Economics of Innovation and New Technology

ISSN: 1043-8599 (Print) 1476-8364 (Online) Journal homepage: https://www.tandfonline.com/loi/gein20

Does research and development capital affect total factor productivity? Evidence from Greece

Ioannis Voutsinas & Constantinos Tsamadias

To cite this article: Ioannis Voutsinas & Constantinos Tsamadias (2014) Does research and development capital affect total factor productivity? Evidence from Greece, Economics of Innovation and New Technology, 23:7, 631-651, DOI: 10.1080/10438599.2013.871169

To link to this article: https://doi.org/10.1080/10438599.2013.871169

Published online: 04 Mar 2014.

Economics of Innovation and New Technology, 2014
Vol. 23, No. 7, 631–651, http://dx.doi.org/10.1080/10438599.2013.871169

Does research and development capital affect total factor productivity? Evidence from Greece

Ioannis Voutsinas* and Constantinos Tsamadias

Department of Home Economics and Ecology, School of Environment, Geography and Applied Economics, Harokopio University, El. Venizelou 70, Kalithea, 17671, Athens, Greece

(*Received 26 July 2013; final version received 16 November 2013*)

The purpose of this study is twofold: Firstly, it investigates the relationship between the research and development (R&D) capital and the total factor productivity (TFP) of the Greek economy over the period 1981–2007. Secondly, it presents an overview of relevant empirical studies. It applies the Johansen methodology to estimate cointegrating vectors and uses vector error correction models to examine causality and short-term dynamics. The results indicate the presence of a long-run relationship between the total R&D capital and TFP and between the public R&D capital and TFP. On the other hand, the private R&D capital is not significantly related to TFP. A 1% increase in total R&D capital raises TFP by 0.038%, whereas a 1% increase in the public R&D capital raises TFP by 0.075%. The productivity of the Greek economy could be enhanced by higher R&D expenditure combined with the necessary structural reforms to improve the efficiency of the innovation system.

Keywords: R&D capital; TFP; economic growth; Greece

JEL Classification: O30; O40; C32

1. Introduction

There is a broad consensus among economists about the critical importance of technological development and innovation among the factors determining productivity and economic growth. Romer (1990) argues that technological change not only lies at the heart of economic growth, but also arises in large part because of the intentional actions taken by people who respond to market incentives. Grossman and Helpman (1994) suggest that improvements in technology are the best chance we have to overcome the apparent 'limits to growth'.

Innovation feeds on knowledge that results from cumulative research and development (R&D) effort on the one hand and contributes to this stock of knowledge on the other. In the theoretical model proposed by Aghion and Howitt (1992), the frequency and size of innovations depend on the level of the R&D input.

Innovation is an important driver of long-run productivity growth, which in turn is a key determinant of long-run economic growth. The development of new products and processes is fundamental in maintaining a firm's competitiveness over its peers. For example, Wakelin (2001) examined the contribution of R&D expenditure to firms' productivity growth and found that R&D expenditure increases the rate of innovation success.

*Corresponding author. Email: ivoutsinas@bankofgreece.gr

The business R&D results in new goods and services and new production processes. On the other hand, the basic research performed by universities enhances the stock of knowledge of the society. Basic research may open new opportunities to business research, which in turn affects productivity (Guellec and van Pottelsberghe de la Potterie 2001).

The purpose of this study is twofold. Firstly, it investigates the relationship between the R&D capital and the total factor productivity (TFP) of the Greek economy over the period 1981–2007. Secondly, it presents an overview of empirical studies that have examined the relationship between R&D and TFP on the basis of country-level data.

This study contributes to the empirical literature in several ways. Firstly, to the best of our knowledge, this is the first study that examines the relationship between R&D capital and the TFP for the Greek economy, taking also into account the special characteristics of the Greek innovation system. Secondly, it distinguishes the impact of private research from that of government and university research on TFP. Finally, it makes use of vector error correction (VEC) models to study the endogeneity, causality and short-run dynamics of TFP and R&D capital.

The rest of this paper is organized as follows: Section 2 refers to the theoretical framework; Section 3 presents a review of empirical studies; Section 4 provides some information on the Greek economy and innovation system; Section 5 introduces the empirical analysis and discusses the results; and finally, Section 6 summarizes the conclusions of the study. In addition, Appendix 1 summarizes some aspects of the reviewed empirical studies and Appendix 2 presents the results of certain diagnostic tests.

2. Theoretical framework

The growth accounting method, which was first introduced by Solow (1957) and later developed by Kendrick (1961) and Denison (1962) begins, with the measurement of factor accumulation and then imputes output expansion to the inputs that have been accumulated by assuming that market factor prices reflect value marginal products. The part of output growth that cannot be attributed to the accumulation of any input, known as the ‘Solow residual’ or TFP, is ascribed to technological progress. Jorgenson and Griliches (1967) extended and refined the growth accounting analysis by considering changes in the quality of capital and labour and argued that TFP should not be equated with technological change.

The role of public and private R&D in productivity growth has deep roots in the early work of agricultural economists. For example, the first estimates of returns to public R&D expenditures (Schultz 1953; Griliches 1958) and the first production function estimate with an added R&D variable (Griliches 1964) originated in agricultural studies. In addition, Griliches (1973) outlined a research programme in which R&D spending was emphasized as the main determinant of the TFP growth rate.

Economic theory points to technological change as the major source of productivity growth in the long run. Both in the neoclassical model of Solow (1956) and in the endogenous growth theories introduced by Lucas (1988) and Romer (1990), the key determinant of economic growth is the rate of technological progress, which can be approximated by the TFP growth. However, a key difference between the endogenous growth theories and the neoclassical theory is that in the former the rate of technological progress can be influenced by economic policy (Howitt 2004).

The new growth models introduced by Romer (1990), Grossman and Helpman (1991a) and Aghion and Howitt (1992) have emphasized the key role of R&D efforts in driving technological progress and productivity. Grossman and Helpman (1991b) showed that TFP remains a meaningful concept in endogenous growth models either with horizontal or vertical product differentiation. For example, they show that TFP is related to the number $n(t)$ of the horizontally differentiated intermediate goods in the following way:

$$\log\ \mathrm{TFP}(t) = \frac{(1-a)}{a} \cdot \log\ n(t),$$

where t denotes time, α is a parameter taking values between 0 and 1 and TFP is defined on the basis of a standard Cobb–Douglas production function.

The number of intermediate goods $n(t)$ is the result of cumulative past research efforts reflecting cumulative past investment in R&D. Therefore, TFP is also an increasing function of cumulative R&D or in other words of the R&D capital.

3. Review of empirical studies

The reviewed literature, mostly based on the ideas of the endogenous growth economic theory, has empirically demonstrated the positive effect of R&D activity on productivity. Most of the reviewed studies estimate the relationship between TFP, usually calculated on the basis of a Cobb–Douglas aggregate production function, and variables such as domestic R&D capital, foreign R&D capital, human capital and others.

The majority of the literature focuses on cross-border knowledge spillovers and private sector R&D capital. A few studies concentrate on the effect that domestic R&D and other national factors have on productivity. Only two studies isolate the impact of publicly performed R&D on TFP. Table A1 in Appendix 1 summarizes some aspects of the reviewed empirical studies. The basic findings are presented below.

3.1. R&D capital and TFP

Most of the studies found that the level of R&D capital which is accumulated as a result of annual R&D expenditures, has a positive and in most cases significant stimulus on the level of TFP. In addition, some studies found a positive correlation between the TFP growth rate and the R&D capital growth rate. Table 1 presents some indicative values of the TFP elasticity in relation to R&D capital found in the literature. The TFP elasticity in relation to R&D capital varies significantly with its values ranging from 0.017 to 0.284. Furthermore, the TFP elasticity with respect to private R&D capital appears to be lower than that of public R&D capital in two studies.

3.2. Cross-border knowledge spillovers

Both domestic and foreign business R&D have a positive effect on TFP of a country. In relation to the influence of foreign business R&D, the literature focuses on the potential channels of cross-border knowledge spillovers. Among others, bilateral total imports (Coe and Helpman 1995), bilateral imports of capital goods (Xu and Wang 1999) and inward and outward foreign direct investment flows (van Pottelsberghe de la Potterie and Lichtenberg 2001) are modelled as possible channels of cross-border knowledge transmission. Coe and Helpman (1995) argued that small open economies usually benefit more from foreign business R&D capital than from domestic business R&D capital. Moreover, van Pottelsberghe de la Potterie and Lichtenberg (2001) concluded that the impact of foreign business R&D is higher in countries where the business R&D intensity is higher.

Not forgetting the importance of international knowledge spillovers especially for a small economy like Greece, in this study we are interested in the domestic spillovers from

Table 1. Indicative values of TFP elasticity in relation to R&D capital.

Authors	No. TFP elasticity with respect to total R&D capital[a]
Coe and Helpman (1995)	0.069–0.134
Engelbrecht (1997)	0.057–0.08
Lichtenberg and van Pottelsberghe de la Potterie (1998)	0.044–0.086
Xu and Wang (1999)	0.035–0.149
van Pottelsberghe de la Potterie and Lichtenberg (2001)	0.017–0.138
Guellec and van Pottelsberghe de la Potterie (2001)	0.13 (private) and 0.17 (public)
Lumenga-Neso, Olarreaga, and Schiff (2005)	0.016–0.093
Coe, Helpman, and Hoffmaister (2009)	0.062–0.144
Ho, Wong, and Toh (2009)	0.08
Luintel, Khan, and Theodoridis (2010)	0.017–0.174 (private) and 0.071–0.284 (public)

Note: The elasticities refer to total R&D capital, unless otherwise specified. [a]On the basis of a selected specification from those presented in the study.

the knowledge production sectors to the other sectors of the economy. In this context, we have chosen not to include the exogenous variable of foreign R&D capital in our analysis, a variable usually taken into consideration in studies based on panel data from a sample of countries.

3.3. *Private vs. public R&D*

Guellec and Van Pottelsberghe de la Potterie (2001) and Luintel, Khan, and Theodoridis (2010) found that both the private and the public sector R&D capital (i.e. R&D capital stemming from public sector research) has a positive and significant stimulus on the level and/or growth rate of TFP. On top of that, they offered econometric evidence suggesting that the R&D performed by the public sector could have stronger impact on economic performance than the private sector R&D, a view also supported by Griliches (1992). In addition, Guellec and Van Pottelsberghe de la Potterie (2001) found that the effect of public research is larger in countries where universities have a higher share in public research and concluded that the TFP elasticity in relation to public research increases together with the business R&D intensity.

3.4. *Inclusion of human capital and other factors*

Certain studies (Engelbrecht 1997) have examined the role of human capital in the relationship between TFP and R&D capital. The usual proxy of human capital is the average years of schooling. In all cases, the inclusion of the human capital variable did not affect either the sign or the significance of the R&D variables.

Some studies examined other factors affecting the relationship between TFP and R&D capital. Coe, Helpman, and Hoffmaister (2009) focused on institutional aspects such as legal origin and patent protection, and concluded that institutional differences between countries are important determinants of TFP. Luintel, Khan, and Theodoridis (2010) found that information and communication technology, public infrastructure, the services sector of the economy, high technology exports and financial deepening appear to be the main non-R&D determinants of productivity. Finally, Keller (2002) offered econometric evidence that technological knowledge is to a substantial degree local, not global, as the benefits from foreign spillover are declining with distance.

3.5. Studies referring to a single country

The majority of the studies were based on panel data from a sample of countries. However, some of them focused on the data of a single country (Teixeira and Fortuna 2004; Ha and Howitt 2007; Ho, Wong, and Toh 2009) and found a positive relationship between the level of domestic R&D capital and the productivity level of the examined countries. We are not aware of any previous study examining this issue for Greece.

4. Greek economy and innovation system during the period 1981–2007

This time period was of particular interest for the Greek economy as a number of structural reforms and adjustments took place. The accession of Greece to the European Economic Community (EEC) in 1981 and the accession to the European Monetary Union (EMU) in 2001 were two major events. Positive growth rates were achieved, especially in the 1990s and from 2000 until the beginning of 2008. In particular, the average annual growth rate of gross domestic product (GDP) was approximately 0% in the 1980s, 2.4% in the 1990s and 4.1% during the period 2000–2007.

The domestic R&D activity was very less before 1980. As mentioned by Hatzikian (2007), 'The Greek sector of R&D was developed substantially afterwards the creation of an institutional frame for scientific research in the country in the beginning of the decade of 1980s.'

The Greek policy on innovation has been greatly influenced by the orientation of the EU policy. Given the absence of a full-fledged national strategy, the fact that the overall direction of the technology and innovation policy is mainly initiated at the EU level has been a mixed blessing, as the EU technology policy is usually based on the economic reality prevalent in the core Western European economies.

Collins and Pontikakis (2006) described the significant institutional changes which took place during the 1980s. These included the establishment of the general overseer body, the General Secretariat for Research and Technology (GSRT) in 1985 and the strengthening of the institutional framework for the protection of intellectual property rights by the foundation of the Greek patent registration office in 1987. Additionally, the law 1514/85 outlined the institutional framework for the development of scientific research and was a legal cornerstone for the Greek technology policy.

During the period 1981–2007, the absolute level of R&D expenditures increased considerably in both the private and public sector. The contribution of the public sector remained higher than that of the private sector, as private firms failed to make systematic efforts in R&D. The share of the higher education sector in public R&D expenditure increased from 20% in 1981 to 70% in 2007. Despite the significant increase in R&D expenditure in absolute terms, the R&D intensity as measured by the ratio of R&D expenditures to GDP has remained very low in comparison to the EU average during the examined period.

Tomadaki (2005) found that the innovation network in Greece appeared to be built around a few highly connected central actors, which were the leading and more innovative Greek firms and the most reputed academic institutions and research centres. As a result of its high clustering and short average distance characteristics, the Greek innovation network was considered an efficient mechanism for knowledge diffusion. However, the majority of Greek firms had very low or no systematic participation in R&D projects.

Souitaris (2002) mentioned that the Greek industry mainly comprised SMEs, which usually do not have the financial resources to support an organized R&D department. Furthermore, he identified a set of firm-specific competencies/determinants of innovation for the Greek manufacturing industry, which among other variables comprised the proportion of university graduates, of engineers and scientists, of managers and of professional staff with previous experience in other companies. At least until the beginning of 2000s, most Greek SMEs lacked these firm-specific competencies/determinants of innovation.

According to a report prepared by OECD and presented in its website, the links between academia and industry are weak and there is little demand from the industry for R&D and innovation.

Moreover, in a report prepared by Deutsche Bank Research and presented in its website, it is mentioned that measures to promote the Greek innovation system rely heavily on financing from the EU structural funds, as there are market shortcomings regarding funding innovations and start-up companies.

On the positive side, the relative strengths of the Greek innovation system may be noted in sciences as evidenced by the share of scientific publications in leading journals. According to a report presented in the website of European Commission, Greece is well placed regarding scientific production. In addition, Greece is above the average in the scientific publications within the top 10% of the most cited publications worldwide as a percentage of total scientific publications of the country.

5. Empirical analysis

This section presents the methodology, the data and sources and the econometric analysis (stationarity properties of the data, cointegration tests, VEC models, Granger causality tests and forecasting analysis). Finally, the section concludes with a discussion of the results.

5.1. Methodology, data and sources

Our empirical analysis is based on the following equation that links TFP to R&D capital, which is usually the basis of the analysis in the reviewed literature:

$$\log(\text{TFP}) = a + b \cdot \log(\text{R\& Dcapital}).$$

In the following empirical analysis, we examine the relationship between the natural logarithm of TFP and that of the total, private and public R&D capital, respectively.

Data refer to the period 1981–2007. It should be highlighted that since 2009 the Greek economy has been heavily affected by a sovereign debt crisis and by the subsequent application of a strict economic adjustment programme. Therefore, the inclusion of more recent data could significantly alter the results of this study.

TFP has been calculated in the following way:

$$\text{TFP} = Y/(K^{\beta} \cdot L^{1-\beta}),$$

where Y is the GDP, K is the physical capital stock, L is the labour input (defined as total employment times average annual hours worked per worker) and β is the physical capital share of total income. We assume constant returns to traditional inputs (K and L) and perfect competition, and two standard assumptions in the reviewed empirical studies (Coe and Helpman 1995) that allow us to define β as the capital income share and $1 - \beta$ as the labour income share to be calculated as residual.

All data for the calculation of TFP have been obtained from the OECD's database. All the amounts provided by OECD in local currency and current prices were divided by GDP deflators (2005 = 1) and expressed in constant 2005 prices.

There were no available historical data in the OECD database regarding the physical capital stock of Greece. Therefore, the physical capital has been calculated by the perpetual inventory method on the basis of data for the annual gross capital formation in Greece provided by the OECD. In particular, the capital stock at the end of each year has been calculated as the sum of the previous year's capital stock and the current year's investment after deducting the amount of depreciated capital, as presented in the following equation:

$$K_t = (1 - \delta) \cdot K_{t-1} + I_t,$$

where K_t and K_{t-1} are the physical capital stocks of the current and previous year, respectively, I_t is the annual investment in year t and δ is the annual depreciation rate of the capital stock. The depreciation rate was set at 5% taking into account the depreciation rates used in previous studies for the Greek economy (Alogoskoufis 1995; Gogos et al. 2012). A sensitivity analysis performed for various values of the depreciation rate up to 10% resulted in no significant changes in the key qualitative conclusions of this study.

The estimate of the capital stock at the beginning of the examined period, which was necessary for the application of the perpetual inventory method, was calculated with the following formula:

$$K_1 = \frac{I_1}{(\delta + g)},$$

where K_1 is the estimate of the capital stock at the end of year 1, I_1 is the annual investment in year 1, δ is the annual depreciation rate and g is the average of yearly growth rates of investment in physical capital during the period 1981–2007.

The data for total, private and public sector R&D expenditures were taken from the Eurostat statistics database. In particular, the data referred to intramural R&D expenditure by sector of performance. It should be highlighted that no data were available for the period after 2007.[1]

R&D expenditures data, which were provided by Eurostat in local currency and current prices, were divided by GDP deflators (2005 = 1) and expressed in constant 2005 prices.

R&D capital stocks were calculated using the perpetual inventory method on the basis of R&D annual expenditure, in a similar way as the physical stock was calculated. However, the depreciation rate was set at 10%, higher than that in the case of physical capital and a pre-sample growth rate of 5% was assumed for real R&D expenditures in order to calculate the initial estimate of each R&D capital. The key qualitative conclusions of this study are still valid for other values of the depreciation rate for R&D capital ranging from 5% to 15%.

Table 2 summarizes some descriptive statistics about the variables used in the empirical analysis.

Table 2. Descriptive statistics.

Label	LPRO	LRDDCP	LRDDCS	LRDDCT
Description	Logarithm of TFP	Logarithm of Private R&D Capital	Logarithm of Public R&D Capital	Logarithm of Total R&D Capital
Mean	−2.994078	6.751198	7.795494	8.097983
Median	−3.021134	6.779393	7.811918	8.116535
Maximum	−2.826397	7.799624	8.690983	9.034642
Minimum	−3.154627	5.589415	6.829945	7.083991
Std Dev.	0.085537	0.688969	0.597218	0.620831

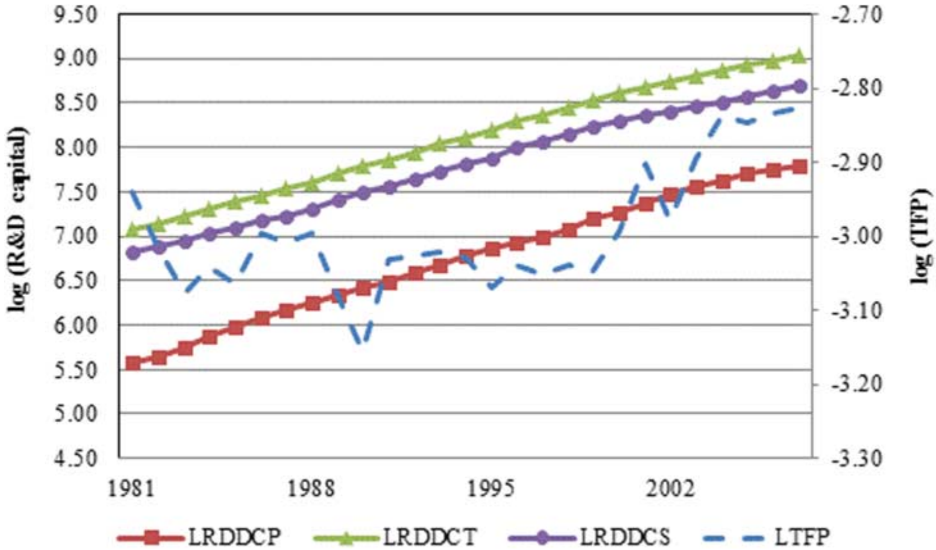

Figure 1. TFP *vs.* R&D capital evolution. Note: On the basis of data from Eurostat database regarding R&D expenditures and data from OECD database for the calculation of TFP.

Figure 1 presents the evolution of the four variables during the examined period.

Although the logarithm of TFP appears to be significantly more volatile, its long-term trend is similar to that of the logarithm of R&D capital. However, the TFP growth rate is lower than that of R&D capital.

5.2. Econometric analysis

5.2.1. Stationarity tests

The stationarity of the data set is examined with the augmented Dickey–Fuller (ADF), Dickey–Fuller GLS (DF–GLS) (1979) and Phillips and Perron (1988) tests. The tests are performed first in level and next in the first difference for each variable. Lag order is automatically selected using the Schwarz information criterion. The null hypothesis is the existence of unit root. Test results are presented in Table 3.

All the variables have unit root and they are integrated of order one in their level, while they are stationary or integrated of order zero in their first difference at the 1% or 5% level of significance. A standard regression analysis on the basis of their levels would produce spurious results, unless the variables are cointegrated.

5.2.2. Cointegration tests

We examine whether the LPRO variable is cointegrated with each one of LRDDCT, LRDDCP and LRDDCS. Cointegration tests are performed using the methodology developed by Johansen (1991, 1995). The cointegration model specification that fits the data is the one with linear deterministic trend in the data and an intercept, but no trend in the cointegrating equations. Lag selection is based on minimizing the Schwarz (1978) and Akaike (1974, 1987) criteria and as a result one lag is selected for the test. Two statistics are used in the tests, namely the trace test and the maximum eigenvalue test. Test results are presented in Table 4.

Table 3. Results of unit root tests.

Variables	ADF test	DF–GLS test	Phillips–Perron test
	With intercept	*With intercept*	*With intercept*
LPRO	−1.097	−1.194	−1.059
Δ(LPRO)	−5.839*	−4.883*	−6.427*
LRDDCT	−1.872	−1.048	−1.872
Δ(LRDDCT)	−3.978*	−1.129	−3.990*
LRDDCP	−2.062	−1.167	−2.062
Δ(LRDDCP)	−2.899**	−2.416**	−3.053**
LRDDCS	−1.348	−0.701	−1.310
Δ(LRDDCS)	−4.219*	−3.848*	−4.218*

* Rejection of the null hypothesis of unit root at the 1%level on the basis of MacKinnon one-sided *p*-values.
**Rejection of the null hypothesis of unit root at the 5% level on the basis of MacKinnon one-sided *p*-values.

Table 4. Results of cointegration tests.

Variables	Null hypothesis: number of cointegrating equations	Trace	5% critical value	Maximum eigenvalue	5% critical value
LPRO & LRDDCP	None	14.431	*15.495*	*10.676*	*14.265*
LPRO & LRDDCP	At most one	3.756	*3.842*	*3.756*	*3.842*
LPRO & LRDDCS	None	18.836*	*15.495***	*15.461**	*14.265*
LPRO & LRDDCS	At most one	3.375	*3.842*	*3.375*	*3.842*
LPRO & LRDDCT	None	24.842*	*15.495*	*19.167**	*14.265*
LPRO & LRDDCT	At most one	5.674*	*3.842*	5.674*	*3.842*

* Rejection of the null hypothesis at the 5% level on the basis of MacKinnon–Haug–Michelis *p*-values.
** MacKinnon–Haug–Michelis (1999) *p*-values.

Table 5. Cointegrating equations.

Variables	CointEquation1	CointEquation2
LPRO	1.000	1.000
LRDDCT	0.038**	
LRDDCS		0.075*
Intercept	−3.311	−3.586

* Significance at the 1% level.
** Significance at the 5% level.

The trace test indicates the existence of one cointegrating equation for the variables LPRO and LRDDCS at the 5% level and also the existence of two cointegrating equations for the variables LPRO and LRDDCT at the 5% level. On the other hand, the null hypothesis of no cointegration cannot be rejected for the variables LPRO and LRDDCP at the 5% level. The trace test results are also supported by the results of the maximum eigenvalue test.

Therefore, a long-run relationship between TFP and total R&D capital, as well as between TFP and public R&D capital has been identified. On the other hand, the relationship between TFP and private R&D capital does not appear to be significant. Table 5 reports the normalized coefficients of the cointegrating equations.

All the TFP elasticities in relation to R&D variables have a positive sign and they are statistically significant. According to the results, a 1% increase in total R&D capital in the long run would raise TFP by approximately 0.038%. Furthermore, a 1% increase in the public R&D capital would raise total productivity by approximately 0.075%.

5.2.3. Causality and short-term relationships

According to the Granger representation theorem, a set of cointegrated variables will have an error correction model, which describes the short-term relationship between the cointegrated variables. The error correction model also allows us to perform Granger causality tests (Granger 1969, 1988). Let us define the error term as

$$y_{t-1} - \beta \cdot x_{t-1} - c,$$

where β is the long-run elasticity and c is the intercept, both of which have been previously estimated. Hence, we can estimate the following VEC models for each pair of cointegrated variables:

$$\Delta y_t = a_1 \cdot (y_{t-1} - \beta \cdot x_{t-1} - c) + \sum_{\kappa} \gamma_{1t-\kappa} \cdot \Delta y_{t-\kappa} + \sum_{\kappa} \gamma_{2t-\kappa} \cdot \Delta x_{t-\kappa} + \sigma_2 + u_{1t},$$

$$\Delta x_t = a_2 \cdot (y_{t-1} - \beta \cdot x_{t-1} - c) + \sum_{\kappa} \gamma_{3t-\kappa} \cdot \Delta y_{t-\kappa} + \sum_{\kappa} \gamma_{4t-\kappa} \cdot \Delta x_{t-\kappa} + \sigma_3 + u_{2t},$$

where Δ is the first difference operator and the coefficients α_1 and α_2 measure the speed of adjustment of the model towards the equilibrium, $y = \text{LPRO}, x = \text{LRDDCS}$ or LRDDCT and κ = number of lags.

The significance of the coefficient of the error term is indicative of long-run Granger causality. For example, if α_1 turns out to be statistically significant then the R&D capital Granger causes TFP in the long run, while if α_2 is statistically significant then TFP Granger causes R&D capital in the long run. Short-run Granger causality is tested by the joint significance of the lagged differentiated variables, i.e. when the aforementioned parameters γ_i are jointly different from zero. If only the long-run test is accepted, while the short-run test is rejected, then the dependent variable of the corresponding equation is weakly exogenous. If both the coefficient of the error term and the parameters γ_i in one equation are not jointly statistically different from zero, something which can be examined on the basis of the F-statistic, then the dependent variable is strongly exogenous (Hendry 1995).

The estimated models are presented in Table 6.

Certain diagnostic tests are performed on the residuals of the two VEC models. More specifically, the Breusch–Godfrey Lagrange multiplier test (Godfrey 1988) is used to check for the presence of serial correlation, the normality of the residuals is checked with a multivariate extension of the Jarque–Bera normality test (Doornik and Hansen 1994) and an extension of the White heteroskedasticity test (Doornik 1995) is also applied.

According to the values of the various test statistics and the associated tail probabilities presented in Appendix 2, the VEC models appear to be broadly well specified. The residuals are serially uncorrelated and homoskedastic. The null hypothesis that residuals are multivariate normal cannot be rejected in the second VEC model, while it is rejected in the first VEC model. However, the rejection in the first model is mainly caused by the excess skewness in the D(LRDDCS) equation residuals, while the normality of the residuals from the D(LRO) equation is not rejected.

Table 6. VEC models.

	VEC Model 1		VEC Model 2	
Variable	D(LPRO)	D(LRDDCS)	D(LPRO)	D(LRDDCT)
Error term	−0.546896	−0.118101	−0.399095	−0.152916
	(0.20783)	(0.07814)	(0.22384)	(0.05491)
	[−2.63148]*	[−1.51149]***	[−1.78297]**	[−2.78505]*
D(LPRO(-1))	0.037869	−0.042077	0.039092	0.011675
	(0.19386)	(0.07288)	(0.21977)	(0.05391)
	[0.19535]	[−0.57732]	[0.17788]	[−0.21658]
D(LRDDCS(-1))	−1.224955	−0.098922		
	(0.63996)	(0.24060)		
	[−1.91411]**	[0.41115]		
D(LRDDCT(-1))			−1.258771	−0.238307
			(0.93727)	(0.22991)
			[−1.34302]	[−1.03655]
C	0.095721	0.079694	0.102928	0.093973
	(0.04703)	(0.01768)	(0.07165)	(0.01757)
	[2.03522]**	[4.50702]*	[1.43664]	[5.34725]*
R^2	0.272048	0.173023	0.15391	0.336370
F-statistic	2.616017***	1.464562	1.278056	3.548041**
Akaike AIC	−3.083687	−5.040229	−2.933865	−5.744465
Schwarz SC	−2.888667	−4.845209	−2.738845	−5.549445

Note: Standard error in parenthesis and t-statistic in brackets.
* Significance at 1%.
** Significance at 5%.
*** Significance at 10%.

From the results presented in Table 6 for the first VEC model (LPRO and LRDDCS), the following observations can be made. In both equations, the error correction terms are negative. The coefficient of the error term in the first equation is statistically significant at the 1% significance level, while the coefficient of the error term in the second equation is significant only at the 10% level. Therefore, the public R&D capital Granger causes the TFP and vice versa. On the other hand, there is limited evidence of a short-term impact of the regressors on the depended variables dynamics given their t-statistics. Apart from the constant terms, only the coefficient of D(LRDDCS(–1)) appears to be statistically significant. Overall, on the basis of the F-statistic, TFP is endogenous both in the long and short run, while the Public R&D capital is weakly exogenous.

In relation to the second VEC model, the following comments can be made. In both equations, the error correction terms are negative and statistically significant. The coefficient of the error term in the first equation is statistically significant at the 5% significance level and the coefficient of the error term in the second equation is significant at the 1% significance level. Therefore, both total R&D capital and TFP Granger cause each other. Moreover, there is limited evidence of a short-term impact of the regressors on the depended variables dynamics given their t-statistics. Overall, on the basis of the F-statistic, TFP is endogenous only in the long run, while total R&D capital is endogenous.

The previous findings in relation to causality are also supported by the results of the pairwise Granger causality tests presented in Table 7.

5.2.4. Forecasting

The estimated models can be used to forecast future values of the variables. Forecasts can be obtained by solving the VEC model. Broyden's iterative method has been chosen to solve

Table 7. Granger causality tests.

Null hypothesis	Lags	F-statistic	Prob.
LRDDCS does not Granger cause LPRO	1	8.16289*	0.0089
LPRO does not Granger cause LRDDCS	1	5.76918**	0.0248
LRDDCT does not Granger cause LPRO	1	8.31829*	0.0084
LPRO does not Granger cause LRDDCT	1	9.39979*	0.0055

* Rejection of the null hypothesis at the 1% level.
** Rejection of the null hypothesis at the 5% level.

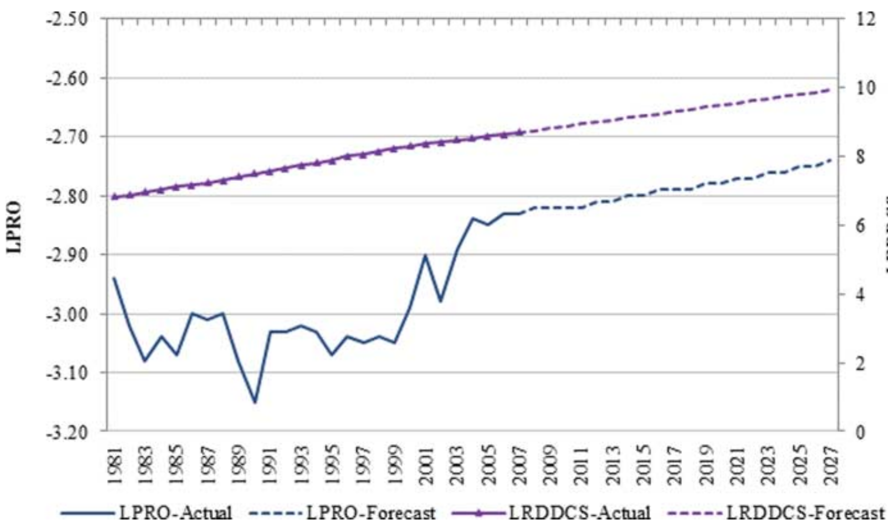

Figure 2. Historical and forecasted values of LPRO and LRDDCS.

the models (Dennis and Schnabel 1983). As we are interested in forecasting the endogenous variables in the out-of-sample period 2008–2027, a dynamic solution of the VEC model is calculated. In this way, each future forecast of the variables is calculated on the basis of the solutions of the equations calculated in previous periods, not from the actual historical values.

Figure 2 shows the historical and forecasted values of the variables LPRO and LRDDCS for the period up to 2027.

The logarithm of TFP is projected to increase almost in parallel with that of public R&D capital.

Figure 3 shows the historical and forecasted values of the variables LPRO and LRDDCT for the period up to 2027.

Again, the logarithm of TFP is projected to increase almost in parallel with that logarithm of total R&D capital.

5.2.5. *Discussion of the results*

According to the results of the empirical analysis, the total R&D capital has a positive and significant impact on TFP during the examined period. The estimated TFP elasticity in relation to total R&D capital is relatively low, taking into account the estimated values in other empirical studies presented in Section 3, which could be interpreted as a sign of lower

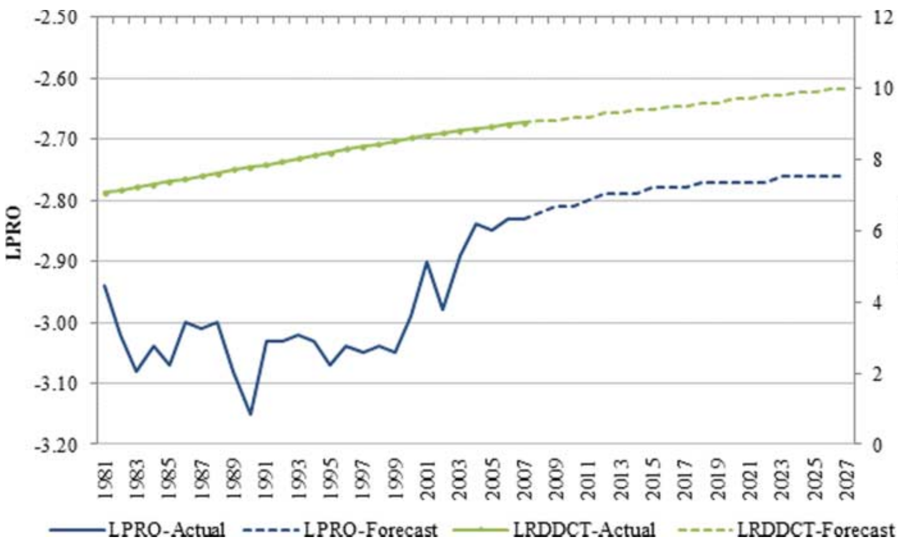

Figure 3. Historical and forecasted values of LPRO and LRDDCT.

efficiency of the Greek innovation system. Nevertheless, an increase in the total R&D capital could significantly increase TFP during the following years, as shown in the forecasting analysis.

The public R&D capital also has a positive and significant impact on TFP. The respective TFP elasticity is included in the range suggested by Luintel, Khan, and Theodoridis (2010), but it is lower than the estimate of Guellec and Van Pottelsberghe de la Potterie (2001). The positive effect of public R&D on TFP may be attributed to the significant knowledge production in Greece, the good quality of public research output, the strong connections between the universities and the leading innovative Greek firms, and also to the fact that public R&D is mainly performed by the higher education sector. The low TFP elasticity with respect to public R&D could be also due to the very low business R&D intensity in comparison to other countries, where the private sector is able to seize the opportunities raised by public research. Even so, an increase in the public R&D capital could significantly increase TFP during the following years, as shown in the forecasting analysis.

Contrary to the empirical literature, the long-term relationship between the private R&D capital and TFP does not appear to be significant, but one should also keep in mind the limited timespan of the data. Having said that, the lack of connection between the private R&D capital and TFP could be explained by the following characteristics of the Greek innovation system: first, the very low participation of the Greek SMEs in collaborative R&D projects and their weak connections to the academic institutions and research centres, taking also into account that the Greek economy is mainly based on SMEs; second, at least until the beginning of 2000s, most SMEs lacked the firm-specific competencies/determinants of innovation identified by Souitaris (2002); finally the R&D projects usually rely heavily on financing from the EU structural funds, which can be quite volatile and cause a discontinuation of such projects. All the aforementioned reasons coupled with the lack of critical mass in certain sectors could explain the absence of a significant relationship between the private R&D and productivity of the Greek economy.

The examination of the relevant VEC model has shown that the total R&D capital and TFP cause each other, a finding that is consistent with the theory. More interesting is the finding that this two-way causality exists also between public R&D capital and TFP, showing that the public research is quite reactive to the changing technological level.

The negative sign of the coefficient of D(LRDDCS(–1)) in the first equation of the first VEC model is counterintuitive, i.e. an increase in the growth rate of the public R&D in one period reduces the growth rate of TFP in the following period. Taking into account the long-term nature of the relationship, this result should be attributed to the specific data patterns.

6. Concluding remarks

The purpose of this study is twofold. Firstly, it investigates the relationship between the R&D capital and TFP of the Greek economy over the period 1981–2007. Secondly, it presents an overview of relevant empirical studies.

In the Greek economy, the total R&D capital as well as the public R&D capital has a positive and significant impact on TFP over the period 1981–2007. Additionally, an increase in the TFP level also causes higher levels of total and public R&D capital. On the other hand, the private R&D capital is not significantly related to the TFP. In addition, there is limited evidence of a short-run relationship between TFP and the examined types of R&D capital. The estimated TFP elasticity is 0.038 in relation to total R&D capital and 0.075 in relation to public R&D capital.

Our findings are partially in line with those of the empirical literature. Most of the studies find that the level of total R&D capital has a positive and significant stimulus on the TFP level and two studies also suggest that the public R&D capital has a positive and significant effect on TFP. On the other hand, according to the literature the private R&D capital has a significant and positive impact on TFP, while in our study there is no significant relationship between the two variables. Finally, the TFP elasticities reported in the literature are higher than our estimated values.

Taking into account the aforementioned findings in relation to the Greek economy, we suggest the following economic policy considerations. An increase in public R&D expenditures could enhance productivity and hence result in economic growth. In parallel, the application of policies, which promote private R&D investment and innovation in Greece would contribute to a more efficient use of knowledge generated by the public sector. In this context, more emphasis should be given on the improvement of R&D capabilities, including human capital and infrastructure, the promotion of stronger links among SMEs, research institutions and universities, the establishment of a venture capital market and the increase in labour mobility.

It would be worthwhile to extend this analysis in the following dimensions. First, the results could be re-examined on the basis of regional data for the Greek economy. Second, a human capital variable could be considered in the analysis. Finally, it would be interesting to examine how the application of the economic adjustment programme in Greece since 2010 has affected the relationship between R&D capital and TFP.

Note

1. The lack of statistical data for R&D expenditures for the period after 2007 has prevented us from extending this study to recent years. For the years prior to 1990, missing data points have been completed on the basis of the data provided by Coe and Helpman (1995). Given that they provided data for business R&D only, it was assumed that the total R&D expenditures followed the trend of the business R&D expenditures. Other missing data points were completed by linear interpolation.

References

Aghion, P., and P. Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60: 323–351.

Akaike, H. 1974. "A New Look at the Statistical Model Identification." *IEEE Transactions on Automatic Control* 19 (6): 716–723.

Akaike, H. 1987. "Factor Analysis and AIC." *Psychometrika* 52 (3): 317–332.

Alogoskoufis, G. 1995. "The Two Faces of Janus: Institutions, Policy Regimes and Macroeconomic Performance in Greece." *Economic Policy* 20: 147–192.

Bayoumi, T., D. T. Coe, and E. Helpman. 1999. "R&D Spillovers and Global Growth." *Journal of International Economics* 47 (2): 399–428.

Coe, D. T., and E. Helpman. 1995. "International R&D Spillovers." *European Economic Review* 39: 859–887.

Coe, D. T., E. Helpman, and A. Hoffmaister. 1997. "North-South Spillovers." *Economic Journal* 107: 134–149.

Coe, D. T., E. Helpman, and A. Hoffmaister. 2009. "International R&D Spillovers and Institutions." *European Economic Review* 53: 723–741.

Collins, P., and D. Pontikakis. 2006. "Innovation Systems in the European Periphery: The Policy Approaches of Ireland and Greece." *Science and Public Policy* 33 (10): 757–769.

Crispolti, V., and D. Marconi. 2005. "Technology Transfer and Economic Growth in Developing Countries: An Econometric Analysis." Working Paper 564, Bank of Italy.

Denison, E. F. 1962. "Sources of Growth in United States and the Alternatives before Us." Supplement Paper 13. New York: Committee for Economic Development.

Dennis, J. E., and R. B. Schnabel. 1983. *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*. London: Prentice-Hall.

Deutsche Bank Research. "Greece, Ireland, Portugal. More Growth via Innovation." http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000283994.pdf

Dickey, D., and W. Fuller. 1979. "Distribution of the Estimators for Autoregressive Time Series with a Unit Root." *Journal of the American Statistical Association* 74: 427–431.

Doornik, J. A. 1995. "Testing General Restrictions on the Cointegrating Space." Manuscript.

Doornik, J. A., and H. Hansen. 1994. "An Omnibus Test for Univariate and Multivariate Normality." Manuscript.

Engelbrecht, H.-J. 1997. "International R&D Spillovers, Human Capital, and Productivity in OECD Countries: An Empirical Investigation." *European Economic Review* 41: 1479–1488.

European Commission. "Innovation Union Competitiveness Report 2011." Country Profile – Greece. http://ec.europa.eu/research/innovation-union/pdf/competitiveness-report/2011/countries/greece.pdf#view=fit&pagemode=none

Eurostat statistics database (data for intramural R&D expenditure; accessed January 2013). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/

Franco, C., S. Montresor, and G. Vittucci Marzetti. 2011. "On Indirect Trade-Related R&D Spillovers: The 'Average Propagation Length' of Foreign R&D." *Structural Change and Economic Dynamics* 22 (3): 227–237.

Godfrey, L. G. 1988. *Specification Tests in Econometrics*. Cambridge: Cambridge University Press.

Gogos, G., N. Mylonidis, D. Papageorgiou, and V. Vassilatos. 2012. "Greece 1979–2001: A (First) Great Depression Seen from the Basic RBC Model Perspective." Working Paper Series 01-2012, Department of Economics, Athens University of Economics and Business, Greece.

Granger, C. W. J. 1969. "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods." *Econometrica* 37 (3): 424–438.

Granger, C. W. J. 1988. "Some Recent Developments in a Concept of Causality." *Journal of Econometrics* 38: 199–211.

Griliches, Z. 1958. "Research Cost and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economy* LXVI (5): 419–431.

Griliches, Z. 1964. "Research Expenditures, Education and the Aggregate Agricultural Production Function." *American Economic Review* LIV (6): 961–974.

Griliches, Z. 1973. "Research Expenditures and Growth Accounting. In *Science and Technology in Economic Growth*, edited by B. R. Williams, 59–95. New York: Macmillan.

Griliches, Z. 1992. "The Search for R&D Spillovers." *Scandinavian Journal of Economics* 94: 29–47.

Grossman, G. M., and E. Helpman. 1991a. *Innovation and Growth in the World Economy*. Cambridge, MA: MIT Press.

Grossman, G. M., and E. Helpman. 1991b. "Quality Ladders in the Theory of Growth." *Review of Economic Studies* 58: 43–61.

Grossman, G. M., and E. Helpman. 1994. "Endogenous Innovation in the Theory of Growth." *Journal of Economic Perspectives* 8: 23–44.

Guellec, D., and B. van Pottelsberghe de la Potterie. 2001. "R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries." OECD Science, Technology and Industry Working Paper 3, OECD Publishing.

Ha, J., and P. Howitt. 2007. "Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory." *Journal of Money, Credit and Banking* 39: 733–774.

Hatzikian, J. 2007. "Research and Technological Development Policy and Innovative Performance: The Greek Case within the EU." In *Economic Integration and Regional Growth*, edited by G. M. Corres, 229–250. Springer Editions.

Hendry, D. F. 1995. *Dynamic Econometrics*. Oxford: Oxford University Press.

Ho, Y. P., P. K. Wong, and M. H. Toh. 2009. "The Impact of R&D on the Singapore Economy: An Empirical Evaluation." *The Singapore Economic Review* 54: 1–20.

Howitt, P. 2004. "Endogenous Growth, Productivity and Economic Policy: A Progress Report." *International Productivity Monitor* 8: 3–15.

Jorgenson, D., and Z. Griliches. 1967. "The Explanation of Productivity Change." *Review of Economic Studies* 34 (99): 249–280.

Johansen, S. 1991. "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models." *Econometrica* 59: 1551–1580.

Johansen, S. 1995. *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press.

Keller, W. 1998. "Are International R&D Spillovers Trade Related? Analyzing Spillovers Among Randomly Matched Trade Partners." *European Economic Review* 42: 1469–1481.

Keller, W. 2000. "Do Trade Patterns and Technology Flows Affect Productivity Growth?" *World Bank Economic Review* 14: 17–47.

Keller, W. 2002. "Geographic Localization of International Technology Diffusion." *American Economic Review* 92 (1): 120–142.

Kendrick, J. W. 1961. *Productivity Trends in the United States*. Princeton, NJ: Princeton University Press.

Lichtenberg, F., and B. van Pottelsberghe de la Potterie. 1998. "International R&D Spillovers: A Comment." *European Economic Review* 42: 1483–1491.

Lucas, E. 1988. "On the Mechanics of Economic Development." *Journal of Monetary Economics* 22 (1): 3–42.

Luintel, K., M. Khan, and K. Theodoridis. 2010. "How Robust Is the R&D-Productivity Relationship? Evidence from OECD Countries." Cardiff Economics Working Papers E2010/7, Cardiff Business School, Cardiff University.

Lumenga-Neso, O., M. Olarreaga, and M. Schiff. 2005. "On 'Indirect' Trade-Related R&D Spillovers." *European Economic Review* 49 (7): 1785–1798.

OECD. "OECD Science, Technology and Industry Outlook 2012." http://www.oecd.org/sti/oecdsciencetechnologyandindustryoutlook.htm

OECD. StatExtracts (data for GDP, annual gross capital formation, total employment, average annual hours per worker and labour income share; accessed January 2013). http://stats.oecd.org/

Phillips, P. C. B., and P. Perron. 1988. "Testing for a Unit Root in Time Series Regression." *Biometrika* 75: 335–346.

van Pottelsberghe de la Potterie, B., and F. Lichtenberg. 2001. "Does Foreign Direct Investment Transfer Technology Across Borders?" *The Review of Economics and Statistics* 83 (3): 490–497.

Romer, P. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98: 71–102.

Schultz, T. W. 1953. *The Economic Organization of Agriculture*. New York: McGraw-Hill.

Schwarz, G. E. 1978. "Estimating the Dimension of a Model." *Annals of Statistics* 6 (2): 461–464.

Solow, R. M. 1956. "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economics* 70 (1): 65–94.

Solow, R. M. 1957. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39: 312–320.

Souitaris, V. 2002. "Firm-Specific Competencies Determining Technological Innovation: A Survey in Greece." *R&D Management* 32 (1): 61–77.

Teixeira, A. A. C., and N. Fortuna. 2004. "Human Capital, Innovation Capability and Economic Growth in Portugal, 1960–2001." *Portuguese Economic Journal* 3 (3): 205–225.
Tomadaki, D. 2005. "The Formation of R&D Networks: The Case of Greece." Paper presented at DRUID academy winter 2005 PhD conference, Skørping, Aalborg, January 27–29.
Wakelin, K. 2001. "Productivity Growth and R&D Expenditure in UK Manufacturing Firms." *Research Policy* 30: 1079–1090.
Xu, B., and J. Wang. 1999. "Capital Goods Trade and R&D Spillovers in the OECD." *Canadian Journal of Economics* 32: 1258–1274.

Appendix 1

Table A1. Empirical studies.

Authors	No. of countries in sample	Time-period of data	Depended variable	Independed variables[a]	Elasticities of R&D variables
Coe and Helpman (1995)	22 countries	1971–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive
Engelbrecht (1997)	21 countries	1971–1985	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital, Human Capital (logs)	Positive and significant
Lichtenberg and van Pottelsberghe de la Potterie (1998)	22 countries	1971–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive
Coe, Helpman, and Hoffmaister (1997)	77 countries	1971–1990	TFP (growth)	Foreign Business R&D Capital (growth)	Positive
Keller (1998)	22 countries	1971–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive and significant
Xu and Wang (1999)	21 OECD countries	1983–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive
Bayoumi, Coe, and Helpman (1999)	G7 countries and aggregate data for other countries' groups	Simulation for the period 2000–2075	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive
Keller (2000)	8 countries	1970–1991	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive
van Pottelsberghe de la Potterie and Lichtenberg (2001)	13 countries	1971–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive and significant
Guellec and van Pottelsberghe de la Potterie (2001)	16 OECD countries	1980–1998	TFP (growth)	Private R&D Capital, Public R&D Capital, Foreign R&D Capital (growth rates)	Positive and significant
Keller (2002)	14 OECD countries	1970–1995	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive

(*continued*)

Table A1. continued.

Authors	No. of countries in sample	Time-period of data	Depended variable	Independed variables[a]	Elasticities of R&D variables
Teixeira and Fortuna (2004)	1 country (Portugal)	1960–2001	TFP (log)	Local R&D Capital, Human Capital (logs)	Positive
Lumenga-Neso, Olarreaga, and Schiff (2005)	22 countries	1971–1990	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital (logs)	Positive and significant
Crispolti and Marconi (2005)	45 countries	1980–2000	TFP (log)	Foreign Business R&D Capital, Human Capital (logs)	Positive and significant
Ha and Howitt (2007)	1 (USA)	1950–2000	TFP (log)	R&D intensity (R&D expenditures as % of GDP)	Positive and significant
Coe, Helpman, and Hoffmaister (2009)	24 countries	1971–2004	TFP (log)	Local Business R&D Capital, Foreign Business R&D Capital, Human Capital, Institutional Factors (logs)	Positive and significant
Franco, Montresor, and Vittucci Marzetti (2011)	20 countries	1995–2005	TFP (log)	Local R&D Capital, Foreign R&D Capital (logs)	Positive and significant
Ho, Wong, and Toh (2009)	1 (Singapore)	1978–2001	TFP (log)	Local R&D Capital (log)	Positive and significant
Luintel, Khan, and Theodoridis (2010)	16 countries	1982–2004	TFP (log)	Private R&D Capital, Public R&D Capital, Foreign R&D Capital, Human Capital (logs)	Positive and significant

Note: The empirical analysis may also include other independent variables not presented in the table. [a] Selected independent variables in relation to R&D and human capital.

Appendix 2

Table A2. VECM diagnostic tests.

1. Residual serial correlation LM test – null hypothesis: no serial correlation

VECM 1			VECM 2		
Lags	LM-statistic	p-Values[a]	Lags	LM-statistic	p-Values[a]
1	4.321855	0.3642	1	6.829486	0.1452
2	2.338816	0.6737	2	5.063699	0.2808
3	5.320299	0.2560	3	3.678469	0.4513
4	1.543025	0.8190	4	1.536101	0.8202

2. Residual normality test – null hypothesis: residuals are multivariate normal

VECM 1

Component	Skewness	Chi-square	Degrees of freedom	p-Values
D(LPRO)	−0.425934	1.037743	1	0.3083
D(LRDDCS)	1.410758	8.530779	1	0.0035
JOINT test		9.568522	2	0.0084
Component	Kurtosis	Chi-square	Degrees of freedom	p-Values
D(LPRO)	2.083763	1.884423	1	0.1698
D(LRDDCS)	5.252631	0.328590	1	0.5665
JOINT test		2.213013	2	0.3307
Component	Jarque-Bera	Chi-square	Degrees of freedom	p-Values
D(LPRO)	2.922166		2	0.2320
D(LRDDCS)	8.859369		2	0.0119
JOINT test	11.78154		4	0.0191

VECM 2

Component	Skewness	Chi-square	Degrees of freedom	p-Values
D(LPRO)	−0.297141	0.515624	1	0.4727
D(LRDDCT)	0.609467	2.042174	1	0.1530
JOINT test		2.557798	2	0.2783
Component	Kurtosis	Chi-square	Degrees of freedom	p-Values
D(LPRO)	2.026804	1.339336	1	0.2472
D(LRDDCT)	3.078747	0.018340	1	0.8923
JOINT test		1.357676	2	0.5072
Component	Jarque-Bera		Degrees of freedom	p-Values[b]
D(LPRO)	1.854960		2	0.3955
D(LRDDCT)	2.060514		2	0.3569
JOINT test	3.915474		4	0.4176

3. Heteroskedasticity test – null hypothesis: no heteroskedasticity

VECM 1

Component	$F(6,18)$	p-Values	Chi-sq(6)	p-Values
res1*res1	0.188640	0.9761	1.479001	0.9609
res2*res2	0.321966	0.9169	2.423007	0.8770
res2*res1	0.113987	0.9935	0.915123	0.9886
Joint test			5.784634[c]	0.9970

(*continued*)

Table A2. (*Continued*)

3. Heteroskedasticity test – null hypothesis: no heteroskedasticity				
VECM 2				
Component	$F(6,18)$	p-Values	Chi-sq(6)	p-Values
res1*res1	0.193631	0.720383	4.840785	0.6385
res2*res2	0.136279	0.473345	3.406980	0.8192
res2*res1	0.088052	0.289661	2.201297	0.9342
Joint test			13.93443[c]	0.7334

[a] Probabilities from chi-square distribution with 4 degrees of freedom.
[b] Probabilities from chi-square distribution.
[c] Chi-square with 18 degrees of freedom.