in terms of its innovative applications, measured usually as numbers of industry patents.

However, in fierce opposition to the idea of a European paradox, Dosi et al. (2006) argue that the EU STS lags behind *both* in terms of scientific research[3] *and* in relation to innovation output, showing that the returns from EU R&D are lagging behind with respect to the US and Japan.[4] However, the evidence is not conclusive about the existence - and importance - of a 'European Paradox', as it depends on measurement and empirical issues. The idea of a 'European Paradox' would be *weakened* by evidence supporting an "imitative" behavior of EU governments in terms of public R&D spending with respect to the US and Japan. This would imply the perception of a gap in the EU national support to basic research and explain the presence of spatial interactions. We shall test and discuss this in the empirical section.

2.2.2 Scientific and technological knowledge in the making: NIS and sectoral structure

Before the concept of a European STS emerged – following the implementation of the Lisbon strategy – there was a flourishing stream of literature on NIS, terminology used by Freeman (1987)[5] (including Lundvall, 1992; Nelson, 1993; Edquist, 1997, 2005). The NIS approach attempts to link systemic innovation performance to national characteristics, including the coordination and performance of public and private organizations and the institutions involved in the creation and diffusion of knowledge for innovation[6]. While traditional country characteristics, such as size, population and GDP per capita, are relevant, the NIS approach posits that a much wider set of features is responsible for innovative performance, including firms, universities, public research centers, local government and sectoral agencies.

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[2] A country's "science base largely is the product of publicly funded research and the knowledge produced by that research is largely open and available for potential innovations to use" (Nelson, 2004).

[3] According to Dosi et al., (2006) if public R&D shares are measured as percentage of GDP or per inhabitant, rather than share of total R&D expenditure, evidence of an EU paradox disappears. In the empirical analysis in this paper, we use per capita R&D expenditure.

[4] For an extensive review of the returns to R&D see Hall et al., (2010).

[5] Actually, Freeman and Lundvall credited each other with being the progenitors of the concept of NIS.

[6] For instance, both Lundvall (1992) and Edquist (1997) consider that the NIS encompasses the entire national socio-economic system, in which cultural, economic and political environment concur to determine the scale, direction and success (or failure) of innovation activities (Freeman, 2002).

There are three core constituents of the NIS (Freeman 1987; Nelson, 1993; Lundvall 1992) as historical cases show (Freeman, 1987, 2002), which explain governments' decision on the level of R&D spending:

(1) The different tools of countries' public support for the innovation process, such as grants, subsidies to firms and R&D tax credits;

(2) The role of private organizations responsible for the creation of knowledge at firm and sectoral levels, which also are representative of an integral part of the technological knowledge system related to the application of basic science;

(3) The university system, which – although it varies across countries – provides essential training for scientists and is responsible for technological knowledge transfer to firms. There is a stream of literature on university-industry linkages (see Mowery and Sampat, 2005 for a review).[7]

In a seminal article, Pavitt (1984) linked technological trajectory to the creation of different technological opportunities, responsible for sectoral heterogeneity in the patterns of innovation. Pavitt's sectoral taxonomy[8] has been very widely cited, tested empirically for a variety of countries, and sparked intense debate (see Archibugi, 2001; Castellacci, 2008). Pavitt's sectoral taxonomy is based on various characteristics, including firm size across sectors, technological opportunities, creation vs. adoption of technology, types of vertical linkages and inter-sectoral knowledge exchange among sectors (which includes the intensity of R&D expenditure).

Castellacci (2008), building on contributions in the literature (Evangelista, 2000) extended Pavitt's taxonomy to the services sector and identified another category - of 'advanced knowledge providers' (AKP) - which resonates with Pavitt's 'specialized suppliers', but adds the set of services sectors that provide highly specialized knowledge (information and communication technologies - ICT, private R&D, engineering, and consultancy) – or Knowledge Intensive Business Services (KIBS) (see Miles, 2005 and Ciarli et al., 2012, for a recent review).

AKP – along with traditional science based sectors – are the private counter-part to and the most likely intensive users of the public knowledge base, which is a necessary condition for countries to innovate and compete. For the purposes of this paper, we conjecture that the presence and intensity of AKP is a core element of the cross-countries similarity in terms of the main determinants of public R&D spending, that is, sectoral specialization and intensity of the knowledge base. The latter is linked closely to the 'demand' for public support for innovation (i.e. national specialization in high-tech sectors – ceteris paribus – requires higher spending on R&D and higher levels of public support for basic and applied research). This leads us to our final consideration within the debate on science policy: that related to the links between public and private R&D spending.

2.2.3   *Public on private R&D: positive spillovers or 'crowding out effect'?*

A research area that is of 'perennial policy relevance' (David et al., 2000, p. 501) is related to

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[7] This literature proposes some additional issues related to NIS –academic systems and the effectiveness of university-industry linkages. We do not include these in the present analysis, which is linked to decisions about the amount of R&D spending rather than its different possible destinations.

[8] This includes: science based sectors; specialized supplier, supplier dominated, scale intensive and information intensive sectors. This last was a later addition to the originally proposed taxonomy (Pavitt et al., 1989).

analysis of the effects of public R&D on private R&D investment at various level of analysis (firm, industry, country), and also on whether private investments affect publicly funded or publicly performed R&D, in order to establish the existence of complementarity. That is, whether public spending spillovers affect private firms' decisions about R&D spending, or whether public funds in the form of direct subsidies 'crowd out' private spending, that is are substitutes (David and Hall, 2000). This is an important issue for policy, and is difficult to disentangle at the conceptual and empirical levels.[9]

While it is relatively straightforward to assess the impact of public funding on private spending on R&D at the micro-level, this relationship is more complex at more aggregate levels – and especially at the country level, the focus of this work. David and Hall (1999) model the factors affecting this relationship, such as relative size of the public R&D sector, elasticity of the supply of qualified R&D personnel, mix of public support for private R&D projects, and marginal rate of returns on private R&D. Another element that must be taken into account is knowledge spillovers from publicly funded science to the private sector, over time. These knowledge spillovers include publicly funded training of scientists, which most certainly would contribute to complementarity rather than crowding out effects (to the extent that private firms value either the direct training received by scientists, or the effects of a public science system that filters researcher quality).

The country-level empirical literature on this topic is limited to the US, with some notable exceptions (Levy, 1990; Von Tunzelmann and Martin, 1998; David and Hall, 1999). Von Tunzelmann and Martin (1998) provide panel data estimations of the effects of changes in industry-financed R&D compared to changes in government expenditure, for 22 OECD countries for the 1969-1995 period. They find significant and positive effects for only a quarter of the countries included in the analysis. David et al. (2000) suggest that the empirical literature so far is inconclusive about the complementarity or substitutability of public and private R&D. Although there is slightly more evidence – especially from aggregate-level as opposed to firm-level studies - supporting the presence of positive spillovers from publicly funded R&D for private R&D investment, in some cases a displacement effect within the two has emerged. By testing competing explanations of public R&D spending decisions, including the intensity of AKP and the amount of private R&D spending, our empirical analysis will also shed light on whether a complementarity or substitutability link emerges between publicly and privately funded R&D.

3. The empirical model

The aim of this paper is to assess the determinants of government spending on R&D in 14 European countries. Our main original contribution is in the inclusion of strategic interactions in government spending among these countries as one of the several possible competing explanations of public R&D spending. Accordingly, we consider spatial dependence in a panel data framework. In line with the literature (see, e.g., Devereux et al., 2002; Brueckner, 2003; Dreher, 2006), we assume that a country's policy reaction function can be written as:

$Z_{i,t} = R_i (Z_{j,t}, X_{i,t})$,

Where:

$Z_{i,t}$ is the vector of public expenditure in a country i at time t;

$Z_{j,t}$ is the vector of public spending in a set of the other countries j ($j≠i$) at time t;
$X_{i,t}$ is the vector of the economic characteristics of country i at time t.
We can replace the vector $Z_{j,t}$ by a weighted average, such as $w_{ij}*Z_{j,t}$ which implies that every country responds in the same way to the weighted average expenditures. The equation then becomes:

$$Z_{i,t}= α_i + ρ W Z_{j,t} + β X_{i,t} + ε_{i,t} \qquad (1)$$

We include several control variables in X, in line with the considerations outlined in section 2.2.

Among these variables, we include private R&D. As mentioned in section 2.2.3, the existing empirical literature does not provide a conclusive answer about the existence of complementarity or substitutability between public and private R&D. The level of significance of the parameter will show if private R&D has an impact on public R&D and the sign will show whether private and public R&D are complements (positive sign) or substitute (negative sign). As a covariate, we also include the production value of Advanced Knowledge Providers (AKP), as suggested by Castellacci's (2008) taxonomy. As argued above in section 2.2.2, these industries are characterized by a high technological capability and the ability to create complex technological knowledge. We expect that national specialization in these high-tech sectors – ceteris paribus – requires higher spending on R&D and higher levels of public support for basic and applied research, therefore positively affecting the level of public R&D. We also include GDP p.c., to test whether macroeconomic conditions have an impact on the level of public R&D expenditure. We expected the sign of this latter coefficient to be positive, since public spending may be used as policy tool to boost low economic activity. Possible endogeneity problems for these three variables are addressed (see below).

We will also include the level of trade openness as a possible covariate. The trade openness index is calculated as the ratio of country's total trade, the sum of exports plus imports to the country's GDP. The higher this openness index, the larger the influence of trade on domestic activities. Although a number of recent papers have shown that trade openness has pro-competitive effects leading to firm selection and stimulating innovation, [10] this is still a controversial and open debate (see Tybout, 2003, for a survey). Other contributions support a negative relationship between trade openness and public expenditure (e.g. Ferris and West, 1996; Ferris, 2003; Borcherding et al., 2004). They argue that international integration inducing more tax competition and, therefore less capacity to increase taxes –such as capital tax- restrict the size of the public sector and consequently public R&D spending. The expected sign is therefore uncertain.

Further, we test for the possible impact of the Lisbon strategy. We use a dummy that is equal to 1 for the years since 2001. There is a large economic literature showing that R&D can be a major advantage and increase countries innovation performance and growth. Therefore we can expect higher levels of public R&D in European countries after 2000 and the expected value for this parameter is positive.

We include the level of public R&D set by the US and Japan. We test the hypothesis that public decisions made by these two countries influence public R&D in Europe, as it is implicit within the European paradox debate. Expected values for the parameters are positive.

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[10] Trade liberalization induces the least productive firms to exit the market and the most productive non-exporter firms to become exporters.

Finally, individual fixed effects are introduced to capture the specific characteristics of each country over time[11].

3.1. Data and descriptive evidence

Data on public R&D are from national R&D surveys that comply with the Frascati Manual (OECD, 2002) recommendations. The overall quality of the R&D statistics can be assessed by comparing the three main sectors of performance: business enterprise, government, and higher education.

In this study, public R&D expenditure refers to government departments and institutes and other public bodies, and profit and non-profit organizations, financed by central or local government.[12] The data for the EU-15 countries are from the Eurostat database for the period 1994-2006. The unit of R&D expenditure is purchasing power standard per inhabitant, at constant 2000 prices. Due to missing values for Luxemburg on our period of study, we have removed this country from our data.[13]

We use a balanced panel data for the remaining 14 EU countries for 1994-2006, which provides 168 observations. A panel data approach allows us to fully exploit the spatial and temporal dimensions of the data.

Figure 1 shows the relatively low level of public R&D spending in Europe compared to the US and Japan (see Section 2.2). The gap is persistent over the 10 years from 1994 to 2004. The figures suggest that the gap between the European countries and its main competitors for R&D[14] is a well-established phenomenon with structural rather than cyclical causes; it suggests also that these structural causes are still in place.

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[11] A summary of the variables included in the empirical analysis is provided by Appendix Table 1a, while Appendix Table 1b reports the correlation coefficients among the variables.

[12] We are aware that the use of aggregate spending in R&D might undermine some of sectoral-specific aspects related to it. However, the framework in which we conduct the empirical analysis is one of aggregate reaction function. The sectoral dimension is accounted for both as an explanatory variable (AKP) and as one of the specifications of the distance matrix is countries' proximity in terms of sectoral specialization.

[13] We need to rely on a balanced panel data to use maximum likelihood techniques.

[14] We are aware that Europe's potential competitors on public R&D expenditures are increasingly emerging countries like BRICS. However, we have decided to focus on the US and Japan only, for simplicity and consistency with the debate on the European paradox mentioned in Section 2.2.1. The strategic interaction on public R&D spending between Europe and the emerging countries is of great interest and is part of our research agenda.

Figure 1: Gross domestic expenditure on public R&D (euro per inhabitant)
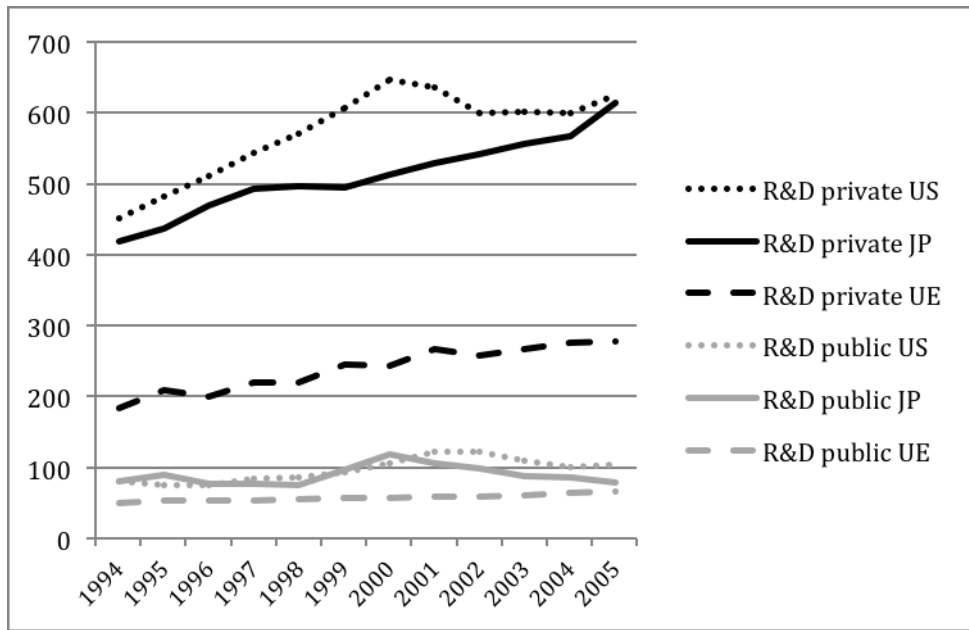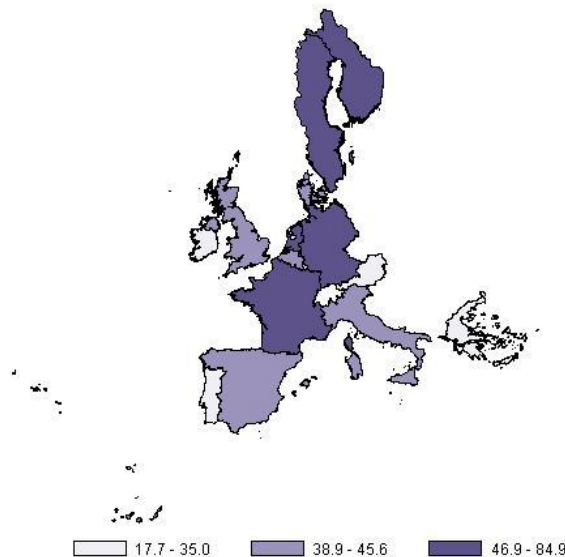

Figure 2 shows the level of public R&D spending in 2006. We cannot exclude the possibility that there is strategic interaction, shown by the spatial interdependence among the European countries for public R&D. We test this econometrically.

Figure 2. European Gross domestic expenditure on public R&D (euro per inhabitant) in 2006.

3.2. Econometric issues

Spatial dependence raises two econometric issues related to equation (2). First, if countries react to the spending decisions of the other countries, then competing countries' spending decisions will be endogenous and correlated with the error term (ε). OLS (ordinary least squares) yields a biased estimate of parameter ρ (Anselin, 1988). Second, if neighbors' localities are subject to correlated shocks, there is likely to be correlation among jurisdictions' spending choices. The omission of spatially dependent explanatory variables may generate spatial dependence in the error term, which is given by the following equation:

$$\varepsilon_{i,t} = \lambda W \varepsilon_{i,t} + \nu_{i,t} \tag{2}$$

If spatial error dependence is ignored, estimation of (1) might provide false evidence of strategic interaction.

Basically, two approaches exist to get consistent estimates of the spatial parameter ρ in equation (1). The first one is based on maximum likelihood (ML) estimation. This method consists of a non-linear optimization routine, used to estimate the spatial coefficient ρ, taking into account the error structure in equation (2). The second one is based on instrumental variables (IV) – two stage least squares (2SLS) method. In this paper, we will provide estimations results using ML method, which does not require the finding of reliable instruments.

Finally, we cannot exclude the hypothesis that there is some persistence in public R&D spending, which means that government spending change only slowly over time (Devereux et al., 2002; Dreher 2006; Redoano 2007). However, including as an explanatory variable the time-lagged dependent variable ($Z_{i,t-1}$) in a spatial lag model remains a major issue using GMM models. Although serial correlation may bias our results, we follow the existing literature and mainly treat the presence of spatial correlation.

3.3. Weight matrices

As suggested by Anselin (1988), an a priori set of interactions (using W) should be defined and tested. While a variety of weighting schemes can be explored to allow different patterns of spatial interaction, a scheme that assigns weights based on Euclidean distance is frequent in the relevant empirical literature (Brueckner, 2003). Therefore we use a geographical definition of neighborhood based on the Euclidean distance between jurisdictions. This scheme is given by the weight matrix W^d and imposes a smooth distance decay, with weights w^d_{ij} given by $1/d_{ij}$ where d_{ij} is the Euclidean distance between jurisdictions i and j for $j \neq i$.

In our case, the degree of interdependence between two countries may not depend on their geographic proximity, but on their relative economic size, the degree to which they are open to international trade flows, or the similarity of their structural sectoral characteristics. We investigate each of these possibilities empirically.

We define an interaction matrix W^{GDP} such that higher weights are assigned to countries with more similar economic characteristic (GDP per capita):

$w^{GDP}_{ij}=1/|GDP_i-GDP_j|$

Following the work of Coe and Helpman (1995), we use intensity of bilateral trade flows (W^{BTF}) as bilateral weights to approximate the intensity of countries' interdependences; more specifically, we use the bilateral import shares (W^{BIS}) of our set of 14 European countries. We assume that the more intense the commercial interrelations between countries i and j, the greater will be the exchanges for innovation between them (Cabrer-Borras and Serrano-Domingo, 2007), and the more interdependent their public R&D policies:

$$w^{BTF}_{ij} = (X_{ij}+M_{ij})/(X_i+M_i) \text{ and } w^{BIS}_{ij} = M_{ij}/M_i$$

where X_{ij} and M_{ij} are respectively bilateral exports and import shares.

Lastly, we introduce a third category of the weight matrix W^{AKP} to account for the specificity of public R&D expenditure. This weight matrix is based on AKP, which are characterized by high (private) R&D intensity and are leaders in the management of complex technological knowledge.[15] We build on Pavitt's (1984) taxonomy and extensions to it (Pavitt, 1989; Archibugi, 2001; Castellacci, 2008). Using Castellacci's (2008) taxonomy, we identify the sectoral category AKP, in which private R&D is a typical core sector. Our assumption is that policy-makers decisions about R&D spending are affected by the degree of specialization in their country and those countries nearest to it, measured as intensity of AKP.[16] In line with the literature reviewed in Section 2.2.3, we may find that a degree of complementarity dominates substitutability between public and private R&D spending (David et al, 2000). An ancillary assumption is that countries that are more specialized in private R&D-intensive sectors exhibit higher public R&D spending. We test the assumption that the more similar the intensity of AKP between two countries i and j, the more interdependent will be their public R&D policy:

$$w^{AKP}_{ij}=1/|AKP_i-AKP_j|$$

In line with the relevant literature, all the weight matrices are standardized so that the elements in each row sum to 1.

4. Results

Our estimation strategy is as follows. First we estimate the model in equation (1) using OLS without taking account of the possible effect of the expenditures set by other countries ($\rho= 0$). We performed the appropriate non-robust and robust spatial tests based on the Lagrange Multiplier (LM) using every weighting scheme. The robust tests indicate the presence of spatial lag dependence only, for all weight matrices except for W^{dist}. Table 2 in Appendix shows these estimations results.

Second, given this result, we estimate the model in equation (1) using ML method when including every weighting scheme except W^{dist}. Country fixed effects are included. Table 3 displays these estimation results using each weighting scheme. To take into account the possible endogeneity of GDP, trade openness, private R&D and sectoral specialization (AKP), we lagged these covariates by one period. Column 1 in Table 3 exhibits within estimates when no spatial lag parameter is included. Since OLS estimations are biased, we will focus on the estimations results derived by ML in Table 3.

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[15]   AKP include two sub-groups of industries: (1) in manufacturing, specialized suppliers of machinery, equipment and precision instruments; (2) in services, providers of specialized knowledge and technical solutions e,g, software, R&D, engineering and consultancy (KIBS).

[16] The variable AKP is measured as the production value of the sector expressed in millions of euros (2000).

Table 3: Estimation results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
W. matrix	-	W_{GDP}	W_{GDP}	W_{AKP}	W_{AKP}	W_{BTF}	W_{BTF}	W_{BIS}	W_{BIS}
Priv. R&D $_{t-1}$	-0.082	0.245***	0.121***	0.188***	0.173***	0.193***	0.175***	0.190***	0.173***
	(-0.8075)	(8.005)	(3.3336)	(4.5317)	(4.1424)	(4.0213)	(3.9403)	(3.9418)	(3.8646)
Lisbon	-0.021	0.033	-0.024	0.023	0.014	-0.020	-0.013	-0.028	-0.021
	(-0.3903)	(0.3358)	(-0.3072)	(0.2477)	(0.1509)	(-0.1889)	(-0.1386)	(-0.2668)	(-0.2171)
U.S. R&D pc	-0.426	0.130	-0.045	-0.359	-0.285	0.239	-0.253	0.243	-0.244
	(-1.359)	(0.3336)	(-0.135)	(-0.8454)	(-0.6749)	(0.5125)	(-0.5743)	(0.5168)	(-0.5467)
Jap. R&D pc	-0.167	-0.042	-0.761	-0.813	-0.800	-0.377	-0.600	-0.354	-0.573
	(-0.3943)	(-0.0664)	(-1.431)	(-1.2975)	(-1.2898)	(-0.5401)	(-0.9286)	(-0.5032)	(-0.876)
Openness $_{t-1}$	-0.021	-0.331***	-0.241***	-0.415***	-0.378***		-0.353***		-0.349***
	(-0.231)	(-5.0767)	(-4.3172)	(-6.7626)	(-5.8049)		(-5.24)		(-5.1255)
GDP $_{t-1}$ p.c.	0.749***		0.518***	0.716***	0.666***	0.182*	0.651***	0.192***	0.653***
	(2.9989)		(2.787)	(2.8799)	(2.6841)	(0.6914)	(2.5195)	(0.7238)	(2.4941)
AKP $_{t-1}$	0.005	0.014*	0.015***		0.013*	0.031***	0.014*	0.031***	0.015*
	(0.7861)	(1.6833)	(2.1842)		(1.6446)	(3.5904)	(1.7067)	(3.5849)	(1.7304)
Spatial lag		0.560**	0.726***	0.585***	0.592***	0.675***	0.622***	0.666***	0.611***
		(10.5369)	(17.5077)	(13.2351)	(13.6174)	(15.6696)	(13.9256)	(15.3024)	(13.4023)
R sq.	0.13848								
Log lik.		-190.3	-189.0332	-184.5	-183.1419	-199.8	-186.3462	-200.7	-187.9354
Observations	154	154	154	154	154	154	154	154	154

Notes: t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.
Dependent variable: E.U. public R&D pc

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Traditional explanatory factors

Let us start with the traditional factors that might explain the level of public R&D. Using ML, four explanatory variables (private R&D, GDP, trade openness and sectoral specialization) have a significant impact on our dependent variable.

First, we find a positive and very significant parameter for private R&D, suggesting the existence of complementarity between public and private R&D. Let us note that this parameter remains significant whatever the specification - including (or excluding)[17] any other weight matrix. Moreover, the significance of private R&D is not affected by the inclusion of the matrix based on sectoral specialization (W^{AKP}).

Second, trade openness index exhibits a significant and negative sign. The significance of trade openness as a direct covariate is not influenced by the inclusion of a matrix based on any of the two matrices based on trade W^{BIS} and W^{BTF} (see columns 7 and 9 in Table 3). Here we contribute to the controversial empirical literature on the relationship between trade openness and public spending, suggesting that international integration involves more tax competition between countries and, therefore, less capacity to increase taxes and public spending.

Third, the coefficient associated with GDP is significant and positive. Again, the significance of GDP as a direct covariate is not influenced by the inclusion of the weight matrix based on GDP (see column 3 in Table 3). This outcome may indicate that public R&D is higher when macroeconomic conditions improve and is not used as a tool of public policy by governments to boost low economic activities.

We also find a significant coefficient for the AKP variable (although only significant at 10% in columns 2, 5, 7 and 9). Let us also mention that this outcome is not due to a strong correlation between private R&D and AKP (see the correlation coefficient -0.24- in Table 1b in Appendix). The estimation results seem to provide new evidence supporting the complementarity between public spending and the presence of the most innovative sectors.

Finally, we find that European countries do not imitate the decisions made about public R&D by leader countries such as the US and Japan. This seems to reject the presence, or at least the perception, of a European paradox. We should have found a significant coefficient in case of a perceived gap in public R&D spending between Europe and the US and Japan, which would have led to an imitative behaviour in terms of public spending in R&D. Also, interestingly, the Lisbon strategy seems not to have had an effect on the levels of public R&D across EU countries.

Geographic, economic and commercial proximity

Let us turn now to the spatial interactions results. We find a positive and significant coefficient associated with the weighted average of competing countries' public expenditures, based on four of our five weighting schemes.

Weighting schemes based on distance (W^d) do not show any strategic interaction in R&D expenditures, which means that European countries do not strategically interact with spatially close countries other when setting their R&D spending. This result is interesting, as it rejects the common findings of the literature on strategic interactions in public choice, which

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[17] See column 1 in Table 3

generally finds an impact of geographical proximity on the amount of public spending on items different than R&D. This confirms that public R&D is special item of public spending, which responds to a variety of more complex country's characteristics, as mentioned in Section 2.2.

Rather, we find a positive and significant coefficient associated with the weight matrix, which assigns higher weights to countries with similar economic characteristic (GDP per capita). This suggests that European countries with similar GDP levels, i.e. similar economic sizes, tend to spend similar amounts on R&D per capita.

We also find a positive and significant coefficient using weighting schemes, based on trade (W^{BTF}) or import share (W^{BIS}). Proximity, defined from a commercial perspective (as in Cabrer-Borras and Serrano-Domingo, 2007), tends to promote similar decisions on R&D spending among the European countries.

Sectoral specialization and complementarity/substitution between private and public R&D spending

We find a positive and significant coefficient associated with the weight matrix W^{AKP}. Therefore, the estimations results using the weighting matrix based on Castellacci's (2008) typology of AKP confirm the existence of strategic interactions among European countries with similar sectoral and innovation structures. This outcome suggests that countries with similar sectoral specialization make similar decision about public R&D spending, knowing that the levels of public R&D will affect private R&D in similar ways.

It is interesting that European countries that are similar economically and commercially display similar decisions related to public R&D expenditure. This result supports the National Innovation Systems approach, confirming that sectoral specialization does affect the overall amount of public expenditure on R&D, driven by the specific demands of sectors with different R&D intensity.

Overall, our results are in line with the small literature on public spending interactions among European states. Redoano (2003, 2007) observes the existence of strategic interactions among European countries using aggregated and disaggregated data on public spending (defence, education, health). The results in our paper support the conjecture that governments act interdependently when they formulate policy choices related to R&D expenditure. However, they are not necessarily influenced by geographic neighbours in making R&D decisions but are likely to interact with countries that are close economically and from an international trade and sectoral structure perspective. Thus, geographic proximity does not seem to affect public R&D spending decisions.

5.   Concluding remarks

The paper has added conceptually and empirically to two different streams of literature on the determinants of public R&D spending: that on countries' strategic interactions in public choice and the National Innovation System approach within the innovation literature.

On the one hand, the literature on strategic interactions has never accounted for a specific item of public spending, R&D. Within this framework, it is therefore important to investigate whether traditional factors affecting tax or public spending competition among countries that are willing to attract (or avoid the migration of) taxpayers, voters, FDI or multinationals, also affect public decision in R&D spending.

On the other hand, science and innovation policy scholars have mainly tackled the issue of the *impact* of public R&D spending on innovation performance of countries. When considering the *determinants* of R&D policy, they have done so mainly from a NIS perspective, which focuses on the interactions between private firms and sectors, Universities and government. Surprisingly, the NIS approach has – to our knowledge - never considered strategic interactions as one of the several possible competing explanations of public choice on the level of R&D spending.

This paper represents an original contribution from a two-fold perspective. Conceptually, it has filled the gap characterizing the two streams of literature by accounting for the specific role of strategic interactions, along a series of traditional factors, affecting a special item of public spending decision, R&D. From the methodological point of view, the paper has shown that the use of spatial econometric techniques is more robust than non-spatial techniques for the purpose at hand.

The relevance of this conceptual and empirical contribution has to be located within the debate on the European paradox, and in general on the rationale of the Lisbon strategy, which is based on the assumption that a certain degree of 'convergence' in the level of R&D spending among EU countries is desirable. However, by reverting to the NIS approach, we have highlighted that decisions on public spending in R&D have to be explained also in terms of national sectoral and technological structures, which represent the 'demand' for public support in R&D coming from the private sectors (including private R&D). This implies that countries' similarities in levels of public R&D spending might be driven by similarities in their sectoral structure rather than top-down European science policy only, especially if this is confined to countries' levels of R&D spending. This is confirmed by the lack of significance of the Lisbon strategy dummy, which allows us to conclude that public spending in R&D is a much more persistent and structural item of public choice.

From the strategic interaction perspective, we have found support to our conjecture that R&D is not comparable to traditional items of public spending and, as such, national science policy is affected by factors that go beyond traditional (i.e. distance-based) strategic interactions to attract (or avoid the migration of) taxpayers and firms. Interestingly, and in contrast with the empirical strategic interaction literature, our results show that competition based on spatial proximity is irrelevant in determining decisions of a typical country to set a certain level of spending in R&D. However, we find support to the existence of strategic interactions in R&D spending among European countries with similar economic, trade and sectoral structure characteristics, especially the intensity of AKP sectors and private R&D.

These results offer general support to the NIS approach. The historical and cumulative aspects of NIS, such as sectoral and trade specialization and the intensity of private R&D, have emerged as being more relevant as determinants of science policy choices (in their form of public R&D spending) than explanations based on yardstick competition.

Further, the results of our empirical analysis allowed us to draw the following conclusions.

First, within the debate on the existence of a European paradox, our results rather show the presence of a two-way and cumulative relationship between basic science and its technological applications. Accordingly, they support the arguments put forward by scholars who are skeptical of the existence of a European Paradox and hypothesize instead structural weakness of both the EU basic science and the overall STS compared to its main competitors (Dosi et al., 2006). Also, we find no impact of the US and Japan decisions on national R&D spending: this

weakens the presence, or at least the perception, of a European paradox. A perceived gap in public R&D spending would most likely have driven an imitative behavior of EU countries toward the US and Japan, which does not emerge.

Second, we find that the not only sectoral and trade specialization of countries in private AKP explain public R&D spending (Pavitt, 1984; Castellacci, 2008), but also that cross-countries similarities in sectoral, technological and trade structures is responsible for their similarities in public R&D spending[18].

Third, within the debate on public/private R&D complementarities, our results support the presence of complementarities rather than substitutability between public and private R&D investments, again offering overall support to the NIS approach, which relies on the synergic interactions between public and private actors to provide an innovation-fertile environment for firms. Overall, this offers reasons to reflect on the overall rationale of the Lisbon strategy and puts in perspective the panacea role of public R&D only, if not supported by attention to sectoral structure and a sensible industrial policy.

Future research would certainly add to the present contribution in two directions: first, considering separately specific public R&D items such as government and higher education R&D, to investigate the role of publicly funded universities, again within a NIS perspective. Second, enlarging the number of EU countries considered here, compatible with data availability, and considering the role that BRICS countries increasingly have in the global production of R&D.

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[18] This has emerged from the comparison of spatial and non-spatial econometric techniques, and might open up a whole new line of investigation within both the innovation and the public strategic interactions literatures.

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Appendix

Table 1a: Descriptive statistics

Variable	Obs.	Mean	Std dev.	Min	Max
E.U. public R&D p.c.	168	3.69	0.53	2.66	4.54
Lisbon dummy	168	0.58	0.49	0	1
Private R&D p.c.	168	5.28	0.96	2.65	6.67
U.S. public R&D p.c.	168	4.54	0.08	4.45	4.66
Japan public R&D p.c.	168	4.16	0.06	4.04	4.25
GDP p.c.	168	9.97	0.22	9.31	10.46
AKP	168	11.81	3.02	0	14.65
Openness index	168	-0.25	0.38	-0.82	0.61

Note: The unit of R&D expenditure is purchasing power standard per inhabitant, at constant 2000 prices. AKP is the production value of the sector expressed in millions of euros (2000). All variables are in log except Lisbon dummy.

Table 1b. Correlation coefficients

	E.U. public R&D p.c.	Private R&D p.c.	U.S. public R&D p.c.	Japan public R&D p.c.	GDP p.c.	AKP	Openness Index
E.U. pub. R&D p.c.	1						
Private R&D p.c.	0.5544 (0.000)	1					
U.S. pub. R&D p.c.	0.0768 (0.3438)	0.1643 (0.0417)	1				
Japan pub. R&D p.c.	0.0883 (0.2763)	0.2182 (0.0066)	0.5740 (0.0000)	1			
GDP p.c.	0.3555 (0.0000)	0.6063 (0.0000)	0.5857 (0.0000)	0.6039 (0.0000)	1		
AKP	0.5111 (0.0000)	0.2450 (0.0022)	0.1774 (0.0277)	0.2314 (0.0039)	0.3608 (0.0000)	1	
Openness Index	-0.2606 (0.0011)	0.2554 (0.0014)	0.0555 (0.4938)	0.0921 (0.2560)	0.3748 (0.0000)	-0.392 (0.000)	1

P-value in parentheses.

Table 2: Estimation results (OLS) with LM tests

Variables	Estimates
Private R&D $_{t-1}$ p.c.	0.278***
	(4.609)
Lisbon	-0.0232
	(-0.170)
U.S. pub. R&D p.c.	-0.470
	(-0.751)
Jap. pub. R&D p.c.	-0.0961
	(-0.104)
GDP $_{t-1}$ p.c.	0.430
	(1.175)
Openness index $_{t-1}$	-0.541***
	(-5.996)
AKP $_{t-1}$	0.00616
	(0.532)
Constant	0.297
	(0.0673)
Observations	154
R-squared	0.499

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable: E.U. public R&D p.c

LM test results (Non robust and Robust tests)

Weight matrix	LM-LAG	LM-ERR	RLM-LAG	RLM-ERR
W^d	14.63***	16.02***	0.04	1.43
	(0.0001)	(0.0001)	(0.8380)	(0.2313)
W^{GDP}	4.57**	2.40	5.40**	3.23*
	(0.0326)	(0.1214)	(0.0201)	(0.0722)
W^{AKP}	16.05***	12.87***	3.77**	0.59
	(0.0001)	(0.0003)	(0.050)	(0.4442)
W^{BTF}	12.00***	8.74***	5.90**	2.64
	(0.0005)	(0.0031)	(0.0151)	(0.1045)
W^{BIS}	14.44***	8.68***	12.36***	6.61
	(0.0001)	(0.0032)	(0.0004)	(0.1010)

P-value in parentheses. (R)LM-LAG and (R)LM-ERR are (robust) non-robust tests.
*** p<0.01, ** p<0.05, * p<0.1

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