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2009

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Documentos de Trabajo
N.º 0925

BANCO DE ESPAÑA
Eurosistema

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(*) The opinions and analyses herein are the responsibility of the authors and, therefore, do not necessarily coincide with those of the Banco de España. The authors thank seminar participants at Banco de España for helpful comments.

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Documentos de Trabajo. N.º 0925
2009

ISSN: 0213-2710 (print)
ISSN: 1579-8666 (on line)
Depósito legal: M. 45413-2009.
Unidad de Publicaciones, Banco de España

Abstract

We develop the barebones of a highly stylized theoretical endogenous growth model for analyzing the impact of R&D investment on long run growth. We use this framework to identify a structural vector autoregressive (SVAR) model on GDP growth, inflation and R&D investment, along with the (exogenous) flows of global knowledge, for the period 1970-2006 for the six more developed economies plus Spain. Besides, we also study the impact of private and public R&D on economic activity and prices or whether public R&D investment crowds out private one. Overall, we find that R&D shocks have a positive impact on economic activity, but a heterogeneous effect on prices. Moreover, public R&D disturbances tend to crowd out private R&D investment, except in the less innovative economies. And finally, demand shocks tend to have a negative impact on private R&D spending in the short- to medium-run.

JEL Classification: O30; O40; H50.

Keywords: R&D; Innovation; Endogenous growth; Crowding out; SVAR.

1 Introduction

It is well known that, once it has been reached the intensive and extensive margins of labour utilization, the only remaining determinant of society welfare is productivity. Therefore, the main target of economic policies should be to enhance this variable or, at least, to create the conditions that favour its improvement. However, the level and evolution of productivity can reflect very different aspects of an economy or, even more, of the society. For example, the educational level of the labour force, the capital intensity and the quality of the productive system, the infrastructure network, the financial system, the institutions of the labour market, the organization of product markets, among others, are features that both the theoretical models and the empirical studies have shown to have an impact on productivity. In any case, the economic literature is unanimous in considering that one of the main determinants of productivity in the long run is technological change.[1]

The development of technology is a consequence of innovation, which is a broad concept that can basically be classified into product-innovation (the introduction of new products in the market or the meaningful improvement of existing ones) or process-innovation (changes in production or distribution processes implying a reduction in the producing cost or an increase in the quality of the product).[2] The basic input of innovation is investment in research and development (R&D), although there are other innovative activities which may be even more important, such as purchases of technology or equipment, learning by doing, accumulated know-how, etc. R&D investment collects the set of creative activities developed in a systematic way in order to increase the stock of knowledge as well as to conceive new applications of existing knowledge. Hence, it is characterized as a "productive process" which is highly uncertain and discontinuous in time, implies large fixed sunk costs and has characteristics of a public good, since knowledge "consumption" is non-rival. These theoretical peculiarities reveal the importance of analyzing the relationship between productivity and R&D investment from an empirical perspective.

There is a considerable amount of empirical evidence on the effects of R&D investment on economic activity for most developed countries. The usual approach consists in estimating a production function [Griliches (1979)], where one of the productive inputs is knowledge, which is proxied by the accumulation of private R&D investment. With respect to the data considered, the analyses include both aggregated and firm-level data, and, in this last case, either in cross-section or panel data form. In general, the results obtained tend to support the existence of a positive impact of private R&D investment on productivity growth, although, not surprisingly, its size varies across studies.[3]

In any case, R&D investment is not only performed by the private sector, the public sector and non-profit institutions also dedicate part of their resources to this activity, thus, potentially influencing aggregate productivity. However, in this case the empirical results are

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1. There are many references supporting this claim. For a new and good overview see D. Acemoglu's book *Introduction to modern economic growth* (2009).

2. The Oslo Manual [OECD (2005)] introduced two new types of innovation, namely, *organizational innovation*, related to improvements in the working place, labour practices or external relations, and *innovation in the methods of marketing* (design, pricing, brands, logos, etc). However, the focus of most papers on this subject has been on the classical forms of innovation.

3. For a survey of this literature and the limitations of the production-function approach see Griliches (2000). In the case of the Spanish economy, the estimated elasticity of output to private R&D investment is lower than in its peer countries; see, among others, Lafuente *et al.* (1986), Fluviá (1990) and Beneito (2001).

not so conclusive, probably because of the difficulty in capturing the lag it takes to influence productivity due to the less applied nature of this investment [Mamumeas (1999)]. Guellec and Van Pottelsberghe (2004) make a brief summary of some literature studying the impact of public research on productivity and find mixed evidence. However, they provide new results that favour a positive role for public R&D in multifactor productivity of the industrial sector across OECD economies. Besides, there is a debate as to whether government funding of R&D activities has a positive impact on private sector R&D expenditures. One the one hand, thanks to public support, or to the basic knowledge produced on government funds, the private return on R&D investment may be improved, triggering higher R&D spending by private businesses. However, it is also possible that government funding (in a broad sense) crowds out private companies, either directly —pre-empting technological opportunities or funding for projects they would have carried out anyway— or indirectly, by increasing the demand, and hence the market price, of resources needed for R&D.[4]

Other aspect stressed in the R&D empirical literature is the existence of spillover effects; that is, the possibility that the analyzed economic agent benefited not only from the R&D performed by itself but also from that performed by other (closer) agents. Thus, both at the firm level [see, for example, Bernstein and Nadiri (1991) or Wolff (1997)] and at the country level [Patel and Soete (1988) or Guellec and Van Pottelsberghe (2004)] these spillover effects has been well documented. In particular, since the pioneer work by Coe and Helpman (1995)[5] there has been several papers estimating a positive and significant effect of foreign R&D on domestic productivity, provided that the country has the capacity to absorb technology from abroad.

In this context, this paper tries to shed some light on the impact of R&D investment on activity and inflation both in the short and the long run using a somewhat original approach. In order to do that we develop a highly stylized conceptual framework for analyzing the impact of R&D investment on long run growth along the lines of Bartelsman (1990), Park (1998) and Estrada (2006). Then, we use this framework to identify a structural vector autoregressive (SVAR) model on GDP growth, inflation and R&D investment, along with the (exogenous) flows of knowledge from the main trade partners. Further, in an expanded version of the model, we also take into account the role of public R&D investment, so that we can disentangle the different roles played by the different sources of technology (private and public research and international knowledge spillovers). We apply the empirical methodology to quarterly data from 1970 through 2006 for the six more developed nations (the US, Japan, Germany, the UK, France and Italy) and Spain.

This aggregate approach to identify technological disturbances and to analyze its impact on economic activity has been widely used in the past [Shapiro and Watson (1988), Blanchard and Quah (1989) and Galí (1999)]. More recently, Shea (1999) made use of two observable indicators of technological change, namely, R&D spending and patent applications, to identify a SVAR on US data on manufacturing firms in order to study how a typical industry's inputs and TFP respond over time to technology shocks. Fisher (2006) pursued a related avenue when identifying technology shocks,[6] although he included the real investment goods price in order to distinguish traditional technology shocks from those embodied in the more recent vintages of capital goods. The advantages of the aggregate

4. Guellec and Van Pottelsberghe (2003) provide an overview of these issues and generally find a positive impact of different public R&D funding instruments on business R&D spending.

5. Coe, Helpman and Hoffmaister (2008) confirm previous results from Coe and Helpman (1995), even after controlling for human capital or institutional differences, though these differences alter the degree of R&D spillovers.

6. Saint-Paul (1993) also studied a SVAR with R&D spending in order to analyze the impact of demand shocks on productivity, both in the short and in the long run.

approach are, among other, that it allows including easily the R&D performed by other sectors apart from the private one, jointly analyzing the different decisions adopted by the private and public sectors, considering the common disturbances affecting the economy and studying the dynamics of the process. Thus, this approach should be seen as a complement and not a substitute of the more disaggregated analysis, which is strictly necessary when, for example, the objective is to study the interaction between innovative activity and the structure of the product market where the firm operates or the effectiveness of a specific public supporting policy.

Thus the document is organized as follows. The second section develops the theoretical model and how it is transformed into an empirical one. The third section makes a descriptive analysis of the data used to estimate the SVAR, discusses the main results and checks their robustness. Section four tries to differentiate the multipliers of private and public R&D on activity and inflation, driving the attention to the possible crowding out-crowding in effects between both sectors. Finally, some conclusions and policy implications are extracted in the last part of the paper.

2 A stylized theoretical model of endogenous growth

The first step in using the SVAR methodology consists in specifying a theoretical model which, by imposing certain constraints on some of the parameters in the underlying VAR, allow to identify the "structural" (in other words, economically meaningful) shocks contained in a given group of variables. Given the difficulties to reach a consensus on the "true" business cycle theoretical model and since the focus of this paper is mostly on the long run impact of innovation activities on the economy, constraints are only imposed in the long run multipliers of the VAR —where the theoretical consensus is somewhat larger—. Moreover, we allow for rich dynamics by letting the data speak freely in the short run, which is why the cyclical economic mechanisms at work are not explicitly modelled. Thus, in this section we present the barebones of a very stylized endogenous growth model that accounts for R&D investment and considers the possibility of knowledge spillovers from other countries, along the lines, *inter alia*, of Jones (2002). A more comprehensive and detailed version of our model might be that of Bartelsman (1990) or Park (1998).

In this model, the growth rate of the economy in the long run is determined by the interaction of two sectors: the final goods and services producing sector and the research sector. Moreover, this last branch of activity can draw "ideas" from a pool of global knowledge relevant to their activity. These new ideas, or knowledge, can be directly used to produce final goods by combining them with labour.[7] Hence, the production function of final goods and services *(Y)* is in logarithmic form:

$$y = ln(b_p) + n + \alpha\, h_{-1} + \theta \qquad [1]$$

where $\alpha>0$, b_p represents the share of employment devoted to this kind of production, N is total employment, H_{-1} the stock of knowledge capital available at the beginning of the decision period and θ a productivity shock not linked to the generation of new ideas, i.e. linked to improvements in the efficiency with which factors of production and technology are combined to produce output (thus, it captures improvements in human capital quality, infrastructures, institutions, and so on). Several features of this production function deserve further explanation. First, replication would justify constant returns to scale to labour, while the knowledge stock can have either increasing ($\alpha>1$), constant ($\alpha=1$) or decreasing ($\alpha<1$) returns. In any case, returns to scale are increasing in both productive factors, which are also complementary. Secondly, the productivity shock contains a unit root on a "traditional" supply shock (ε^s) and it shows persistence, so it evolves according to the following stochastic process:

$$\Delta\theta = \rho_\theta \Delta\theta_{-1} + \varepsilon^s \qquad [2]$$

where $0<\rho_\theta<1$.

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7. In order to keep the problem tractable, we consider that the only capital stock is knowledge, while the physical capital stock is given. The model could be extended to include an intermediate sector which buys ideas from the research sector in order to package them into a physical capital good used for final output production; the identification of this model is very similar to that proposed here.

In the model, we allow for the possibility that scientists, engineers and researchers in general can benefit from the knowledge generated in other countries, which, in line with most empirical literature [see, inter alia, Coe and Helpman (1995), Coe, Helpman and Hoffmaister (2008) or Guellec and Van Pottelsberghe (2004)], could generate positive international spillovers on multifactor productivity. Thus, we assume that foreign ideas contribute indirectly to the final output, which seems quite sensible, given the need to adapt the different technologies to the idiosyncrasies of the domestic economy. Therefore, the flow of new ideas *(ID)* is determined by combining labour, the private stock of knowledge and that generated in other countries *(F),* through the following production function (again, in logs):

$$id = \phi_1 \left[ln(1-b_h) + n \right] + \phi_2 h_{-1} + \phi_3 f_{-1} + \omega \qquad [3]$$

where ϕ_1 (>0) can be lower than 1 (decreasing returns to scale) if replicating new ideas is senseless, or higher than 1, when there exists strong positive externalities between private researchers.[8] Intertemporal spillovers are collected through ϕ_2, that can be either negative, when easier ideas come first and additional ones are more difficult to find out (that is, there are so called "step on other toes" effects), or positive, when past ideas facilitate the discovery of new ideas (so called "standing on giant's shoulders" effects). Finally, we expect that $0<\phi_3<1$, meaning that there exist international knowledge spillovers, but foreign ideas are not a perfect substitute for domestic knowledge. For instance, as an illustration of this fact, Guellec and Van Pottelsberghe (2004) find that the exploitation of these international spillovers is larger the higher is your own knowledge stock, or in other words, the higher your absorptive capacity.

To end with this sector, we assume that the shock to new ideas also follows an ARI(1,1) process,

$$\Delta\omega = \rho_\omega \Delta\omega_{-1} + \varepsilon^{id} \qquad [4]$$

with $0<\rho_\omega<1$ and the stock of private knowledge accumulates according to the following law of motion:

$$h = (1-\delta)\, h_{-1} + \delta \; id \qquad [5]$$

meaning that knowledge becomes obsolete at a temporal rate of δ, and there exist adjustment costs in R&D investment that are proportional to that depreciation rate. We consider that the foreign stock of ideas evolves in the same way:

$$f = (1-\delta)\, f_{-1} + \delta \; if \qquad [6]$$

were *IF* is the foreign flow of new ideas.

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8. When you double the number of scientists, society can always open a replica of the same production facility —laboratory— and, in the absence of externalities, this will generate the same set of discoveries to be made twice, not to double, thereby leaving the output of new ideas unchanged. Thus, it would be possible to have decreasing returns to scale. On the contrary, spillovers among researchers or fixed set up costs may be so important that doubling the resources devoted to R&D more than doubles its output (hence, increasing returns to scale). See Romer (2006) or Acemoglu (2009) for a discussion of these issues.

In order to close the model, we consider that the labour supply is inelastic and that employment is pre-allocated to both productive sectors, implying the following equilibrium condition:

$$N = N_p + N_{id}\,; \quad N_p = b_p\, N \qquad [7]$$

Besides, employment is assumed to grow at a constant rate n_0, identical to population growth:

$$\Delta n = n_0 \qquad [8]$$

Finally, similar to Blanchard and Quah (1989), the aggregate demand equation is specified as:

$$y = m - p + \eta\left(h + \theta\right) \qquad [9]$$

which depends on real money balances *(M/P)* and all the elements that shift the aggregate final goods production function through its impact on permanent income (and, obviously, money velocity if we interpret that equation as the quantitative monetary theory). We expect η to be positive but lower than 1, to ensure that supply shocks have a positive impact on demand, but negative on prices in the long run, and that:

$$\Delta m = \rho_m \Delta m_{-1} + \varepsilon^d \qquad [10]$$

($0<\rho_m<1$) is a typical aggregate demand shock, which might also encapsulate a monetary policy shock.

We can algebraically manipulate this system of equations in order to obtain the following reduced form solution, a moving average representation with respect to structural shocks[9]:

$$\begin{pmatrix} \Delta id \\ \Delta y \\ \Delta p \end{pmatrix} = \begin{pmatrix} c_{11}(L) & 0 & 0 \\ c_{21}(L) & c_{22}(L) & 0 \\ c_{31}(L) & c_{32}(L) & c_{33}(L) \end{pmatrix} \begin{pmatrix} \varepsilon^{id} \\ \varepsilon^{s} \\ \varepsilon^{d} \end{pmatrix} + \begin{pmatrix} d_1(L) \\ d_2(L) \\ d_3(L) \end{pmatrix} \Delta if =$$

$$\begin{pmatrix} \Delta id \\ \Delta y \\ \Delta p \end{pmatrix} = C(L) \begin{pmatrix} \varepsilon^{id} \\ \varepsilon^{s} \\ \varepsilon^{d} \end{pmatrix} + D(L)\,\Delta if \qquad [11]$$

where L is the lag operator and the $c_{i,j}(L)$'s and $d_i(L)$'s (i,j=1,…,3) are non-linear functions of the structural parameters. Equation [11] implies that all variables should be I(1) and, also, since we have three trends and three endogenous variables, that there should be no cointegration relationship among them, which will be tested in the empirical section. Since we want to identify the SVAR along the lines of Blanchard and Quah (1989), that is,

9. Constants are omitted for the sake of clarity.

employing long run identifying restrictions, we are interested in the matrix *C*(*1*), which provides the long run multipliers for the endogenous variables of our model. This matrix is:

$$C(1)=\begin{pmatrix} c_{11}(1) & 0 & 0 \\ c_{21}(1) & c_{22}(1) & 0 \\ c_{31}(1) & c_{32}(1) & c_{33}(1) \end{pmatrix} = \begin{pmatrix} \frac{1}{(1-\phi_2)(1-\rho_\omega)} & 0 & 0 \\ \frac{\alpha}{(1-\phi_2)(1-\rho_\omega)} & \frac{1}{1-\rho_\theta} & 0 \\ \frac{\eta-\alpha}{(1-\phi_2)(1-\rho_\omega)} & \frac{\eta-1}{1-\rho_\theta} & \frac{1}{1-\rho_m} \end{pmatrix} \quad [12]$$

As expression [12] makes clear, aggregate demand shocks do not have permanent effects neither on R&D investment nor on final output, which is an assumption usually held in the literature.[10] Besides, shocks to the final goods production function —"traditional supply shocks"— have no long run effects on R&D investment, while the two supply-side shocks have lasting effects on final output. The signs of the unrestricted elements in [12] depend on the relative magnitudes of structural underlying parameters.

This identification strategy differs from that used by other papers which include technological variables in a VAR framework. Saint-Paul (1993), following Galí and Hammour (1991), assumes no immediate effect of demand shocks on productivity and allows for a long term effect of a demand shock both on TFP and on R&D, since he wants to check whether recessions have a long run impact on productivity and productivity-enhancing activities, such as R&D investment. Shea (1998), on his part, employs a short run Cholesky-type identification scheme whereby he orders his variables by putting first the productive input, second the TFP and last the technological variable (R&D spending or patents). He favours this ordering because R&D or patent shocks are likely to affect industrial activity only with a lag.

On the contrary, our scheme would be closer to Fisher (2006). He introduces embodied technical change into a conventional real business cycle model to motivate his long-run identifying restrictions. Thus, embodied technological change is an additional source of permanent shocks to labour productivity; besides, the model predicts that investment-specific change is the unique source of the secular downward trend in the real price of investment goods. This way, the real price of investment is introduced to "isolate" the traditional technology shocks from those embodied in the capital goods. The proper working of this strategy depends crucially on the methodology used to calculate the capital goods prices, and, in particular, if they take into account changes in quality in the capital goods or not. From mid-nineties, the US statistics consider hedonic techniques to obtain these prices, so quality is taken on board, but this does not need to be the case in other countries.

10. This assumption would be inconsistent, however, with some business cycle models with endogenous growth [Stadler (1990)] and with models in which recessions cleanse the economy by wiping out the less productive firms [Caballero and Hammour (1994)]. In the latter, demand shocks are detrimental for long run productivity, while in the former they are beneficial, since they stimulate further R&D investment.

3 An overview of the empirical results

3.1 Data description

We are going to apply the SVAR methodology to quarterly data from 1970 through 2006 for the six more developed economies —namely, the US, Japan, Germany, the UK, France and Italy—, and Spain. The empirical counterparts of the theoretical variables identified in the previous section are the following —see Appendix 1 for specific details and the sources of information—. First, the final output of goods and services is approximated by real GDP, while its price is, correspondingly, the GDP deflator. Second, R&D investment is disaggregated in that performed by the private sector and that attributed to the public and higher education sectors; the criterion to break down both components is the sector of performance as opposed to the financing one. Thus, private R&D investment is proxied by gross domestic expenditure on R&D by the private business sector, as usual in the empirical literature on innovation, deflated with a specific aggregate R&D spending deflator that takes into account the cost structure of R&D spending. As regards public R&D spending, we have added gross domestic expenditure on R&D by the public sector and the higher education sector, along the lines, *inter alia*, of Guellec and Van Pottelsberghe (2004), deflated by the same price than private R&D investment. This aggregation is justified by the fact that the government controls much of the research budget, or even agenda, of those institutions, through grants, contracts or fellowships in most countries. Finally, we build the proxy for international R&D flows as the weighted sum of total domestic R&D flows from the countries under study —in real PPP 2000 US dollars—, the weights being the shares of each foreign economy's imports, following along the lines of Coe and Helpman (1995).

One issue that deserves particular attention is that of the quarterly interpolation of all R&D-related data, since its original periodicity is annual. Basically, the temporal disaggregation methods based on indicators rely on minimizing the "distance" between the interpolated series and a linear combination of related indicators at the higher frequency, subject to a constrain that ensures consistency between the original series and the interpolated one. Several methods have been proposed in the literature but we employ that developed by Denton (1971). In any case, the quality of this interpolation (that is, the informational content added by this task) depends on the degree of "closeness" between the series and the indicators. For the case at hand, one could think of indicators such as the number of patents, or the flows from the technological balance of payments, or the number of scientific publications, or the amount of high-skilled labour employed in specific technology-intensive sectors, or the industrial production index for the sectors that invest the most in R&D (Chemistry, Machinery and Electronic and Electric devices and the Car Industry). The problem with all of these variables is that there is no long enough quarterly series for them to be useful, except for one, the industrial production index. Therefore, we have used this variable to quarterly interpolate private R&D spending. As regards public R&D, we could only come across with public consumption, which one would expect to be reasonably correlated with other components of government expenditure such as R&D expenditures.[11]

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11. Appendix 1 presents the adequacy of these indicators and the R&D annual series for every country. In general, the fit is quite good, so we think that the interpolation adds valuable information for this exercise.

3.2 Long run multipliers

Table 1 shows a summary of the main properties of the estimated reduced form VARs for each economy[12]. The VAR lag length, ranging from 3 to 5 in all the cases, has been chosen according to the usual information criteria statistics and trying to ensure residual whiteness. The residuals are roughly well behaved in terms of lack of autocorrelation, except for the cases of France and Germany, while the normality tests are mostly rejected. We cannot be very demanding as regards the desired properties of the residuals because we are using R&D quarterly series which have been imperfectly interpolated. Therefore, we consider the results from these specification tests reasonable given our context.

Table 1. Summary statistics of the reduced form VAR

Country	VAR lag length	Exogenous Variables	Deterministic components	Residual correlation and normality tests (p-values) LM(1)	LM(4)	LM(8)	Jarque-Bera
Spain	5	Δif	C, T	0.633	0.273	0.326	0.000 (y, p)
USA	5	Δif	C, T	0.513	0.056	0.056	0.405
Japan	3	Δif, Δif_{-1}	C,T	0.530	0.392	0.079	0.000 (y, p)
Germany	4	Δif	C, T, Dummy post-reunificat.	0.158	0.009	0.319	0.000 (y, p)
France	5	Δif, Δif_{-1}, Δif_{-2}	C, T	0.253	0.002	0.038	0.000 (y, p)
UK	5	Δif	C, T	0.392	0.248	0.035	0.000 (y)
Italy	5	Δif, Δif_{-1}, Δif_{-2}	C, T	0.353	0.586	0.281	0. 000 (y)

LM(h): Lagrange-Multipliers test of residual correlation up to order h; Jarque-Bera test of normality of residuals, between parentheses the equations for which it is rejected.

The long run multipliers estimated for each country, which are shown in Table 2, strongly support the stylised theoretical model. To begin with, for the three endogenous variables in every country, the own structural shock has a positive and statistically significant effect. Thus, the long-run multiplier of a R&D investment disturbance on R&D investment oscillates between 0.02 in most of the countries and 0.04 in Spain and Italy. In fact, the size of the effect is higher in the countries that invest less in knowledge. This suggests that stimulating R&D investment in the laggard economies could have very persistent effects. The long-run multiplier of the supply shock on activity is positive, as expected, and very similar across countries, implying that a one-standard deviation shock increases activity by 1%. Finally, the impact of the demand shock on prices is also positive and very similar among countries (0.02), with two exceptions: the US and Germany, where it is significantly lower (0.01).

Moving to the cross multipliers, the shock to R&D investment has a positive and significant impact on GDP in all the countries, although there are important differences in its magnitude. Thus, the innovation process seems to be quite efficient in Japan, Germany, UK and Spain, while it is less productive in Italy, France and the US. On the contrary, the impact on prices is negative, with just one exception, the US, where

12 Appendix 2 contains the analysis of the stochastic properties of these variables. Overall, all variables seem to be stationary after first differencing, in some cases needing the introduction of a deterministic trend. Besides, we reject the existence of any cointegration relationship among activity, prices and R&D investment for all the countries considered in this paper. Hence, it seems appropriate to estimate a SVAR in first differences and with no cointegration relationship, as suggested by the theoretical model.

prices increase in the long run following an R&D shock. This last (surprising) result could be justified on the basis of the product differentiation or quality improvements that this investment could generate, which might allow firms in that country to charge higher prices in the long term. Notice that the long run in this kind of model is very similar to the protection span that patent regulations provide in the US.

Table 2. Long run multipliers of the SVAR

Cumulative effects of a one-standard deviation shock								
		Spain	USA	Japan	Germany	France	UK	Italy
R&D shock (ε^{id})	ID	0.04* (0.002)	0.02* (0.001)	0.02* (0.001)	0.02* (0.001)	0.02* (0.001)	0.02* (0.001)	0.04* (0.002)
	Y	0.007* (0.001)	0.003* (0.001)	0.008* (0.001)	0.007* (0.001)	0.003* (0.001)	0.007* (0.001)	0.002* (0.001)
	P	-0.003 (0.002)	0.004* (0.001)	-0.009* (0.001)	-0.005* (0.001)	-0.008* (0.002)	-0.002 (0.002)	-0.005** (0.002)
Supply shock (ε^{s})	Y	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)
	P	-0.01* (0.002)	-0.01* (0.001)	-0.005* (0.001)	-0.001** (0.0005)	-0.01* (0.002)	-0.02* (0.002)	-0.01* (0.002)
Nominal shock (ε^{d})	P	0.02* (0.001)	0.01* (0.001)	0.02* (0.001)	0.007* (0.0004)	0.02* (0.001)	0.02* (0.001)	0.02* (0.001)
Foreign R&D flows (IF)	ID	-0.01 (0.12)	0.19*** (0.11)	-0.003 (0.14)	0.008 (0.06)	0.18 (0.12)	-0.04 (0.05)	0.73** (0.32)
	Y	0.01 (0.03)	-0.02 (0.04)	-0.009 (0.10)	0.007 (0.03)	0.07 (0.04)	-0.009 (0.03)	0.13*** (0.07)
	P	0.12 (0.13)	0.05 (0.04)	-0.06 (0.17)	-0.02 (0.03)	0.21 (0.15)	0.01 (0.11)	0.36 (0.32)

Notes: Standard deviations between parentheses. *, **, ***, denote statistical significance at 1%, 5% and 10%, respectively

The traditional supply shock seems to be properly identified in all the countries. Thus, as we saw, it has a positive and significant effect on activity, as it happened with the R&D shock. However, in all the countries the multiplier of the "traditional" supply shock is higher than that of the R&D shock, implying that this kind of investment is not the only tool available to improve the productivity at this aggregate level; enhancing human capital, improving the firm environment or investing in infrastructure are other examples of efficiency-oriented policies. On the contrary, the impact on prices is negative in all the countries and significant. These multipliers are very similar among countries, except for Germany and Japan, where it is smaller.

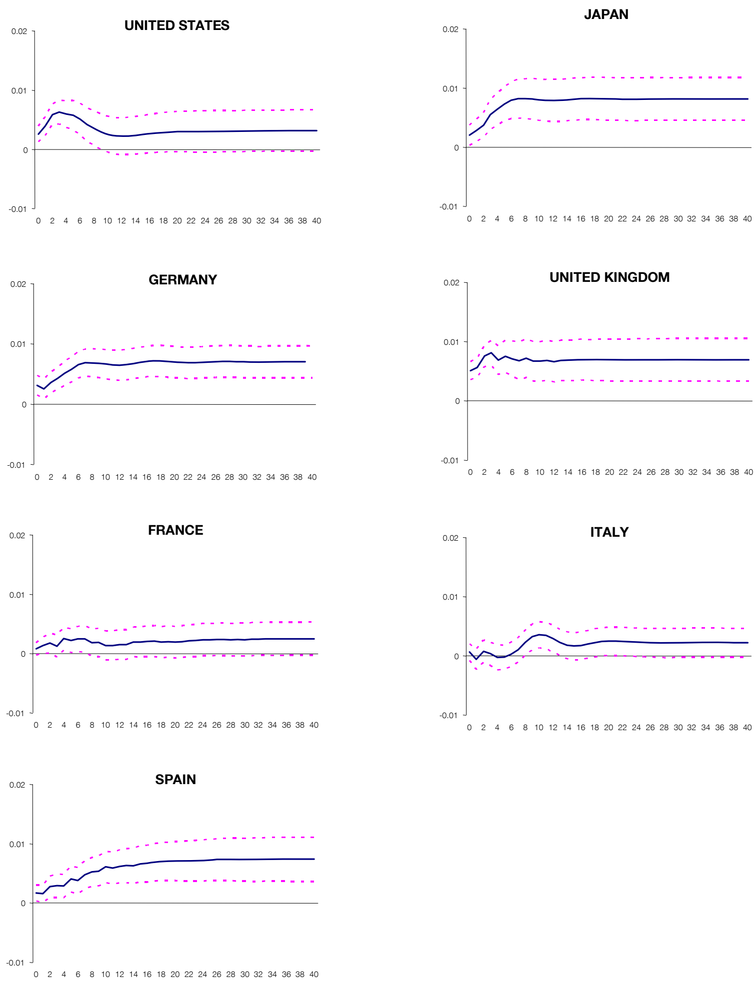
Finally, and contrary to the conclusions of recent papers, we find that international spillovers of R&D investment are very reduced or inexistent. As can be seen from Table 2, only three parameters in two countries are significant at standard levels of significance. Besides, one of them belongs to the US, precisely the country that leads most of the research fields, so that it can be regarded a "spillover generator" rather than a "spillover receiver". As we will see in the robustness of results section, the removal of international R&D investment form the system does not modify these results.

3.3 Impulse response analysis

In order to illustrate the short-term responses of the estimated models, we have computed the Cumulative Impulse Response Functions (CIRFs) for the three different structural shocks. Figures 1 to 6 contain the CIRFs for the different countries, gathered by shock and variable, along with the one standard deviation confidence intervals obtained using the traditional bootstrapping procedure.[13]

To begin with, the CIRFs of the different endogenous variables with respect to its own shock (which are available upon request) show the typical pattern of a positive auto-regressive response, with an increasing path and being statistically significant all the time. Only for Germany and Spain the CIRFs for the R&D shock show an oscillating path, which could be related to the quarterly interpolation of the variable. Besides, the CIRFs reach its long-run values in much less than ten years. That long-run value is reached later in the case of the demand shock; this is probably associated to the difficulty in distinguishing whether the GDP deflator is an I(2) stochastic process or an I(1) with a trend (see Appendix 2).

Figure 1. Cumulative Impulse-Response Functions of real GDP to ε^{id}

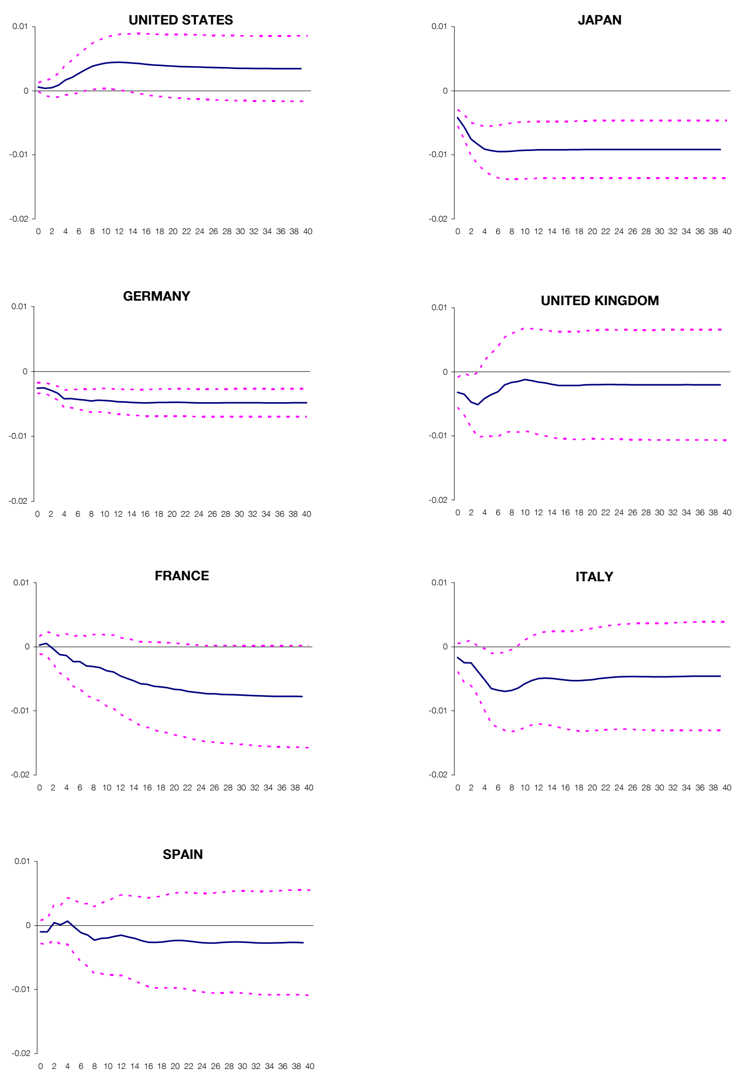


Note: The solid lines plot the IRFs, while the dotted lines depict one standard error bands from a bootstrap based on 2000 replications.

13. The statistical inference regarding impulse responses is based on bootstrap methods, because it has been shown [Kilian (1998) or Benkwitz, Lütkepohl and Wolters (2001)] that more reliable small sample inference is possible than by using asymptotic theory.

Moving now to the cross-multipliers, Figure 1 shows the response of activity to a R&D shock for the different countries. As predicted by the theoretical model for the long run, the response is also positive in the short and medium run and it is estimated quite precisely for all the countries. However, there are some differences among them that are interesting to highlight. In the first place, the US is the only country where it is estimated a statistically significant overshooting effect, being lower the medium run response than the short run one. In the second place, the speed of transmission of the impulse is relatively high; in fact, in all the countries the CIRF is stabilised at the long-run value between one and two and a half years after the shock is observed. The only exception is Spain, where it takes more than four years to reach the long-run multiplier; this result tends to confirm one of the main problems of the Spanish innovation system, which is the difficulty in transforming new ideas into productive uses. In the next section, we will see that there is ample room for improving the efficiency of the transfer process between basic research institutions and the productive apparatus.

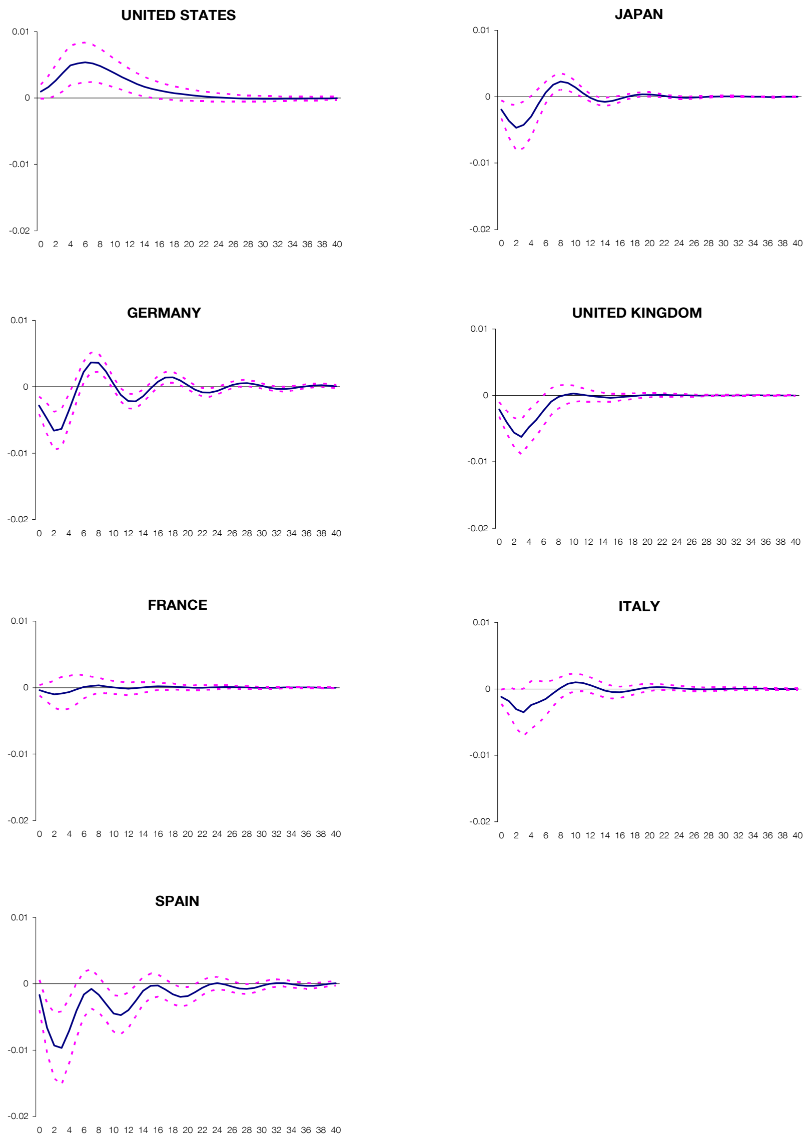
Figure 2. Cumulative Impulse-Response Functions of Prices to ε^{id}



Note: See previous figure.

As expected from a supply-side shock, the effect of the R&D shock on prices (Figure 2) is negative in most of the countries, although these multipliers are estimated with great uncertainty, except for Germany and Japan where they are statistically significant from the first quarter. Besides, the long-run value of the multiplier is reached quite fast in all the countries, apart from France, which only converges nine years after the shock is implemented. The only exception is the US, which shows a positive response both in the short and the medium run. This sign could be rationalized in terms of the market power that provides the current patent legislation in this country, although the confidence intervals show this multiplier is estimated very imprecisely, especially in the long-run. This result highlights one of the advantages of this empirical approach, since, by controlling for the endogeneity of the variables, it allows to identify a component of innovation that causes market power (at least in the US), as opposed to the view that only firms with market power can (profitably) perform R&D investment due to the fixed costs it implies and the uncertainty surrounding this activity implying strong financial support.

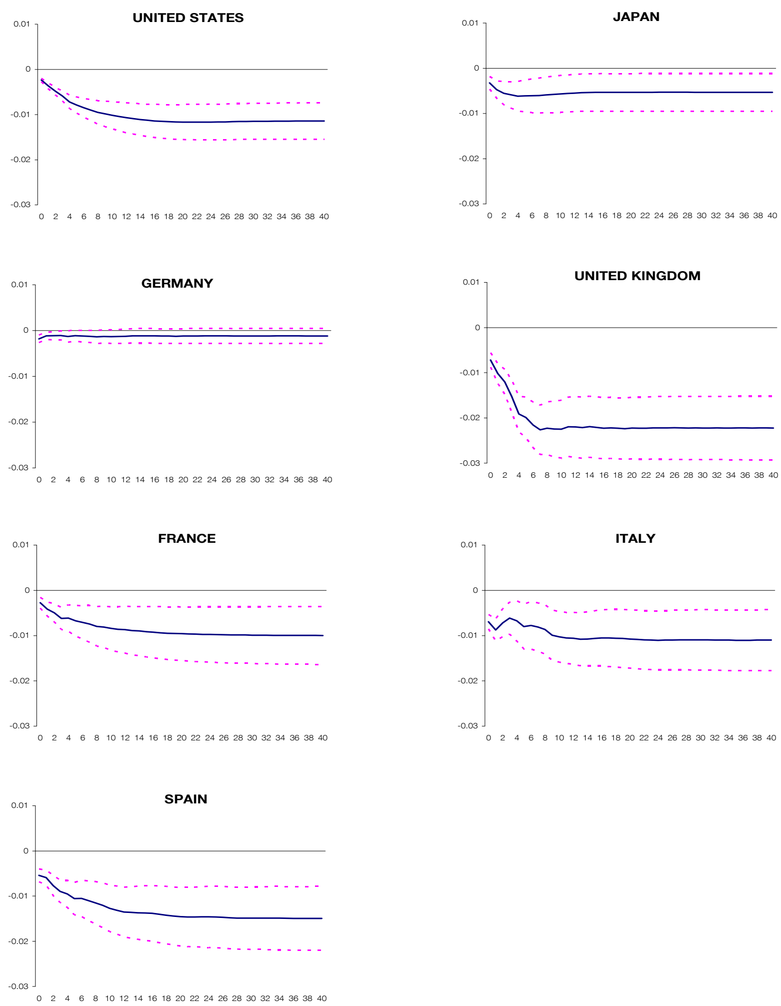
Figure 3. Cumulative Impulse-Response Functions of R&D investment to ε^s



Note: See previous figure.

Moving now to the CIRFs of R&D investment with respect to the supply shock, Figure 3 shows how the US is, as in the previous case, an outlier, because the dynamic response in that country is positive, while in all the other countries the short and medium term response is negative (remember that the model imposes a null response in the long run). It could be rationalized by appealing to frictions in the adjustment of labour. A shock that improves the productivity of the final goods sector implies an increase in the demand for labour —and hence its price— which, for a certain degree of substitutability, may be detrimental for the R&D sector in the sort term. The US economy may be escaping this effect by importing foreign labour. Further, since that shock captures the improvements in productivity not associated to innovation, such as human capital or the business environment, one could also argue that a positive shock makes less necessary to devote more resources to research because it is more profitable to spend more on the production of final output. This would call for more comprehensive supply-side reforms (for example, enhancing competition in the product and labour markets and, at the same time, generating the conditions that favour private R&D investment) in order to avoid negative spillovers on the research sector.[14]

Figure 4. Cumulative Impulse-Response Functions of Prices to ε^s



Note: See previous figure.

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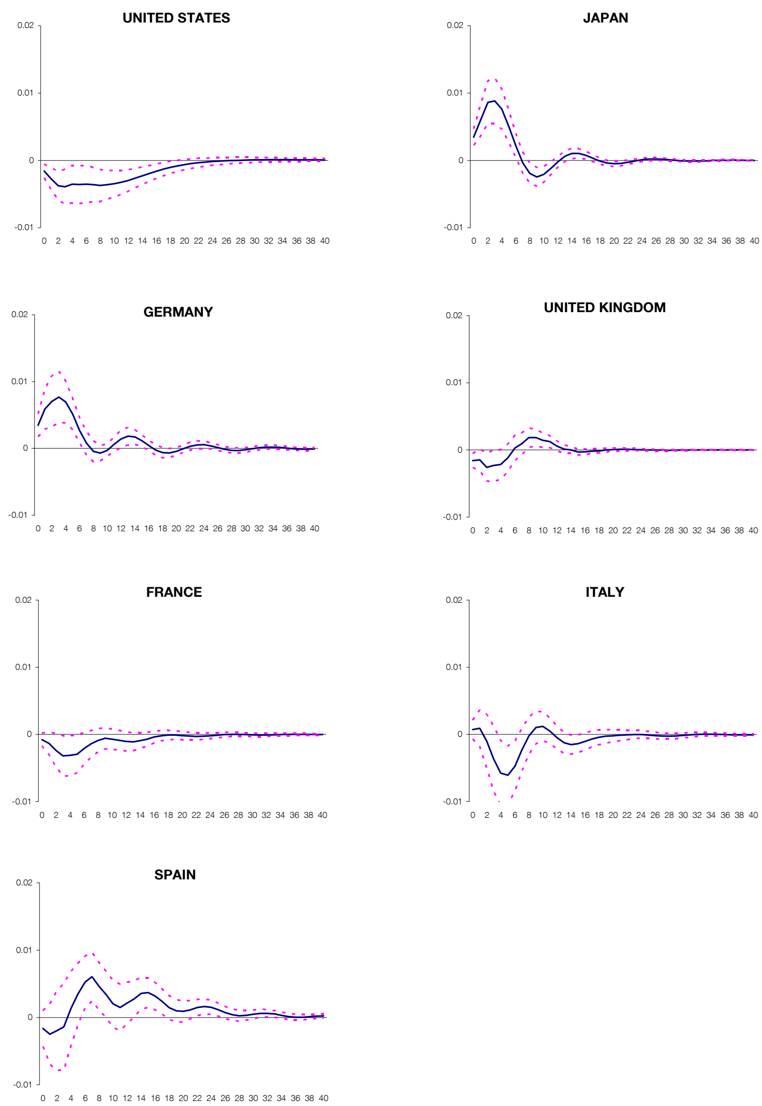
14. An illustrative example might be the Spanish case, where a positive supply shock in the form of a huge increase in immigration and a substantial decrease in financing costs resulted in a construction boom which detracted resources from innovative activities.

Figure 4 shows the CIRFs of the GDP deflator with respect to the supply shock. As expected, the multipliers are negative for all the countries and they are estimated with great precision, except in the case of Germany, where the estimated effect is lower. The convergence of the multiplier to its long-run value is quite fast in the US, the UK, Germany, Japan and Italy (less than two years); while in France and Spain it takes more than four years.

Figure 5. Cumulative Impulse-Response Functions of R&D investment to ε^d

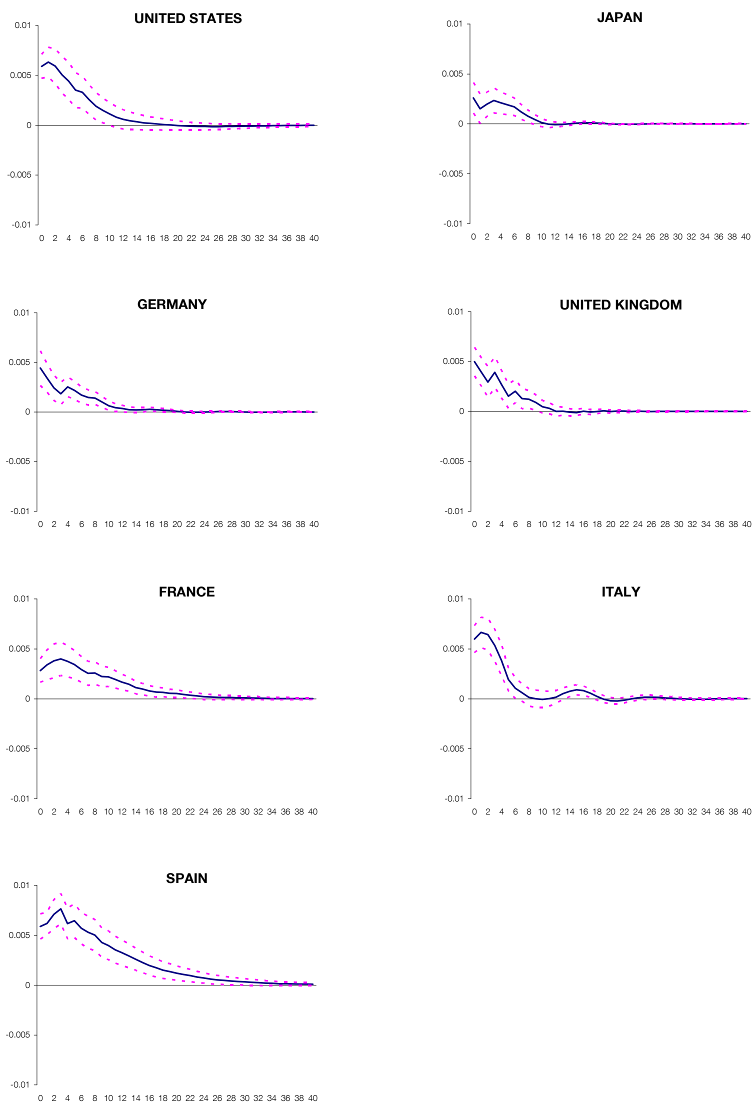


Note: See previous figure

Further, in the case of the demand (nominal) shock, Figure 5 shows that the response of R&D investment is different in the short and medium run depending on the country. Thus, in the US, UK, France and Italy the multipliers are negatively signed and, in the last two cases, there is a certain lag before significance is reached. This could be rationalized within our framework if we think that a nominal shock implies an increase in uncertainty and a reaction of the monetary policy that would increase the cost of this investment. Moreover, if we believe that demand shocks capture the business cycle, then R&D investment would be counter-cyclical, which would somewhat be consistent with the literature on the cleansing effect of recessions, at least in the short to medium run (remember that the theoretical model imposed a zero response in the long-run). On the contrary, in Japan, Germany and Spain the multipliers are positive mainly because, as we will see below, the response of public R&D investment is positive, while private R&D investment diminishes. Probably, the increase in public R&D expenditures following a demand shock is a consequence of the higher receipts the public sector achieves following this shock.

Finally, as it is usual in models with nominal rigidities (but without controlling by raw material prices), activity increases in the short term following a demand shock (Figure 6), as long as not all the firms change their prices immediately. Only in France, Italy and Spain a (very short-lived) overshooting effect is estimated, and there are also differences among countries in terms of the nominal inertia. Thus, the multipliers vanish in between 2 and 3 years in the cases of USA, Japan, UK and Italy; it takes 3 years in Germany, 5 in France and more than 6 in Spain.

Figure 6. Cumulative Impulse-Response Functions of real GDP to ε^d



Note: See previous figure.

3.4 Some robustness checks

In order to check the time invariance of our model, we adopt the general framework proposed by Elliott and Müller (2006). They contrast a stable regression model $y_t = \beta' X_t + \delta' Z_t + \varepsilon_t$ against the unstable alternative $y_t = \beta_t' X_t + \delta' Z_t + \varepsilon_t$, for which they develop a single unified framework, noting that the "seemingly different approaches of 'structural breaks' and 'random coefficients' are in fact equivalent". This way, they improve the power properties of their test, which is, moreover, relatively straightforward to compute and does not require the specification of an exact breaking process. We use three broad specifications (see Table 3), one in which the coefficients linked to total R&D and real GDP are allowed to vary across equations —first row for each variable—, other where the parameters of total R&D and prices are time-varying —second row— and a last one in which we test for persistent time variation in the parameters of real GDP and prices —third row—. Critical values are included in the note to the table. Entries in bold and italic represent a qLL statistic that is significant at better than the 95% level of confidence. As can be seen in the table, the Elliott-Müller qLL test indicates that the stability of our VAR models, allowing for instability in the three subset of coefficients, cannot be rejected, in general, by the data. Thus, we tend to view these results as reasonably supportive of the stability of our VAR models.

Table 3. Elliott-Müller qLL test for time-varying coefficients

Dependent variable	$\beta_t X_t$	δZ_t	***qLL statistic***
	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta y_{t-1},\ldots,\Delta y_{t-5}$	$\Delta p_{t-1},\ldots,\Delta p_{t-5}$ Δif_t, trend	Spain=-33.33; USA=***-55.05;*** Japan=***-33.65;*** Germany=-38.65; France=-44.00; UK=-38.68; Italy=-40.64
Δid_t	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ Δif_t, trend	Spain=-40.99; USA=-48.62; Japan=-32.25 Germany=-24.25; France=-42.67; UK=-42.66; Italy=-36.84
	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ Δif_t, trend	Spain=-39.33; USA=-40.27; Japan=-30.89; Germany=-38.84; France=-40.92; UK=-36.42; Italy=-39.49
	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta y_{t-1},\ldots,\Delta y_{t-5}$	$\Delta p_{t-1},\ldots,\Delta p_{t-5}$ Δif_t, trend	Spain=-41.94; USA=-37.30; Japan=-26.67; Germany=-36.85; France=-41.27; UK=-47.77; Italy= -45.53
Δy_t	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ Δif_t, trend	Spain=-44.84; USA=-44.02; Japan=-23.54; Germany=-32.24; France=-41.53; UK=-39.33; Italy=-42.18
	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ Δif_t, trend	Spain=-41.10; USA=-35.81, Japan=-25.14; Germany=-30.91; France=-41.91; UK=-41.17; Italy=-43.89
	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta y_{t-1},\ldots,\Delta y_{t-5}$	$\Delta p_{t-1},\ldots,\Delta p_{t-5}$ Δif_t, trend	Spain=-42.67; USA=-52.21; Japan=-23.91; Germany=-38.77; France=-36.04; UK=-40.69; Italy=-41.57
Δp_t	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ Δif_t, trend	Spain=-36.81; USA=-46.17; Japan=-27.10; Germany=-31.51; France=-31.16; UK=-36.92; Italy=-39.36
	$\Delta y_{t-1},\ldots,\Delta y_{t-5}$ $\Delta p_{t-1},\ldots,\Delta p_{t-5}$	$\Delta id_{t-1},\ldots,\Delta id_{t-5}$ Δif_t, trend	Spain=-42.04; USA=-39.81; Japan=-30.20; Germany=-36.59; France=-39.61; UK=-38.00; Italy= -43.23

Note: qLL efficient test for general persistence in time variation in regression coefficients proposed by Elliott and Müller (2006). Critical values for Spain, USA, France, UK and Italy are –61.77, –56.14 and –53.38 at the 1%, 5% and 10% significance level, respectively; for Germany are –51.18, –46.18 and –43.59, respectively; and for Japan are –40.24, –35.74 and -33.45 respectively. The test contrasts a stable regression model $y_t = \beta' X_t + \delta' Z_t + \varepsilon_t$ against the unstable alternative $y_t = \beta_t' X_t + \delta' Z_t + \varepsilon_t$. See Baum (2007).

We have further checked the sensitivity of our results to several changes in the baseline specification. Firstly, and against the findings of a large strand of literature, we did away with international R&D flows, which in our context would seem relevant given the lack of statistical significance of most estimated coefficients. Overall, both the long-run multipliers and the cumulative impulse response functions were quantitatively and qualitatively very similar to our baseline specification.[15] In fact, the only minor difference happened in the Italian specification where the multiplier of prices with respect to the R&D shock changed its sign, although it remained insignificant both in the short and long run. Secondly, given the poor results for global knowledge flows, we built another proxy for this by using only private business R&D spending, again trade-weighted. This would also be justified by the fact that, as far as we know, most literature tends to emphasize the role of private international R&D flows. Again in this case, the dynamic response of the endogenous variables remains very similar to our baseline specification and the long term dynamic multipliers are barely affected.

Additionally, we have run the same VAR models but including the variables in annual, instead of quarterly, frequency. The main reason in performing this exercise lies in that we have interpolated R&D investment with quarterly indicators. Although from a statistical point of view the interpolation exercise was quite sound for all the countries (see Appendix 1), it could bias the estimated short and medium run multipliers. In particular, we find that the long run multipliers have the same sign than those estimated with quarterly information, with only one exception: the multiplier of prices with respect to the R&D shock in the UK, which changes from negative to positive, although it was not significant at standard levels. The size of the long term multipliers is also identical from a statistical point of view, once they are corrected for the different magnitude of the shocks at each frequency. Finally, the short to medium run dynamic responses are also very similar, showing the same shape in most of the cases. The only difference is that these multipliers reach their long-term values in just two or three periods at annual frequency, consistently with the evidence encountered at quarterly frequency.

15. These results are available from the authors upon request.

4 Private and public R&D investment

As we saw in the introduction, most growth theories and empirical studies have emphasized almost exclusively the important role played by private sector innovation in the impulse of productivity, and relatively few papers have paid due attention to the contribution of the public system of innovation to long run potential growth. This is probably due to the concentration of public research on basic research, which takes more time to be incorporated into the productive process, generates more externalities and, since it implies a higher degree of uncertainty, is associated with a higher social return. In fact, there is a marked controversy among researchers as to whether government funding of R&D activities has a positive or negative impact on private sector R&D expenditures. The awareness of this debate is probably behind the European Commission establishment of two targets for R&D investment in its Lisbon Agenda, one for total R&D investment as a percentage of GDP and other for the share between private and public R&D funding.

In order to incorporate this aspect into our analysis, we extend our theoretical model (section 2) to treat separately both components of R&D investment. Again, our model would be a simplified version of those by Bartelsman (1990) and Park (1998). Thus, we consider a third productive sector that generates new public sector knowledge (IG) as a function of the labour devoted to public R&D activities, as well as on the public (G) and foreign stocks of knowledge considered above; that is:

$$ig = \beta_1 \left[ln(1 - b_p - b_h) + n \right] + \beta_2 g_{-1} + \beta_3 f_{-1} + \gamma \qquad [13]$$

where the β's can be interpreted similarly to the ϕ's in equation [3]. Besides, we assume that the shock to new public ideas also follows an autoregressive process with identical restrictions, although it may encapsulate the government's discretionary fiscal policy stance regarding its innovation policy:

$$\Delta\gamma = \rho_\gamma \Delta\gamma_{-1} + \varepsilon^{ig} \qquad [14]$$

($0<\rho_\gamma<1$) and the stock of public knowledge accumulates according to identical law of motion than the private knowledge:

$$g = (1 - \delta)\, g_{-1} + \delta\ ig \qquad [15]$$

Since public R&D investment is concentrated on basic research, we cannot assume this stock of knowledge to enter directly in the production function of final goods and services. However, it has an indirect impact, as this stock of knowledge facilitates the production of new ideas by the private sector. Thus, equation [3] would be transformed into:

$$id = \phi_1 \left[ln(b_h) + n \right] + \phi_2 h_{-1} + \phi_3 g_{-1} + \phi_4 f_{-1} + \omega \qquad [16]$$

From this expression it is easy to see that the substitutability or complementarity of public vs. private R&D is captured by the parameter ϕ_3; as argued before, the knowledge generated by the public sector can induce or help investment in private R&D, which is more industrially-oriented (ϕ_3>0). However, some authors would favour the thesis that public R&D crowds out private one (hence, ϕ_3<0), especially when the labour supply of R&D workers is inelastic —time is needed to generate more scientists and engineers—, since a significant portion of R&D spending is salary payments [see Bartelsman (1990)].[16] Therefore, increased government R&D investment can crowd out private innovative activity.

Solving the full model, it is relatively easy to show that is possible to obtain a similar representation in matrix form as in [11] and [12]. Thus, the long-run matrix of multipliers to the four structural shocks is similarly lower triangular, allowing us to apply again the Structural VAR methodology with identification à la Blanchard-Quah. The only empirical difficulty is that the identification of the shocks is more demanding in this case, since we are trying to separate three shocks that, in nature, are supply shocks and of which two are technology-related. This results in more uncertainty surrounding the estimates, which makes us concentrate the analysis on the impact of both R&D among them and on activity and prices.

Beginning with the long-run multipliers, Table 4 shows the results obtained when disaggregating both R&D components. Firstly, it is noteworthy that the multipliers for the common (traditional supply and nominal) shocks in both models are roughly the same. Secondly, the addition of the multipliers of public and private R&D shocks for activity and prices are higher (in absolute values) than those in Table 2 for the aggregate R&D shock.

16. According to OECD statistics, over 50% of total R&D spending corresponds to salary payments.

Table 4. Long-run multipliers of the SVAR. Model with private and public R&D

		Cumulative effects of a one-standard deviation shock						
		Spain	USA	Japan	Germany	France	UK	Italy
Public R&D shock (ε^{ig})	IG	0.04* (0.002)	0.03* (0.002)	0.05* (0.003)	0.06* (0.004)	0.02* (0.001)	0.02* (0.001)	0.05* (0.003)
	ID	0.02* (0.005)	-0.002 (0.002)	-0.01* (0.002)	-0.02* (0.003)	0.004*** (0.002)	-0.004*** (0.002)	0.02* (0.003)
	Y	0.01* (0.001)	0.003** (0.001)	0.002 (0.001)	0.001 (0.001)	-0.001 (0.001)	-0.002*** (0.001)	0.0003 (0.001)
	P	-0.01* (0.002)	-0.01* (0.004)	-0.002 (0.001)	0.002* (0.001)	0.02* (0.002)	0.01* (0.002)	-0.01* (0.002)
Private R&D shock (ε^{id})	ID	0.06* (0.003)	0.03* (0.002)	0.03* (0.002)	0.03* (0.002)	0.03* (0.002)	0.03* (0.001)	0.03* (0.002)
	Y	0.002*** (0.001)	0.002*** (0.001)	0.008* (0.001)	0.01* (0.001)	0.002* (0.001)	0.01* (0.001)	0.004* (0.001)
	P	0.01* (0.002)	0.02* (0.004)	-0.01* (0.001)	-0.01* (0.001)	-0.02* (0.002)	-0.003 (0.002)	0.001 (0.002)
Supply shock (ε^{s})	Y	0.01* (0.001)	0.01* (0.001)	0.01* (0.001)	0.01* (0.0005)	0.01* (0.0005)	0.01* (0.001)	0.01* (0.0004)
	P	-0.01* (0.002)	-0.04* (0.003)	-0.00 (0.001)	-0.002* (0.0004)	-0.003* (0.001)	-0.02* (0.002)	-0.01* (0.002)
Nominal shock (ε^{d})	P	0.02* (0.001)	0.02* (0.001)	0.01* (0.001)	0.004* (0.0002)	0.01* (0.001)	0.02* (0.001)	0.02* (0.001)
Foreign R&D flows (IF)	IG	0.01 (0.10)	0.34 (0.23)	-0.02 (0.35)	-0.01 (0.23)	0.02 (0.05)	-0.05 (0.07)	0.17 (0.34)
	ID	0.21 (0.26)	-0.004 (0.12)	0.13 (0.19)	0.04 (0.07)	0.08 (0.12)	-0.004 (0.08)	0.81** (0.39)
	Y	0.03 (0.04)	-0.001 (0.06)	-0.08 (0.10)	0.002 (0.03)	-0.01 (0.04)	-0.03 (0.04)	0.21* (0.08)
	P	0.30 (0.24)	-2.04 (9.07)	0.07 (0.16)	-0.02 (0.02)	-0.04 (0.11)	0.01 (0.11)	0.65 (0.40)

Notes: Standard deviation between parentheses; *, **, ***, statistically significant at 1%, 5% and 10%, respectively.

In the third place, the long-run responses of public and private R&D investment to its corresponding shocks are positive and statistically significant; their relatively higher values reveal that the process of knowledge generation is very persistent, so it should be seen from a long term perspective. Further, there is not a homogeneous response of private R&D investment with respect to the public R&D shock among these economies. In fact, there seems to be crowding-out effects in Japan, Germany and the UK, no effects in the US and crowding-in effects in Spain, France and Italy. The crowding-out has been justified on the existence of bottleneck effects, since both the private and the public sector compete for a scarce resource: highly qualified human capital. Thus, these results are probably reflecting just a matter of size, at least for the cases of Italy and Spain, the countries that dedicate less resources to public R&D, and which have not probably reached yet the position of displacing private R&D investment. From this point of view, it is remarkable the non-significance of the multiplier estimated for the US, even though it is one of the economies that invests in R&D the most. A possible explanation is the "brain drain" that the US scientific system generates in the other countries, including the developed ones, that relaxes the human capital constraint existent in the other cases.

Additionally, the public R&D shock generates a positive jump in activity in all the countries except the UK, although this multiplier is estimated quite imprecisely (it is non-significant in several countries) confirming the difficulty the empirical literature has found in capturing this effect [Guellec and Van Pottelsberghe (2004)]. Furthermore, this coefficient is, in general, lower than that of the private R&D shock, which, besides, is positive and statistically significant for all the countries. This corroborates that private R&D investment is more oriented to the productive process of final goods and services. Seventh, the long-run impact of the public R&D shock on prices is also country-dependent. Thus, it is negative —as expected— for Spain, the US and Italy, and positive for Germany, France and the UK. This last result could be the consequence of the expansion of public expenditure that might imply this investment, which, perhaps, compensates the "supply-side" effect of this type of shock. Finally, the effect of the private R&D shock on prices is negative —as expected— for Germany, France and the UK, and positive for Spain, the US and Italy. This anomalous impact of private R&D investment on inflation in the second group of countries could be justified on the patent legislation, which guarantees the investor monopoly power for a certain period of time.

The impulse-response functions do not provide much more information than the long-run multipliers, so they are not shown for the sake of brevity.[17] Perhaps, an interesting result is that in the short and medium run a private R&D shock also crowds-out public R&D investment in a number of countries, although the effects are estimated quite imprecisely. Another outcome that is worth mentioning in connection with the literature on the impact of business cycles on productivity-enhancing activities, is the dynamic response of both types of research to a demand shock. Overall, private R&D expenditures react negatively to demand disturbance, thus lending some support to the Schumpeterian thesis that these activities should be countercyclical. As regards public R&D, there is no clear pattern of response across countries. There is a positive response in Spain and Japan, and a negative one in France, Italy and the UK.

17. As in the other cases, they are available upon request.

5 Conclusions

This study confirms the importance of both private and public R&D investment in spurring long term growth, while the role of foreign technology spillovers is more imprecisely estimated, contrary to other papers. Thus, the estimated long run multipliers of economic activity with respect to R&D shocks are positive and significant in general, while the coefficients for prices are somewhat heterogeneous. Besides, we detect a generalized crowding out effect of public R&D investment on the private component, except in the cases of Spain and Italy, where it attracts more private R&D, and the US, where there is no impact. This may be due to the fact that these economies are less developed in terms of innovation, so they have not reached a critical level from which increases in R&D spending require detracting resources —particularly, high-skilled labour— from other sectors. As regards the dynamic transmission of shocks —as exemplified by the cumulative impulse-response functions—, the impact of the R&D disturbance on output is positive and increasing in most of the cases, reaching its long-run value in two-to-three years. The impact on prices tends to be negative across countries, with the US as a notable exception. This somewhat anomalous result could be related to the protection provided by patent legislation in that country, which provides pricing power to innovative firms.

An interesting by-product of our study is that demand disturbances tend to have a negative impact on R&D investment in the short to medium run —except for the cases of Japan, Germany and Spain—, as predicted by some Schumpeterian theories of the business cycle. This result is reinforced when we distinguish between public and private R&D.

Regarding the Spanish case, there are some results that are worth remarking. First, the positive traction exerted by public R&D investment on private one, which is, additionally, quite persistent. Secondly, the dynamic response of GDP to R&D shocks is slow and it takes four years to reach its full long-term impact. When both types of R&D are considered —results not shown—, they have a delayed impact (three to four years) on economic activity. This fact would signal a problem with the transformation of ideas into value added, an issue that warrants closer inspection. This is particularly worrisome in the case of private R&D, since it is relatively less productive than public one —although within the parameters of other developed economies—. Besides, attention should be paid to the fact that private innovation results in higher prices, which would hint at non-competitive behaviour by private businesses. Hence, it would be advisable to complement the promotion of private R&D with reforms to improve the degree of competitiveness in product markets.

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Appendix 1. Data building and definitions

Endogenous variables:

GDP: seasonally adjusted data from the IMF's International Financial Statistics, base year 2000. These data have been complemented with figures from the Economic and Social Research Institute in Japan (1970Q1-1978Q4) and from Datastream (1970Q1-1979Q4) in Italy.

GDP deflator: seasonally adjusted data from the IMF's International Financial Statistics, base year 2000. These data have also been complemented with figures from the Economic and Social Research Institute in Japan (1970Q1-1978Q4) and from Datastream (1970Q1-1979Q4) in Italy.

R&D flows: In the official data sources, both the private and the public component of R&D investment are only available at annual frequency and in nominal terms; besides, there are some breaks in the series. Thus, from 1980 to 2006 the information has been taken from Eurostat, complemented with the OECD database on sectoral private R&D evolution to fill in the gaps. From 1970 to 1980 the data have been obtained from Coe and Helpman (1993).

To eliminate the effect of inflation on these nominal time series, specific (aggregate) R&D deflators have been developed. These deflators take into account the aggregate cost structure for R&D activities (data from the OECD's Science and Technology database) and distinguishes between labour costs, capital costs and other expenditures. Thus, the deflators are a weighted average of the private sector wages (for labour costs), the investment deflator (for capital costs) and the GDP deflator (for the other expenditures), which have been obtained through the OECD's Economic Outlook database.

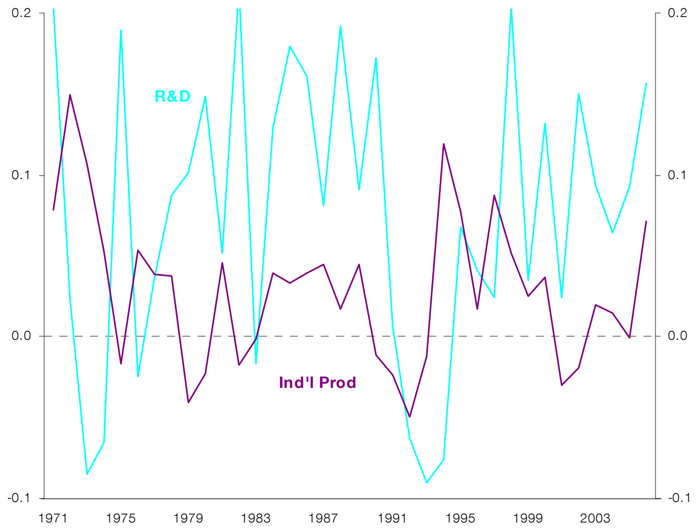
Finally, in order to produce a quarterly profile the interpolation procedure proposed by Denton (1971) has been applied, using indicators (see section 3.1). In the case of private R&D and for all the countries except for the US, the indicator was the Industrial Production Index of the branches that accumulate the majority of R&D investment (Chemistry, Machinery, Electric and Electronic Items and Transport Material); this information was taken from the OECD MEI database. In the case of the US, the indicator used was durable consumption and equipment investment, taken from the NSA database. For public R&D investment, the indicator considered in all the countries was government final consumption expenditure, taken from the IMF's International Financial Statistics.

Exogenous variables:

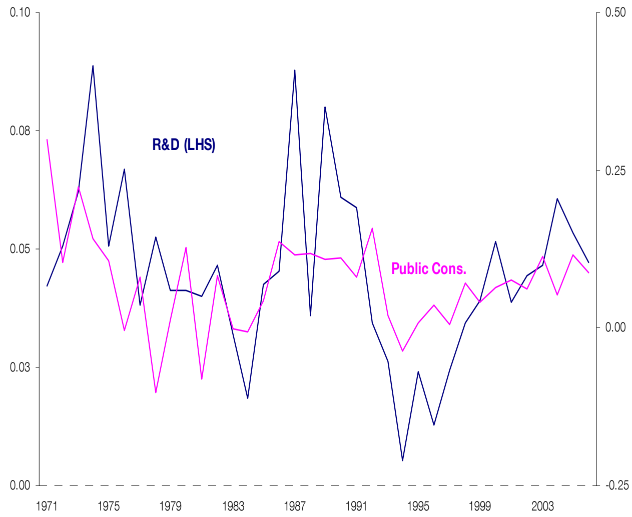
International R&D flows: these flows are calculated as the weighted sum of the total domestic R&D flows of the countries under study (in PPP dollars), excluding the country concerned. The weights —following Coe and Helpman (1995) and others— are the shares of each foreign country's imports (computed with figures from the IMF's Direction of Trade Statistics). The PPP dollar exchange rates come from the IMF's World Economic Outlook database for the period 1980-2006, which have been extended back until 1970 using data from the Penn World Tables.

Figure A.1.1. Comparison of annual series (%y-o-y): R&D series vs indicator

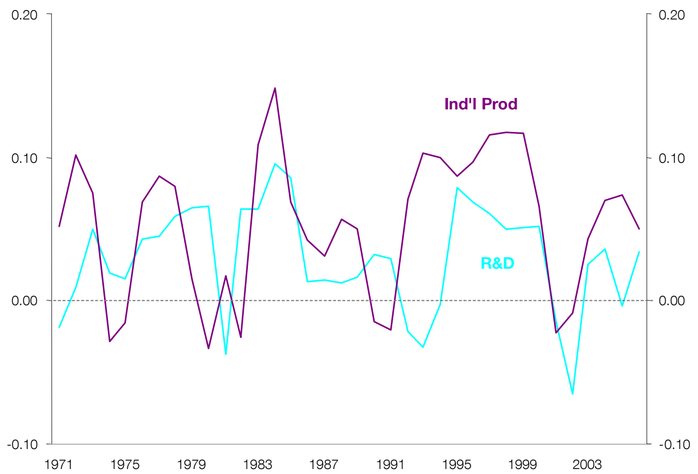
Spain: Private R&D spending vs Technological industrial production



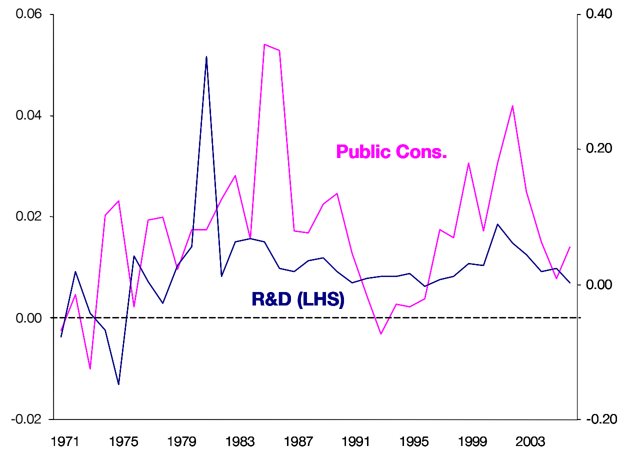
Spain: Public R&D Spending vs Public Consumption



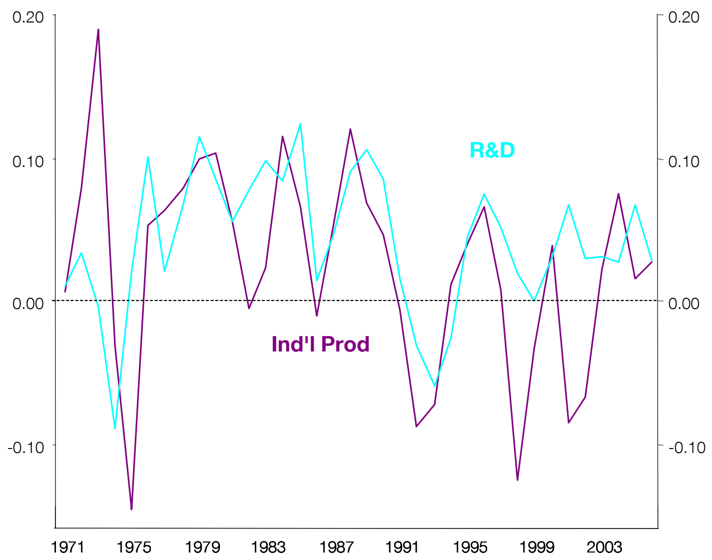
United States: Private R&D spending vs Technological industrial production



United States: Public R&D Spending vs Public Consumption



Japan: Private R&D spending vs Technological industrial production



Japan: Public R&D Spending vs Public Consumption

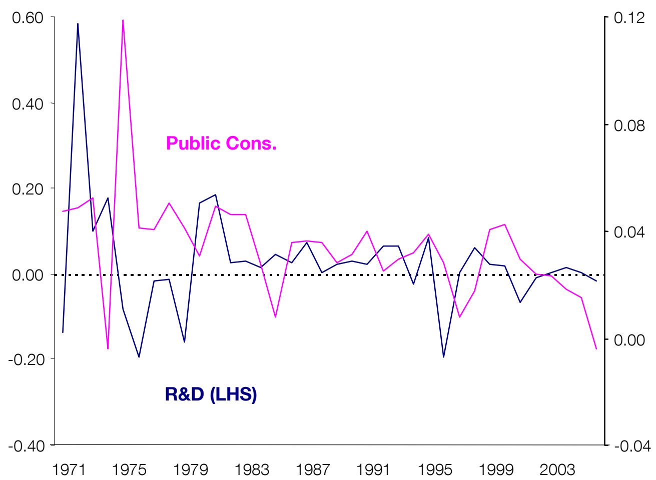
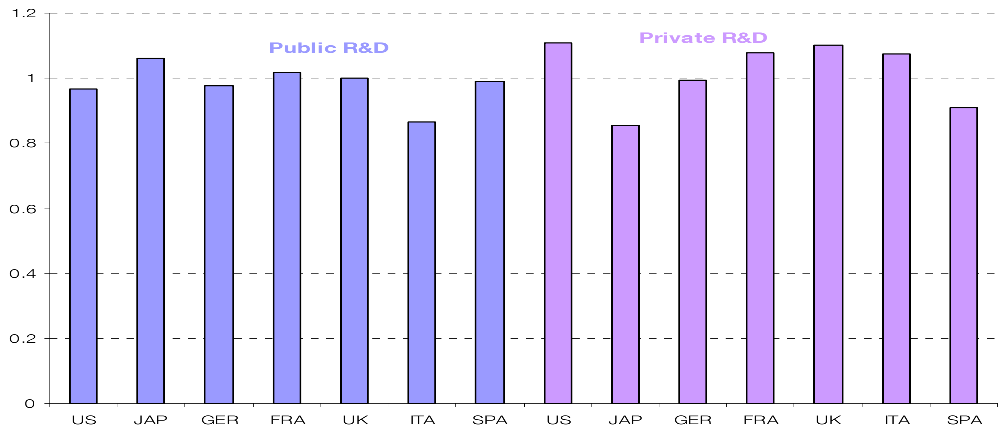


Figure A.1.2. OLS coefficients of the regression of the R&D variable on its indicator



Appendix 2. The stochastic properties of the variables

This appendix presents, with a certain detail, the stochastic properties of the variables used in the analysis. As it is well known, a minimum requirement to apply the SVAR methodology is that all the variables had the same integration order and that no linear combination of them configures a cointegrating vector.

In order to determine the stationarity of the time series considered in the paper, the traditional ADF test was applied to both the levels and the first differences of the (log) variables; as it will be seen below, one difference is enough to achieve the stationarity in all the cases. In the final regressions, both the deterministic components and the lags of the left hand side variables were chosen based on its statistical significance, and the tests were applied to the variables in annual frequency, following the recommendation of Muellbauer and Hendry (1998).

Table A.2.1. Order of integration of the variables

COUNTRY	VARIABLE	FIRST DIFFERENCE		LEVELS		CONCLUSION
		DET. COMP.	ADF TEST	DET. COMP.	ADF TEST	
SPAIN	REAL GDP	C	-3.2**	C, T	-2.7	ONE UNIT ROOT
	GDP DEF.	C, T	-3.3***	C, T	-2.0	ONE UNIT ROOT
	TOTAL R&D	C	-2.9*	C, t	-2,5	ONE UNIT ROOT
	PRIVATE R&D	C	-5.2*	C, T	-1.6	ONE UNIT ROOT
	PUBLIC R&D	C	-2.9**	C, T	-2.9	ONE UNIT ROOT
	INTERN. R&D	-	-5.3*	C	-2.7	ONE UNIT ROOT
USA	REAL GDP	C	-5.1*	C, T	-3.2***	ONE UNIT ROOT
	GDP DEF.	C, T	-3.3***	C, T	-1.9	ONE UNIT ROOT
	TOTAL R&D	C	-3.6*	C, T	-2,0	ONE UNIT ROOT
	PRIVATE R&D	C	-4.1*	C, T	-2.2	ONE UNIT ROOT
	PUBLIC R&D	C	-4.8*	C, T	-2.4	ONE UNIT ROOT
	INTERN. R&D	C	-3.3**	C, T	-1.1	ONE UNIT ROOT
JAPAN	REAL GDP	C	-3.5*	C	-2.4	ONE UNIT ROOT
	GDP DEF.	C, T	-3.8**	C, T	-2.2	ONE UNIT ROOT
	TOTAL R&D	C	-3.7*	C, T	-1.7	ONE UNIT ROOT
	PRIVATE R&D	C	-3.4*	C, T	-1.8	ONE UNIT ROOT
	PUBLIC R&D	-	-5.3*	C	-1.4	ONE UNIT ROOT
	INTERN. R&D	C	-4.3*	C, T	-2.0	ONE UNIT ROOT
GERMANY	REAL GDP	C	-4.3*	C, T	-2.2	ONE UNIT ROOT
	GDP DEF.	C, T	-3.3***	C, T	-1.2	ONE UNIT ROOT
	TOTAL R&D	C	-5.6*	C, T	-2.4	ONE UNIT ROOT
	PRIVATE R&D	C	-3.8*	C, T	-2.1	ONE UNIT ROOT
	PUBLIC R&D	C	-7.8*	C, T	-5.0*	STATIONARY
	INTERN. R&D	C	-4.6*	C, T	-2.2	ONE UNIT ROOT
FRANCE	REAL GDP	C	-4.8*	C, T	-3.3***	ONE UNIT ROOT
	GDP DEF.	C, T	-2.5	C, T	-3.3***	ONE UNIT ROOT
	TOTAL R&D	C	-6.0*	C, T	-1.2	ONE UNIT ROOT
	PRIVATE R&D	-	-2.7*	C, T	-2.6	ONE UNIT ROOT
	PUBLIC R&D	C	-9.1*	C	-2.4	ONE UNIT ROOT
	INTERN. R&D	C	-3.7*	C	-1.7	ONE UNIT ROOT
UK	REAL GDP	C	-4.5*	C, T	-2.7	ONE UNIT ROOT
	GDP DEF.	C, T	-3.5**	C, T	-1.7	ONE UNIT ROOT
	TOTAL R&D	C	-5.0*	C, T	-2.6	ONE UNIT ROOT
	PRIVATE R&D	C	-4.5*	C, T	-3.3***	ONE UNIT ROOT
	PUBLIC R&D	C	-8.7*	C, T	-2.8	ONE UNIT ROOT
	INTERN. R&D	C	-5.7*	C, T	-2.6	ONE UNIT ROOT
ITALY	REAL GDP	C	-5.6*	C	-1.4	ONE UNIT ROOT
	GDP DEF.	C, T	-4.8*	C, T	-1.9	ONE UNIT ROOT
	TOTAL R&D	C	-3.8*	C, T	-1.6	ONE UNIT ROOT
	PRIVATE R&D	-	-3.2*	C	-1.4	ONE UNIT ROOT
	PUBLIC R&D	C	-6.2*	C, T	-2.3	ONE UNIT ROOT
	INTERN. R&D	C	-5.6*	C, T	-2.2	ONE UNIT ROOT

Notes: C, constant; T, trend; *, **, ***, statistically significant at 1%, 5% and 10%, respectively.

Thus, as can be seen in Table A.2.1, most variables seem to behave as a first order integrated process. This is even the case for prices, although it is necessary to include a deterministic trend component to reject the second difference at the usual levels of significance. Although this is a non desirable property, it is only the result of the first part of the sample; as long as price stability has become the main target of monetary policy, the rejection of stationarity for inflation would imply a lack of credibility on the part of the monetary authorities. Other surprising results are real GDP for the US and France, private R&D in France and public R&D in Germany, which can not be rejected to be stationary around a trend at least at a 10% level of significance. Since it is very difficult in a finite sample to distinguish between a random walk and a deterministic trend, they are treated as being integrated of first order. Lastly, the tests obtained for the international R&D are not really necessary, as they are linear combinations of I(1) variables, but on a priori basis there is a remote possibility for cointegration that was necessary to check.

In order to reject the presence of cointegration among these five variables for each country, three tests were performed. In the first place, the Johansen methodology, which is the most general as it considers all the variables to be potentially endogenous. The problem is that the results were not very robust and they tend to accept more than two cointegrating vectors. Thus, a more traditional methodology was applied: to estimate by OLS just one equation (changing the left hand side variable to assess the robustness of the results) and then calculating the ADF tests of the residuals and including the residuals lagged one period in an error correction model (again trying different left hand side variables) as it was proposed by Banerjee et al. (1998). As Table A.2.2 shows, the existence of cointegration among these five variables was rejected for all the countries. Notice that this specification is more general than other including total R&D investment; thus, if cointegration is rejected for the disaggregation of R&D it will be also rejected for total R&D.

Table a.2.2. Cointegration tests

COUNTRY	JOHANSEN METHODOLOGY			ADF TEST	MCE TEST	CONCLUSION
		Trace	Max-Eigenv.			
	None	100.7*	35.2**			
	At most 1	65.5*	25.6			ZERO
SPAIN	At most 2	39.8*	18.5	-2.7	-1.5	COINTEGATING
	At most 3	21.3*	13.7			VECTORS
	At most 4	7.6*	7.6*			
	None	118.2*	44.8*			
	At most 1	73.4*	43.2*			ZERO
USA	At most 2	30.2*	19.4***	-2.0	-1.3	COINTEGATING
	At most 3	10.8	9.3			VECTORS
	At most 4	1.4	1.4			
	None	127.9*	45.9*			
	At most 1	82.0*	35.7*			ZERO
JAPAN	At most 2	46.2*	23.8*	-2.4	-1.1	COINTEGATING
	At most 3	22.4*	16.8*			VECTORS
	At most 4	5.6*	5.6*			
	None	98.6*	41.8*			
	At most 1	56.8*	30.0*			ZERO
GERMANY	At most 2	26.7	16.2	-2.5	-1.8	COINTEGATING
	At most 3	10.6	7.8			VECTORS
	At most 4	2.8***	2.8***			
	None	124.3*	54.5*			
	At most 1	69.8*	39.0*			ZERO
FRANCE	At most 2	30.8*	15.8	-1.7	-1.9	COINTEGATING
	At most 3	15.0**	11.6			VECTORS
	At most 4	3.4**	3.4**			
	None	77.4*	31.9**			
	At most 1	45.6**	25.6**			ZERO
UK	At most 2	20.0	10.9	-3.0	-1.7	COINTEGATING
	At most 3	9.0	14.3			VECTORS
	At most 4	1.3	1.3			
	None	99.3*	37.8**			
	At most 1	61.5**	23.8			ZERO
ITALY	At most 2	37.7	18.8	-2.9	-1.9	COINTEGATING
	At most 3	18.9	12.3			VECTORS
	At most 4	6.7	6.7			

Notes: see previous table.

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