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Abstract:
The aim of this paper is to test the presence of strategic interactions in government spending on Research and Development (R&D), among EU-15 countries. We add to the literature on public choice strategic interactions in general, and to work on R&D spending in particular. We take account of traditional and some rather overlooked factors related to countries' public R&D spending, including (i) the international context – i.e. Lisbon strategy; (ii) country characteristics - the National System of Innovation; (iii) national similarities in relation to (a) trade and economic size and (b) sectoral specialization. Sectoral specialization is likely to affect government spending, depending on the mechanisms of complementarity or substitution between public and private R&D. Using a dynamic spatial panel model in which spatial matrices are specified in terms of traditional Euclidean distance, and sectoral specialization proximity, we confirm the existence of strategic interactions in relation to R&D spending among European countries with similar economic, international trade and sectoral structure perspectives. Unlike the results for strategic interactions in public choice, geographic proximity seems not to affect interactions related to public spending on R&D.

Keywords: Public R&D expenditures, National Systems of Innovation, complementarity public and private R&D, spatial interactions, EU countries, spatial dynamic panel data.

JEL codes: H5; 03

1. Introduction

The literature on fiscal policy provides evidence of strategic interactions in public decisions on both taxes and public expenditure, across countries. There is a series of factors that might explain these interactions among governments, including 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, but depend partly 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).

To our knowledge, though, none of these contributions deals with R&D as a specific item in public expenditure. 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 from innovation, and the higher are national growth rates. There is a large conceptual and empirical literature on the role of R&D as an important lever of national innovation performance and growth, which has sparked lively debate on – among other issues - comparative EU-US advantage, the optimal combination of science policy interventions, and whether public R&D spills over to private firms and affects their R&D expenditure. We review a selection of this literature highlighting factors that drive policy makers' choices related to R&D expenditure, and might affect spatial 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, the issue is more nuanced; a neighbor with higher levels of R&D expenditure might be in a more favorable position to attract firms or foreign direct investment (FDI) and negatively affect typical national competitiveness. 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 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 these decisions related to the amount of EU countries' R&D expenditure and, if so, what are their determinants. Our conjecture is that, in addition to factors traditionally affecting public expenditure, such as 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. Our results add to the findings on complementarity versus substitutability of public and private R&D.

We test the existence of spatial interactions related to public R&D expenditures for the EU-15 countries using panel data for the period 1994-2006. We employ dynamic panel estimations and different spatial matrix specifications, which account for the specificity of public R&D expenditure. We obtain three main results. 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. Second, we show that the proximity of European countries from an economic and commercial perspective tends to be accompanied by 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.

The paper is organized as follows. Section 2 reviews the relevant literature and justifies the empirical strategy and analysis. Section 3 discusses some econometric issues in the empirical implementation of the model. Section 4 summarizes and discusses the estimation results. Section 5 concludes.

2. Background literature

2.1. Mainstream theory: strategic interactions in public decisions

A number of empirical studies show the relevance of the theoretical literature on strategic interactions related to fiscal or 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 were obtained using data for 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 papers estimate reaction functions for taxes using OECD country datasets (see Besley et al. , 2001; Devereux et al. , 2002; Altshuler and Goodspeed, 2002).

Most of the empirical literature is concerned with reaction functions for taxes. However, local or national governments tend to focus on how their expenditure compares with that of their neighbors. The reasons for these behaviors may be broadly similar, that is, fear of driving taxpayers to migrate to another state or of attracting welfare recipients from other states, if social benefits are too generous. This is the hypothesis related to tax and welfare competition. Another reason is yardstick competition and, more generally, the existence of spending spillover effects on neighboring regions or states. A few papers focus explicitly on public expenditure. Exceptions are papers by Case et al. (1993), Figlio et al. (1999), Baicker (2005) and Redoano (2003, 2007). Most of this work is based on US data. For instance, Case et al. (1993) estimate the effect of one 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 state spending causes spending in neighboring states to increase by between 37cents and 88 cents. Redoano (2003) estimates reaction functions for (aggregated and disaggregated) taxes, public expenditure using a dataset of EU countries for the period 1985-1995. She finds that governments behave strategically with respect to expenditure that is more directly comparable, such as spending on 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.

To our knowledge, the literature on strategic interactions reviewed above does not deal with R&D expenditure. R&D spending decisions are part of long-term, structural government policy at the intersection between science, innovation and industry and competition policies. Within the strategic interaction 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, public R&D expenditure

is a very specific item of public policy that is likely to be linked to a more complex set of factors than only competition. We address this possibility below.

2.1 *The specificity of public R&D expenditures in the EU: framing the debate*

We review three streams of the large literature on R&D policy that are relevant to the present work, are illustrative of its motivations, and support the empirical model proposed. In 2.2.1, we discuss the debate on the so-called 'European Paradox', and the features of EU-wide science and technology policy (the European Science and Technology System – STS) vis-a-vis that of the US and Japan. We review the literature on the determinants of R&D policy and (2.2.2) country characteristics or NIS, which measures a country's ability to foster innovation. We account specifically for 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 a crucial issue (see 2.2.3): the relation between private and public R&D and particularly whether they are complements or substitutes.

Our overall aim in the context of the debate on public R&D includes:

1. going beyond the traditional strategic interaction literature, which might not capture the specific determinants of countries' similarities in public R&D spending;

2. identifying the main determinants of national similarities in public R&D spending in the innovation and science policy literature (NIS, sectoral specialization, public-private R&D complementarity) and translating them into an empirical strategy (see below);

3. testing the efficacy of both streams of the literature in an empirical analysis that uses spatial econometric techniques.

2.1.1.   The logic of basic scientific research and the 'European Paradox'

The Lisbon strategy 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, EU, 2004; Nelson, 2006; Dosi et al., 2006). As a way of reframing debate on the nature and impact of public R&D and 'basic research', Dosi et al. (2006) reprised some stylized facts related to scientific and technological knowledge being public goods, subject to uncertainty and serendipity. 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), however, the literature points to a two-way, self-reinforcing link between basic research and its technological and industrial applications

(Pavitt, 1987).

It is the co-evolution and the mutual enrichment of basic science and technological advances that increase national technological competitiveness (Pavitt, 1987; Freeman, 1982, 1994). R&D spending decisions, therefore, are not just a matter for central government policy - although it is governments that take these decisions (Pavitt, 2001; Nelson, 2004, 2006) – they are also partly affected by the behavior of private businesses.

Scholars who highlight the 'European Paradox', depict the European STS 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 not only in terms of scientific research[1] but also in relation to innovation output, and shows that the returns from EU R&D are lagging with respect to the US and Japan.[2] However, the evidence is not conclusive about the existence - and importance - of a 'European Paradox' since it depends on measurement and empirical issues.

2.1.2. *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)[3] (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. 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). While traditional country characteristics, such as size,

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[1] 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.

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

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

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 and so forth.

There are three elements of the NIS approach that are important for the present study:

(1) the role of public R&D spending decisions and − more widely − public support for the innovation process in the form of 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 (see above);

(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).[4]

These three elements are all core constituents of the NIS (Freeman 1987; Nelson, 1993; Lundvall 1992) as historical cases show (Freeman, 1987, 2002). The first point represents the main variable of interest for this work; the second element, the role of those sectors and firms that create and develop the national technological knowledge base, should be considered in some detail before examination of public R&D spending at the national level.

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[5] has been very widely cited, and 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'

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[4] This literature proposes some additional issues related to NIS –academic systems and the effectiveness of university-industry linkages. We do nt include these in the present analysis, which is linked to decisions about the amount of R&D spending rather than its different possible destinations.

[5] 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)NOT IN REFS.

(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).

AKP – along with traditional science based sectors – are the private counter-part to 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 across countries is a core element of the closeness 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 public R&D expenditure: that related to the links between public and private R&D spending in particular.

2.1.3.   *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 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 affects publicly funded or publicly performed R&D, in order to establish the existence of complementarity. That is, whether public spending spillovers affect private 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.[6]

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

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[6]   See David et al. (2000) for a review of the econometric evidence from, mostly, firm level studies.

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 towards 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 not 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 the opposite effect has emerged, with a displacement effect within the two.

One of the contributions of the present study is to investigate whether public R&D spending decisions are influenced by the structure and intensity of private R&D-related sectors – the AKP referred to above. Although framed slightly differently in relation to the determinants of public spending decisions rather than their explicit effects on privately funded R&D - providing evidence of the spatial interactions in public R&D caused by countries' sectoral structures and technological innovation intensity, may shed light on whether these elements are complements or substitutes.

2.2 The empirical contributions

We acknowledge the importance of the debate over the European Paradox reviewed in Section 2.1.1, and add to in taking account not only the determinants of public decisions related to R&D spending but also their spatial interactions across the EU 15 countries compared to the US and Japan. Traditional determinants are considered along with the sectoral structures and technological strengths of countries. If these latter two factors positively and significantly affect public R&D expenditure, this will provide support for: (1) a two-way and cumulative relationship between basic science and its technological applications; and (2) the arguments proposed by scholars who are skeptical of the existence of a European Paradox and hypothesize instead structural weakness of the EU STS compared to its main competitors (Dosi et al., 2006).

We also make two contributions to the NIS literature (reviewed in Section 2.1.2): first we conjecture

and empirically test whether there are interactions among NIS (although the countries and NIS in the European STS are fairly different). Second, we argue that this heterogeneity stems from the inter-linkages between public R&D spending and sectoral specialization of countries in private AKP (Pavitt, 1984; Castellacci, 2008). We construct spatial interaction matrices based on countries' similar industrial and technological structures.[7] This allows us to analyze whether there is complementarity or substitutability between private and public R&D since AKP include private R&D sectors (see Section 2.1.3), which contributes to the empirical literature.

Finally, we contribute to the large spatial strategic interaction literature by focusing on a specific public expenditure item, R&D, which has not been a focus in the literature so far.

3. The empirical model

The objective of this paper is to test the existence of interactions among the EU-15 countries in relation to public R&D expenditure. 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 ($j{\neq}i$) at time t, and $X_{i,t}$ 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:

$$Z_{i,t} = \alpha_i + \rho W Z_{j,t} + \beta X_{i,t} + \varepsilon_{i,t} \tag{1}$$

We also include as an explanatory variable the time-lagged dependent variable ($Z_{i,t-1}$), because government spending change only slowly over time not instantaneously (Devereux et al., 2002; Dreher 2006; Redoano 2007). The equation then becomes:

$$Z_{i,t} = \alpha_i + \gamma Z_{i,t-1} + \rho W Z_{j,t} + \beta X_{i,t} + \varepsilon_{i,t} \tag{2}$$

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[7] These methodological issues are detailed in the next section.

We include several the control variables in *X*.

For the reasons outlined in section 2.2., we include private R&D. However, the existing empirical literature does not provide a conclusive answer about the existence of complementarity or substitutability between public and private R&D. The sign of the parameter will indicate whether private and public R&D are complements (positive sign) or substitute (negative sign). To cope with possible endogeneity, we use instruments for this variable (see Table 3).

We want to test also 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 the EU-15 countries after 2000 and the expected value for this parameter is positive.

We include the level of public R&D set by the leader countries (US and Japan) expressed as innovation. We test the hypothesis that public decisions made by these two countries influence public R&D in Europe. Expected values for the parameters are positive.

Finally, individual fixed effects are introduced to capture the specific characteristics of each country over time. Expected signs for each control variable are summarized in Table 1a.

3.1. Data and descriptive evidence

Data on public R&D are from national R&D surveys that comply with Frascati Manual (OECD, 2002) recommendations. The overall quality of the R&D statistics can be assessed by comparing among 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.[8]

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[8] 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 as one of the specifications of the distance matrix is countries' proximity in terms of sectoral specialization.

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.

We use pooled data for the 15 EU countries for 1994-2006, which gives 195 observations. A panel data approach allows us fully to exploit the spatial and temporal dimensions of the data. Appendix Table 1a presents the variables used in the model and the expected signs of the control variables. Appendix Table 1b presents the correlation coefficients of our variables.

Figure 1 depicts 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 EU-15 and its main competitors for R&D is a well established phenomenon with structural rather than cyclical causes; it suggests also that these structural causes are still in place.

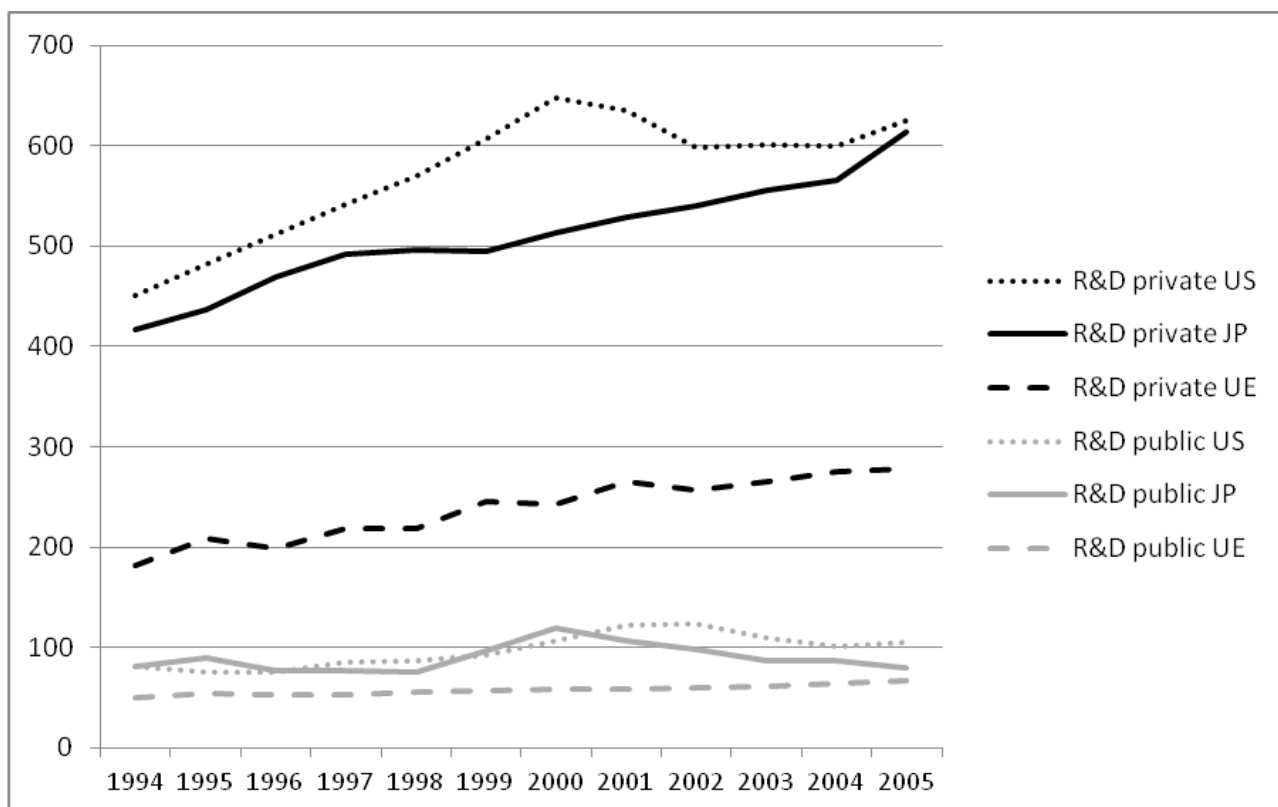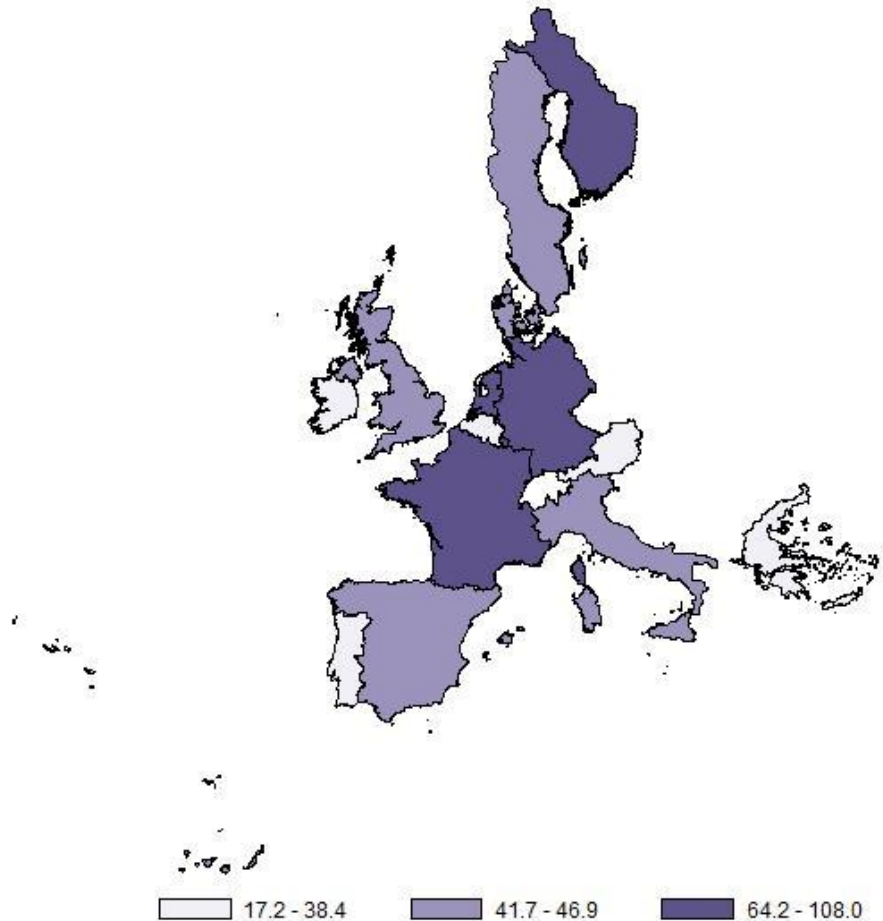Figure 1: Gross domestic expenditure on public R&D (euro per inhabitant)

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 EU-15 for public

R&D. We test this econometrically.

Figure 2. Gross domestic expenditure on public R&D (euro per inhabitant) in the EU-15 for 2006.

17.2 - 38.4	41.7 - 46.9	64.2 - 108.0

3.2. Econometric issues

Spatial dependence raises two econometric issues. First, if countries react to the spending choices 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:

$$\varepsilon_{i,t} = \lambda W \varepsilon_{i,t} + v_{i,t} \tag{3}$$

If spatial error dependence is ignored, estimation of (2) might provide false evidence of strategic

interaction.

If the time-lagged dependent variable ($Z_{i,t-1}$) is included in the regression, the Arellano and Bond (1991) GMM (General Method of Moment) estimator is appropriate. However, since there is some persistence in expenditures, it might be more appropriate to estimate a system-GMM (Veiga and Veiga, 2007). Blundell and Bond (1998) show that this extended GMM estimator is preferable to Arellano and Bond's (1991) GMM if the dependent variable, or the independent variables, or both are persistent. If the level of an explanatory variable is correlated with the fixed effects but its first-differences are not, lagged values of the first-differences can be used as instruments in the equation in levels (Arellano and Bover, 1995). Lagged differences of the dependent variable can also be valid instruments for the levels equations. The validity of the instruments used in the regressions is evaluated using the Sargan (or overidentifying restriction) test, which examines the hypothesis that the instruments are not correlated with the residuals.

Following Kukenova and Monteiro (2008), to estimate a spatial, dynamic panel model, it is appropriate to use the system-GMM estimator developed by Blundell and Bond (1998). Table 3 shows the set of instruments used for the endogenous variables. For neighbors' spending decisions, following Devereux et al. (2002) and Redoano (2007), we use the weighted average of the neighbor control variables, that is, their socio-economic characteristics (*WX*), as instruments.

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 related 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 Euclidian 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 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):

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

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 the EU-15. 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} respectively are bilateral exports and import shares.

Lastly, we introduce a third category of the weight matrix W^{AKP} to take account of 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.[9] We build on Pavitt's (1984) taxonomy and extensions to it (Pavitt, 1989; Archibugi, 2001; Castellacci, 2008). Using Castellacci's (2008) taxonomy, we identify and assess the extent of 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. In line with the literature reviewed in Section 2.2.3, we assume 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:

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

As is common in this literature, all the weight matrices are standardized so that the elements in each row sum to 1.

4. Results

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[9]   AKP are characteristic of two sub-groups of industries in this category: (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).

Our estimation strategy is as follows. First we estimate the model using OLS without taking account of the possible effect of the expenditures set by other countries ($\rho = 0$) and without taking account of the lagged value of our dependent variable ($\gamma = 0$). We run the appropriate spatial tests based on the Lagrange Multiplier (LM) using every weighting scheme. This test indicates the presence of spatial lag dependence but not spatial error dependence, for four of the five weight matrices. The estimations results of the non-robust and robust LM tests using OLS are shown in Appendix Table 2.

Table 3 shows the estimation results of the dynamic model using system-GMM. Column 1 estimates equation (2) without taking into account the possible effect of other countries' expenditure ($\rho = 0$) but allowing for the time-lagged value of the dependent variable ($\gamma \neq 0$). Columns 2 to 6 show the estimation results taking account of the lagged value of the dependent variable ($\gamma \neq 0$) and the possible impact of the level of expenditure set by other countries ($\rho = \neq 0$) using the five weighting schemes. Country fixed effects are included.

Insert Table 3

Table 3 shows that the lagged endogenous variable ($Z_{i,t-1}$) is always significant and has a positive sign in all the specifications. This confirms both the consistency of the autoregressive specification in equation (1) and the hypothesis that R&D spending is likely to change only slowly over time.

We find a positive and significant coefficient associated with the weighted average of competing countries' public expenditures, using four of our five weighting schemes. Weighting schemes based on distance (W^d) do not provide any strategic interaction in R&D expenditures, which means that European countries that are geographically close do not mimic each other when setting their R&D spending.

Geographic proximity and R&D spending
In contrast to the literature on strategic interactions in public choice, we find no evidence of an impact of geographic proximity on amounts of public spending on R&D. However, we find a positive and a significant (at the 10% level) 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, that is similar economic sizes, tend to spend similar amounts on R&D.

We find a positive and significant (at the 10% level) coefficient using either weighting scheme, 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 about spending on R&D among the EU-15 countries.

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

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. We find a positive and significant coefficient associated with the weight matrix W^{AKP}.

It is interesting that European countries that are similar economically and commercially display similar strategic interactions related to public R&D expenditure. This result supports the spirit of the Innovation Systems literature, 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.

As a corollary of these findings, we found also that strategic interaction occurs in relation to public R&D spending, among European countries with similar technological structures and patterns of private R&D spending.

This supports the empirical conjectures in section 2.4. that:

1. there is a strong link between government investment in basic science and its technological applications. This supports those who are skeptical about the existence of a European paradox: if the EU were excellent at basic research, our results suggest that it would also demonstrate excellent technological application and innovation performance.

2. public R&D investments are similar in countries with similar specialization in private knowledge providers– i.e. in specialised private R&D sectors. This contributes to the literature on NIS – to the extent that advanced knowledge providers are part of the national systemic innovation performance.

3. The above results adds indirectly to the empirical literature on public-private R&D by demonstrating complementarity rather than substitutability, which is in line with David et al. (2000) – at least at the country level (see discussion below on the private R&D coefficient as a control variable).

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 (defense, 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 neighbors 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. Note that further research is needed to investigate whether those interdependencies are due to tax competition, that is, whether countries imitate each other in order to avoid taxpayers leaving for other jurisdictions, or to yardstick competition to avoid alienating voters and risking not being reelected.

None of the control variables was significant. When private R&D is introduced as an exogenous variable (as in Table 2), it is positive and highly significant. However, we cannot rely on this result since private R&D is likely to be endogenous. When private R&D is properly instrumented as an endogenous variable (see Table 3), it is no longer significant whatever the specification - including (or not) any other weight matrix. Therefore, the non-significance of private R&D is not due to the inclusion of the matrix based on sectoral specialization. We can conjecture that public R&D affects private R&D but that the reverse does not apply. The high significance of the sectoral specialization distance matrix – testing for closeness in sector specialization in AKP including private R&D - 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. Since they have similar sectoral specialization characteristics, they will have similar levels of public R&D.

Finally, we find that European countries do not copy the decisions made about public R&D by leader countries such as the US and Japan. These two countries are innovation leaders, but the EU countries do not seem to be influenced by the levels of public R&D in those countries. Also, the Lisbon strategy seems not to have an effect on the levels of public R&D in EU countries.

5.   Concluding remarks

This paper aimed to contribute to several strands in the literature – on spatial and strategic interaction of public choices, and on the motivations for and the debate around public expenditure on R&D. While NIS and sectoral specialization arguments are familiar to innovation scholars, their exploitation in relation to strategic interactions in public spending and more particularly within a spatial interaction framework, is less frequent. We have provided new evidence on the extent to which closeness in sectoral and technology structure and private R&D expenditure affect trends in public R&D spending decisions.

We estimated a spatial dynamic panel model. The results confirm the existence of strategic interactions in R&D spending among European countries with similar economic, commercial and innovation conditions. Interestingly - and in contrast to the findings for public strategic interactions - we found that geographical proximity does not seem to influence public spending.

The results in this paper show that competition based on traditional proximity does not hold for the case of public R&D. Similarity of public R&D expenditure is related to NIS characteristics and especially sectoral specialization. The historical and cumulative aspects of NSI as a determinant of science public choice emerged as being more relevant than mainstream explanations based on yardstick competition. This result will add to the work on strategic interaction in public choice scholars, which so far has ignored R&D policy. .

Future research could consider separately specific R&D items through an investigation of business enterprise, government and higher education R&D.

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Appendix

Table 1a: Descriptive statistics

Variable	Min	Max	Mean	Std deviation	Expected sign
E.U. public R&D p.c.	14.09	99	47.24	23.93	Dep. Var.
Japan. public R&D p.c.	57.2	69.7	63.95	4.0	+
U.S. public R&D p.c.	85.2	101.8	93.24	5.59	+
Dummy Lisbon	0	1	0.55	0.49	+
Private R&D p.c.	14	787.5	286.21	194.8	+/-

Source: Eurostat

Table 1b. Correlation coefficients

	Priv. R&D	US pub R&D	Jap. pub R&D	W^d*pub R&D	W^{GDP}*pub R&D	W^{AKP}* pub R&D	W^{BTF}*pub R&D
US pub R&D	0.1309 (0.1023)	1.0000					
Jap. pub R&D	0.2325 (0.0034)	0.4904 (0.0000)	1.0000				
W^d*pub R&D	0.3515 (0.0000)	0.5206 (0.0000)	0.4401 (0.0000)	1.0000			
W^{GDP}*pub R&D	0.0392 (0.6257)	0.2876 (0.0003)	0.4776 (0.0000)	0.4901 (0.0000)	1.0000		
W^{AKP}* pub R&D	0.5327 (0.0000)	0.1751 (0.0283)	0.4552 (0.0000)	0.5999 (0.0000)	0.3292 (0.0000)	1.0000	
W^{BTF}*pub R&D	0.2740 (0.0005)	0.2812 (0.0004)	0.4563 (0.0000)	0.6348 (0.0000)	0.4502 (0.0000)	0.6858 (0.0000)	1.0000
W^{BIS}*pub R&D	0.2423 (0.0022)	0.2520 (0.0015)	0.3933 (0.0000)	0.5841 (0.0000)	0.4101 (0.0000)	0.6831 (0.0000)	0.9701 (0.0000)

Note: P-value in parentheses

Table 2: Estimation results (OLS) with LM tests

VARIABLES	(1) EU Pub R&D ($Z_{i,t}$)
Priv. R&D $_{i,t}$	0.545***
	(19.6)
US pub R&D $_{i,t}$	0.050
	(0.03)
Jap. pub R&D $_{i,t}$	0.007
	(0.007)
Lisbon $_{i,t}$	-0.025
	(-0.117)
Constant	0.533
	(0.060)
Observations	165
R-squared	0.070

Notes: T-statistic in parentheses
*** p<0.01, ** p<0.05, * p<0.1

LM test results (Non robust and Robust tests)

Weight matrix	LM-LAG	LM-ERR	RLM-LAG	RLM-ERR
W^d	7.79***	5.56**	2.31	0.08
	(0.0052)	(0.0183)	(0.1282)	(0.7717)
W^{GDP}	0.92	0.02	3.14*	2.24
	(0.3383)	(0.8967)	(0.0762)	(0.1342)
W^{AKP}	22.79***	3.12*	32.92***	13.25***
	(0.0000)	(0.0772)	(0.0000)	(0.0002)
W^{BTF}	9.33***	0.65	39.59***	30.91***
	(0.0022)	(0.4188)	(0.0000)	(0.0000)
W^{BIS}	9.44***	0.96	37.53***	29.05***
	(0.0021)	(0.3262)	(0.0000)	(0.0000)

Notes: 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

Table 3: Estimation results (GMM)

VARIABLES	(1) $Z_{i,t}$	(2) $Z_{i,t}$	(3) $Z_{i,t}$	(4) $Z_{i,t}$	(5) $Z_{i,t}$	(6) $Z_{i,t}$
$Z_{i,t-1}$	0.602**	0.704***	0.842***	0.797***	0.860***	0.891***
	(2.364)	(2.871)	(5.076)	(6.530)	(11.21)	(15.67)
Priv R&D $_{i,t}$	0.155	0.120	0.0488	0.0431	0.0344	0.0159
	(1.110)	(0.901)	(0.490)	(0.469)	(0.573)	(0.342)
Lisbon $_{i,t}$	-0.0500	-0.0717	-0.0631	-0.0480	-0.0420	-0.0395
	(-1.436)	(-1.640)	(-1.483)	(-1.308)	(-0.972)	(-0.900)
US pub R&D $_{i,t}$	0.221	0.306	0.320	0.280	0.150	0.145
	(0.740)	(0.935)	(1.209)	(1.129)	(0.583)	(0.563)
Jap. Pub R&D $_{i,t}$	-0.0546	-0.240	-0.394	-0.510*	-0.331	-0.311
	(-0.269)	(-0.768)	(-1.626)	(-1.863)	(-1.363)	(-1.289)
$W^{d}* Z_{j,t}$		0.0572				
		(0.540)				
$W^{GDP}*Z_{j,t}$			0.302*			
			(1.743)			
$W^{AKP}* Z_{j,t}$				0.245**		
				(1.972)		
$W^{BTF}*Z_{j,t}$					0.397*	
					(1.680)	
$W^{BIS}* Z_{j,t}$						0.419*
						(1.798)
Constant	-0.0801	-0.0781	-0.567	0.509	-0.480	-0.648
	(-0.0428)	(-0.0588)	(-0.395)	(0.376)	(-0.353)	(-0.471)
Observations	142	142	142	142	142	142
Sargan test (p. value	(0.384)	(0.427)	(0.619)	(0.788)	(0.747)	(0.777)

Notes: Robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Dependent variable ($Z_{i,t-1}$) is instrumented by its 2nd and lower lags values and the exogenous variables. Endogenous variables ($W^{d}* Z_{j,t}$, $W^{AKP}* Z_{j,t}$) are instrumented by their first lag value and the exogenous variables (X). Endogenous variables ($W^{GDP}*Z_{j,t}$, $W^{BTF}*Z_{j,t}$, $W^{BIS}* Z_{j,t}$) are instrumented by their first and lower lags values and the exogenous variables (X). Endogenous variables (Priv R&D $_{i,t}$) is instrumented by its first and lowers lags value and the exogenous variables (X)