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SEMI-ENDOGENOUS VERSUS FULLY ENDOGENOUS GROWTH THEORY: A SECTORAL APPROACH

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This paper analyses the validity of second generation endogenous growth theories for six developed countries and ten manufacturing sectors over the period 1979-2001, applying modern tests and estimation procedures for the treatment of panel data. The basic autonomous innovation-driven model is extended to include international technology transfer and different measures of absorptive capacity. The estimates give great support to semi-endogenous growth theory. Furthermore, Schumpeterian or fully-endogenous growth theory has some support in the high impact of distance to the frontier variable which represents autonomous technology transfer.

JEL classification codes: C33, F14, F43, O32, O47
Key words: endogenous growth, total factor productivity, technical change, panel data

I. Introduction

The 1990s saw much development of theoretical models of economic growth. Most of them had one feature in common: the existence of productive inputs such as technology and human capital which, under the assumption of non-decreasing returns to scale, ensured long-term economic growth. The first generation endogenous growth models — Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) — ensured that the sustained increase of these inputs

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should accelerate TFP and per capita output growth. This is the so-called “strong scale effect”: the long-run rate of TFP growth and, hence, the long-run growth rate of per capita output were increasing functions of the growth of the knowledge stock which was, in turn, an increasing function of the scale of the economy, quantified by the level of population.

Two pieces of empirical evidence questioned the validity of the prevailing theoretical framework. Firstly, in two influential papers, Jones (1995a, 1995b) has shown a new empirical paradox by pointing out that, historically, TFP growth in developed economies and, particularly, in the United States, has remained constant, or even decreased, despite the continued increase in R&D expenditure and in the number of scientists and engineers. Secondly, and more recently, several empirical studies (see, for example, Stiroh and Botsch 2007) have shown that U.S. productivity underwent continuous acceleration at the start of the present century, even though investment in information and communication technology (ICT) had clearly been reduced.

What might be termed “Jones’s paradox” led to the development of new theoretical approaches that introduced certain changes to the basic assumptions of the first generation endogenous growth models. Firstly, semi-endogenous growth theory, initially proposed by Jones himself (1995b), Kortum (1997) and Segerstrom (1998), presupposes the existence of decreasing returns to scale in the production of knowledge. Consequently, if a permanent acceleration in productivity is to be observed, a continued increase in population growth rate is required. The scale effect thus takes its weak form: TFP growth (and per capita output growth) is proportional to the growth rate of population, not to its level.

The development of semi-endogenous growth theory runs parallel with another research trend in the Schumpeterian framework, known as fully-endogenous growth theory, which appeared initially in the works of Aghion and Howitt (1998, chap.12), Dinopoulos and Thompson (1998) and Peretto (1998). They maintain the assumption of constant returns to scale in the knowledge-creation function, admitting, however, the existence of a sectoral differentiation process — horizontal and vertical — associated with economic growth which causes the effectiveness of the “R&D input” to be diluted among a larger number of sectors. Product differentiation prevents population size from having a scale effect on long-run growth, which was a characteristic of the first generation models. In addition, in the long run, constant returns to scale in the knowledge-creation function ensure that TFP growth depends on economic factors and economic policy measures. This establishes a crucial difference with respect to the semi-endogenous growth model, whose parameter restrictions eliminate policy impact on the long run growth rate.

Empirical studies — such as Ha and Howitt (2007), Madsen (2008), Madsen et al. (2010), Islam (2009), Zachariadis (2004), Ulku (2007b) and Ang and Madsen (2011) — have adopted a macroeconomic perspective and obtained evidence supporting the Schumpeterian hypothesis. Sectoral studies performed in the context of second generation endogenous growth models have focused on the validation of the Schumpeterian hypothesis with a common denominator: the use of different proxies for research intensity in order to analyze the influence of this variable on productivity growth. Among these, Griffith et al. (2003), Griffith et al. (2004), Zachariadis (2003, 2004) or Ulku (2007 a) have provided evidence in favour of Schumpeterian endogenous growth theories.

In this line of research, the present study uses sectoral data to test the validity of the two second generation endogenous growth theories. To our knowledge, the present paper is the first contribution in this field of research which focuses on sectoral panel data, standardized for ten manufacturing sectors of six developed countries over 22 years, 1979-2001. This innovation is particularly significant, since, as Aghion and Durlauf (2009) point out, this is the correct field to assess the usefulness of certain models — innovation-based endogenous growth models — that have been designed in terms of companies and sectors, not in terms of aggregate economies. Secondly, to measure product proliferation at a sectoral level we use four different variables: TFP adjusted for hours worked, value added adjusted by cycle, total employment and the number of hours worked. Lastly, growth regressions extend the baseline models to include alternative measures of sectoral international technological spillovers, distance to the frontier and absorptive capacity as potential determinants of TFP growth.

The rest of the paper is structured as follows. Section II undertakes a brief review of the analytical implications of the various endogenous growth models. In Section III these formulations are transferred to the empirical field, variables and data sources are described, and the validity of those models is discussed in two phases: firstly, by applying the adequate unit root and cointegration tests for the various panel data models and, secondly, by estimating different models to explain the increase in TFP. Section IV improves and extends the model, refining the measures of research intensity and incorporating absorptive capacity as an explanatory variable.[1] Finally, Section V discusses the main findings and conclusions.

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[1] We refer to R&D-based absorptive capacity, as Islam (2009) does.

II. Basic approach of endogenous growth models

Following Ha and Howitt (2007), it is possible to synthesize each of the three growth theories mentioned starting from the central idea, common to the different versions, that the explanatory role of TFP growth is equivalent to the knowledge-creation function, and that both, therefore, depend on an R&D input and on other inputs. Thus, from a common expression, one can test various theoretical models considering different null hypotheses regarding the parameters:

$$g_A = \lambda \left(\frac{X}{Q}\right)^{\sigma} A^{\phi-1},\ 0<\phi\leq 1, \lambda>0 \text{, and } Q\ \alpha\ L^{\beta} \text{ in the steady state}, \tag{1}$$

where g denotes growth rate, A is productivity (knowledge),[2] X is a proxy for the so-called "R&D input",[3] Q is a measure of product proliferation, L is employment, λ is a research productivity parameter, σ is a duplication parameter (0 if all innovations are duplications and 1 if there are no duplicated innovations), ϕ represents returns to scale in knowledge and β is the parameter of product proliferation.

Endogenous growth models can be distinguished by the parameters ϕ and β. The first generation endogenous growth models predict the existence of constant returns to scale in knowledge, that is to say, $\phi = 1$;[4] there are no external effects so the rate of generation of new ideas is independent of the knowledge stock. In these models product proliferation is not considered, so that $\beta = 0$, and thus productivity growth is expressed as:

$$g_A = \lambda X^{\sigma}\ , \tag{2}$$

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[2] This paper does not go into the eternal and complex debate over the definition of TFP and technical progress. Ha and Howitt (2007: 736), for instance, define productivity in labor-augmenting terms and refer to it as TFP.

[3] R&D input is measured by R&D expenditure, patents or number of researchers in the semi-endogenous growth model and by R&D expenditure adjusted for productivity in the Schumpeterian growth model.

[4] As Jones (1995b: 766) indicates, it is a completely arbitrary assumption, essential to ensure the endogeneity of growth in the traditional sense.

In this model, with constant returns to scale in the creation of new knowledge, a positive growth in input is enough to cause an acceleration of productivity, which leads to the scale effect in its strong form: economic growth is proportional to population size.[5]

On the contrary, semi-endogenous theory assumes that there are diminishing returns to scale in knowledge (that is, $\phi < 1$). This is the case known in literature as "fishing out" and implies that the rate of innovation decreases with the knowledge stock because the most important ideas arise early on and, as the knowledge stock increases, the discovery of a new idea becomes less and less likely. Additionally, the assumption of the absence of product proliferation effects ($\beta = 0$) is maintained.[6] In short, TFP growth is expressed as follows:

$$g_A = \lambda X^{\sigma} A^{\phi - 1}, \quad \phi < 1 \quad , \tag{3}$$

The existence of diminishing returns to scale in the knowledge stock solves the problem of a strong scale effect that is characteristic of first generation models. In expression (3) the scale effect takes the weak form: the increase in the growth rate of productivity requires a continued increase in the R&D input growth rate, not merely in its level. Ultimately, long-run growth in per capita income is proportional to the population growth rate, traditionally considered exogenous.[7] The parameters' restrictions of semi-endogenous growth theory preclude any option of promoting growth through economic policy.

Finally, the so-called fully endogenous growth theory maintains the assumption of constant returns to scale in knowledge, characteristic of the first generation models ($\phi = 1$), but assumes that the effectiveness of R&D investment decreases as the range of products increases, $\beta = 1$,

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[5] The σ parameter is important because it serves to distinguish between endogenous models and traditional neoclassical models in which the parameter takes the value zero, which means accepting that technical progress is exogenous.

[6] However, it is possible to propose an extended semi-endogenous growth model, which combines the existence of decreasing returns to scale in the production of knowledge and imperfect product proliferation with $\beta < 1$. In section III of this paper this possibility is considered empirically.

[7] Although population growth is often referred to as an exogenous explanatory factor, Jones (1995b) quotes Kremer's (1993) model as an example where population growth is endogenously determined by a Malthusian process.

$$g_A = \lambda\left(\frac{X}{Q}\right)^{\sigma}. \tag{4}$$

As a result, product proliferation avoids the scale effect of the growth of R&D inputs on productivity growth, so that long-run growth in TFP and per capita income is proportional to the increase in research intensity *X/Q*, and not to the mere increase in *X*.

III. Empirical testing of endogenous growth models

A. Empirical model approach

In order to empirically validate the model, Ha and Howitt (2007) transform (1) with a log-linear approximation, representative of an error correction model:

$$\ln\left(\frac{\dot{A}_t}{A_t}\right) = \ln\lambda + \sigma\left[lnX_t - \ln Q_t + \left(\frac{\phi-1}{\sigma}\right)\ln A_t\right] + \varepsilon_{1,t} , \tag{5}$$

This model is valid to verify the two theories, so that, if $\ln\left(\frac{\dot{A}_t}{A_t}\right)$ is indeed stationary, the expression included in brackets must also be stationary:

$$E_t = \left[\ln X_t - \ln Q_t + \left(\frac{\phi-1}{\sigma}\right)\ln A_t>\right], \tag{6}$$

Taking into account the parameter differences that characterize the two theories, the analytical expressions and econometric requirements of both approaches will be set out below.

Semi-endogenous growth theory. Since, in the semi-endogenous growth models, $\beta = 0$, *Q* is constant and, therefore, the stationarity of the term in brackets requires

$$E_t = \left[\ln X_t + \left(\frac{\phi-1}{\sigma}\right)\ln A_t\right], \tag{7}$$

to be stationary. Following Ha and Howitt (2007), the stationarity of expression (7) implies that ln$X$ and ln$A$ should be integrated of the same order and, if they are not stationary, there should be a cointegrating relationship between them with a cointegrating vector $[1, \left(\frac{\phi-1}{\sigma}\right)]$ where, if it is assumed that $\phi < 1$, the second element in the vector is strictly negative.

Fully endogenous growth theory. The Schumpeterian approach maintains the assumption of constant returns to scale ($\phi = 1$) but admits the pernicious effect of product proliferation, $\beta = 1$. The combination of the two restrictions implies that the expression

$$E_t = \ln X_t - \ln Q_t \ , \tag{8}$$

representative of the R&D input adjusted by product proliferation, must be stationary.

As stated in Madsen (2008), the following cointegration model nests both previous versions:

$$\ln X_t = \mu \ln Q_t + \kappa \ln A_t + \mathrm{e}_{2,t} \ , \tag{9}$$

where $\kappa = (1-\phi)/\sigma$. Schumpeterian growth theory presupposes that $\kappa = 0$ and $\mu = 1$, whereas semi-endogenous growth theory implies that $\kappa > 0$ and $\mu = 0$, $e_{2,t}$ being the stationary error term. The application of the cointegration test to this expression will allow us to determine which of the two approaches is the most consistent with the data, although, as Madsen (2008) points out, the existence of a cointegrating relationship between the variables A, X and Q is a necessary but non-sufficient condition to conclude that TFP growth is explained by either model.

Thus, and following Madsen (2008), different estimations of the TFP growth equation have been carried out in this paper. The basic regression takes the form:

$$\Delta \ln A_t = \tau \ln\left(\frac{X_t}{Q_t}\right) + \left(\frac{\sigma}{1-\phi}\right) \Delta \ln X_t + \xi \left(\frac{A_{t-1}^{max} - A_{t-1}}{A_{t-1}^{max}}\right) + \varepsilon_t \ , \tag{10}$$

where A^{max} represents, for each sector, the TFP value in the country which is the technological leader in each of the years under study. Equation (10) nests Schumpeterian theory (extended to allow for the gravitation of TFP towards leading edge technology) and semi-endogenous theory. As is well known, while Schumpeterian growth theory predicts that $\tau > 0$ and $\xi > 0$, semi-endogenous growth theory assumes that $\tau = 0$ and $\sigma/(1-\varphi) > 0$.

B. Variables and data sources

The data cover the period 1979-2001 and comprise ten aggregations of the manufacturing sector in six countries (see details in Table A1 of online Appendix).

Sectoral value added (*V*). Sectoral value added data were taken from the STAN database of the OECD. The figures for the “value added” variable were expressed in 1997 local currency units using STAN volume indexes, except in the case of sectors 30–33 (Electrical and optical equipment), for which hedonic prices were used. Hedonic prices were available at the Industry Labour Productivity Database of the Gröningen Growth and Development Center (GGDC). Subsequently, the figures for value added were converted into 1997 US dollars using the unit value ratios (UVR) published by the GGDC in the Manufacturing Productivity and Unit Labour Cost Database.

Capital (*K*). Sectoral gross fixed capital formation at current prices was taken from the STAN database of the OECD. The variable was expressed in real 1997 units and converted into US dollars of the same year, using purchasing power parity (PPP) for gross fixed capital formation calculated for the OECD. With these figures, accumulated physical capital stocks were calculated by applying the perpetual inventory method, frequently used in the empirical literature, as López Pueyo et al. (2008) propose.

Hours worked (*L*). The sectoral labour factor was approximated by the “total employment, hours worked” variable, taken from the STAN database of the OECD.

TFP (*A*). The data used in this paper are the result of an intensive effort to improve the calculation of TFP and obtain comparable measures both among sectors and among countries. Thus, the empirical analysis is performed only for those industrial manufacturing sectors for which the information available is sufficiently detailed and homogeneous. This condition must be taken into account when interpreting the results presented in the following paragraphs.

The logarithm of TFP (*A*), that is, the change in output not explained by changes in the use of inputs, can be expressed in index form:

$$\ln A_{rz} = (\ln V_z - \ln V_r) - \left[\frac{1}{2}(\hat{s}_z + \bar{s})(\ln L_z - \overline{\ln L}) + \left[(1 - \frac{1}{2}(\hat{s}_z + \bar{s}) \right] (\ln K_z - \overline{\ln K}) \right]$$
$$+ \left[\frac{1}{2}(\hat{s}_r + \bar{s})(\ln L_r - \overline{\ln L}) + \left[(1 - \frac{1}{2}(\hat{s}_r + \bar{s}) \right] (\ln K_r - \overline{\ln K}) \right], \tag{11}$$

where V is the gross value added; r, z are two different observations (e.g., sector-country r and sector-country z in the same year or the same sector-country in two different years); L is employment, $\hat{s}$ is an estimate of the share of labour income in the value added; $\bar{s}$ is the average estimate of the shares of labour income of the value added; K is the physical capital stock;

$$\overline{\ln L} = \frac{1}{M} \sum_{n=1}^{M} \ln L_n, \tag{12}$$

$$\overline{\ln K} = \frac{1}{M} \sum_{n=1}^{M} \ln K_n, \tag{13}$$

where M is the total number of observations.

To take into account the different position of the countries in the cycle and to facilitate international comparisons, the value added was adjusted by the output gap of the manufacturing sector of each country, calculated by the Hodrick-Prescott smoothing method, as López Pueyo et al. (2008) propose.

The TFP index used is the Tornqvist index, transformed using the Elteto-Koves-Szulc (EKS) method.[8] This index is superlative, because it can be derived from a determined form of the production function (quadratic or translogarithmic). The index took base 100 in 1997 for each individual (the sectors of the different countries), because that year was chosen to express the monetary magnitudes in real terms.

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[8] For multilateral comparisons in panel data (with spatial and temporal dimensions, as in this paper), the best indices are chain volume type — such as those of Fisher and Törnqvist (to avoid the bias of the fixed weighted indices) — transformed by means of the Elteto-Koves-Szulc (EKS) method — as Caves et al. (1982) did — so that they are transitive.

Engaged (*N*). Sectoral employment was proxied by the “total employment (number engaged)” variable, taken from the STAN database of the OECD.

Real R&D expenditure in each sector (*R*). Real R&D expenditure in each sector was taken from the OECD ANBERD database and deflated using the OECD producer price index for manufactures.

Productivity-adjusted real R&D expenditure (*R/A*). Productivity-adjusted real R&D expenditure was calculated as the quotient between real R&D expenditure and the variable *A* (TFP) in sector *i*.

Product proliferation (*AL*, *V*, *N* and *L*). Four variables have been calculated to represent product proliferation. They are the sectoral TFP adjusted by the labour variable (*AL*), the sectoral value added variable (*V*), total employment in sector *i* (*N*) and the hours worked in sector *i* (*L*).

Research intensity (*R/AL*, *R/V*, *R/N* and *R/L*). Research intensity in sector *i* was calculated as the quotient between real R&D expenditure and the variable *AL* (TFP adjusted by labour variable). Other measures of research intensity were also considered, like the quotients between real R&D expenditure to value added (*R/V*), real R&D expenditure to total employment (*R/N*) and real R&D expenditure to hours worked (*R/L*).

International technology spillovers (R^f and $(R/Q)^f$). International technology spillovers for sector *i* in country *z* were approximated to test semi-endogenous theory with the variable

$$R^{f}_{izt} = \sum_{n} \frac{m_{izvt}}{M_{izt}} R_{ivt} \ , \tag{14}$$

where *n* is the number of import partners for sector *i* in country *z* in year *t*;[9] m_{izvt} is the imports of products of sector *i* in country *z* from country *v* in year *t*; M_{izt} is the total imports of products of sector *i* in country *z* in year *t*; and R_{ivt} is the real R&D expenditure of sector *i* in country *v* in year *t*.

To test Schumpeterian theory, international technology spillovers were proxied by the variable

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[9] The calculation of foreign R&D was based on the R&D expenditure of Australia, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Spain, Sweden, the United Kingdom and the United States.

$$(R/Q)^{f}_{izt} = \sum_{n} \frac{m_{izvt}}{M_{izt}} (R/Q)_{ivt} \,, \tag{15}$$

where Q is product proliferation, which is measured by the value added (V). To perform the sensitivity analysis, other measures of Q were considered, like total employment (N) and hours worked (L).

Distance to technological frontier (*DF1* and *DF2*). Distance to the technological frontier is proxied by

$$DF1_{ijt} = \left(\frac{A^{\max} - A_i}{A^{\max}} \right)_{ijt-5} \,, \tag{16}$$

$$DF2_{ijt} = \left(\frac{A^{\max}}{A_i} \right)_{ijt-5} \,. \tag{17}$$

In the first case, the distance to the technological frontier is measured for each individual (sector-country) as a ratio whose numerator is the difference between the value of the TFP of the leader and the value of the TFP of each sector-country and whose denominator is the value of the TFP of the leader. In the second case, the distance to the technological frontier is defined as the ratio value of the TFP of the leader and the value of the TFP of each sector-country.

Absorptive capacity (*CAB*). Absorptive capacity is measured by the interaction between research intensity and the distance to the frontier. As mentioned above, research intensity was measured in four alternative ways (*R/Y*), (*R/L*), (*R/N*) and (*R/AL*). The interaction between these four variables and the two specifications of the distance to the technological frontier, *DF1* and *DF2*, permits the eight proxies of absorptive capacity to be obtained.

In the online Appendix, Tables A2 to A4 contain the cumulative average annual rates of growth in value added, TFP and domestic R&D expenditure growth for selected manufacturing sectors across sample countries, between 1979 and 2001. Table A5 includes the average value for domestic research intensity (measured as *R/V*) in the period under study.

C. A first approach: results of unit root and cointegration tests

A first step in testing whether second generation endogenous growth theories are consistent with the data is to analyze whether the variables involved in the various versions are stationary and, if they are not, whether there is a cointegrating relationship between them.

As described in Section III.A, to test the semi-endogenous growth model, the following cointegration model has been proposed (assuming TFP growth is stationary)

$$\ln A_{ijt} = \alpha_{0ij} + \alpha_1 \ln X_{ijt} + \varepsilon_{ijt} \,, \tag{18}$$

in which variable X will be R (estimate 18a in Table 1) or, alternatively, R/A (estimate 18b); i denotes the sector and j denotes the country. The prediction of the semi-endogenous growth model is that $\alpha_1 > 0$ and the error term is stationary.

Additionally, following Madsen (2008), an extended semi-endogenous growth model has been proposed by including product proliferation (Q):

$$\ln A_{ijt} = \beta_{0,ij} + \beta_1 \ln X_{ijt} + \beta_2 \ln Q_{ijt} + \varepsilon_{ijt} \;. \tag{19}$$

Product proliferation is measured by TFP, adjusted by the labour variable (AL in estimate 19a in Table 1), sectoral value added (V in estimate 19b), sectoral employment (N in estimate 19c) and sectoral hours worked (L in estimate 19d). If this model is true, it is expected that $\beta_1>0$ and $\beta_2=0$.

Finally, the Schumpeterian hypothesis has been tested by means of the following expression:

$$\ln X_{ij\,t} = \chi_{0,ij} + \chi_1 \ln Q_{ijt} + \varepsilon_{ijt} \quad , \tag{20}$$

where, again, the real R&D expenditure flow (R) is used as a proxy for knowledge input and two variables are used as a proxy for product proliferation: TFP adjusted for employment (*AL* in estimate 20a in Table 1), sectoral value added (*V* in estimate 20b), sectoral employment (*N* in estimate 20c) and sectoral hours worked (*L* in estimate 20d). The prediction is that $\chi_1 = 1$ and that the error term is stationary.

All the models have been estimated using data from the six countries and ten sectors described in Section III.B, for the period 1979-2001. The technique used is dynamic ordinary least squares (DOLS), developed by Stock and Watson (1993), which takes into account, and corrects, endogeneity bias and serial correlation. The cointegration analysis starts with a test of the existence of unit roots in all the variables included in different estimations. Concretely, there are three technological variables (R, R/A, R^f), four variables representing product proliferation (*AL, V, N, L*), four variables representing research intensity (*R/AL, R/V, R/N, R/L*) and the corresponding foreign versions of these last three, which are denoted with the superscript *f*.

With the aim of deciding which unit root test should be applied in each case we initially used the test proposed by Pesaran (2004) to check the existence of cross sectional dependence between the panel units. As can be seen in the online Appendix, the null hypothesis of cross-sectional independence is rejected for all the variables in the model, whether expressed in levels or in first differences.

When there is cross-sectional dependence, the appropriate unit root test to be applied is the one developed by Pesaran (2007). Two different versions of the test are shown in the online Appendix, applied to all variables included in our estimations, also expressed in levels and in first differences. The qualitative results are the same for all the variables: they are I(1) in levels, but the null hypothesis of a unit root is rejected when the variables are expressed in first differences.

Having proved the non-stationarity of the variables involved in each model, the validity of the different endogenous approaches requires us to demonstrate that there is a cointegrating relationship between them. To do so, we initially applied two panel cointegration tests: the Pedroni (1999) residual-based test –which can be applied only in the case of multiple regressors– and the error-correction-based tests for panel cointegration devised by Westerlund (2007).

Pedroni (1999) suggests seven residual-based panel cointegration tests for testing the null hypothesis of non-cointegration. Four of the seven proposed statistics are based on pooling along the within dimension and the other three pools over the between dimension. In both cases, under the null hypothesis the variables are not cointegrated for each member of the panel; the difference arises in terms of the autoregressive coefficients of the estimated residuals under the alternative hypothesis of cointegration: it is common for all individuals only in the former pooled cointegration statistics, but different for each individual in the latter mean-group cointegration statistics.

The error-correction based test by Westerlund (2007) allows for various forms of heterogeneity and provides p-values which are robust against cross-sectional dependencies (when the bootstrap option is used). Persyn and Westerlund (2008) developed the *xtwest* command, a Stata command for the Westerlund (2007) cointegration tests. The underlying idea is to test for the absence of cointegration by determining whether there exists error correction for individual panel members or for the panel as a whole. To this end, four statistics are calculated: *Ga, Gt*, *Pa* and *Pt.* These last two can be taken as evidence of cointegration for the panel as a whole.[10]

The results related to semi-endogenous models are presented in the first two rows of Table 1 (estimates 18a and 18b). The null hypothesis of non-cointegration can be rejected for all the Westerlund (2007) tests. The results of estimation 18a, where *R* is included as the research activity variable, offer strong support for semi-endogenous growth theory. On the contrary, the variable *R/A* in equation (18b) displays a negative sign, suggesting that *A* is not a good proxy of the complexity of technological progress. This mixed evidence regarding the semi-endogenous hypothesis is also found in other empirical studies. Ha and Howitt (2007) and Madsen (2008) obtained mixed results from the use of different R&D input variables.[11]

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[10] As Westelund (2007: 718) states, the four tests may be justified in cases where T is substantially larger than N (because limit arguments are taken as $T \to \infty$ and then $N \to \infty$).

[11] Ha and Howitt (2007) find that the *ADF* test rejects the null hypothesis of a unit root in *lnX* for two R&D inputs (the number of workers engaged in R&D in G5 countries and productivity-adjusted R&D expenditure) while it is not rejected either for R&D employees in the U.S. or the *lnA*. In differences, the null hypothesis of the existence of a unit root is rejected in all cases. Madsen (2008) finds a cointegrating relationship between the logarithm of R&D expenditure or patents on the one hand, and TFP, on the other, using the DF test proposed by Kao (1999).

Table 1. Panel cointegration tests

Estimate	Equation	Pedroni (1999)							Westerlund (2007)			
		Panel-v	Panel rho	Panel PP	Panel ADF	Group rho	Group PP	Group ADF	Statistic	Value	Z-value	Robust P-value
(18a)	Semi-endogenous growth model								*Gt*	-2.147	-8.717	0.000
	$lnA_{ijt}=\alpha_{0,ij} + 0.15lnR_{ijt} + \varepsilon_{ijt}$								*Ga*	-5.177	-2.342	0.000
	(5.58)								*Pt*	-9.411	-4.675	0.004
									Pa	-3.214	-5.853	0.001
(18b)	Semi-endogenous growth model								*Gt*	-2.022	-7.786	0.000
	$lnA_{ijt}= \alpha_{0,ij} - 0.07lnR/A_{ijt} + \varepsilon_{ijt}$								*Ga*	-4.094	-0.498	0.000
	(-2.07)								*Pt*	-10.177	-5.331	0.003
									Pa	-2.096	-2.862	0.009
(19a)	Extended semi-endogenous growth model								*Gt*	-1.688	-2.268	0.004
	$lnA_{ijt}= \beta_{0,ij} + 0.05lnR_{ijt} + 0.67lnAL_{ijt}+\varepsilon_{ijt}$	27.41	-22.31	-8.77	-171.26	-33.6	-11.03	-10.75	*Ga*	-3.910	2.710	0.019
	(3.19) (17.96)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	*Pt*	-10.297	-2.287	0.031
									Pa	-2.841	-0.540	0.019
(19c)	Extended semi-endogenous growth model								*Gt*	-1.468	-0.640	0.575
	$lnA_{ijt}= \beta_{0,ij} + 0.28lnR_{ijt} - 0.32lnN_{ij,t}+\varepsilon_{ijt}$	23.47	-29.07	-10.42	189.26	-47.33	-13.31	-13.34	*Ga*	-2.071	5.316	0.873
	(12.70) (-3.87)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	*Pt*	-5.875	1.041	0.990
									Pa	-1.491	1.592	0.995
(19d)	Extended semi-endogenous growth model											
	$lnA_{ijt}= \beta_{0,ij} + 0.28lnR_{ijt} - 0.31lnL_{ijt}+\varepsilon_{ijt}$	21.83	-28.15	-10.18	-189.5	-47.22	-13.27	-13.29	*Gt*	-1.646	-1.956	0.260
	(12.38) (-4.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	*Ga*	-2.139	5.219	0.753
									Pt	-5.054	1.659	0.029
									Pa	-1.569	1.469	0.129

Table 1. (continued) Panel cointegration tests

Estimate	Equation	Pedroni (1999)							Westerlund (2007)			
		Panel-v	Panel rho	Panel PP	Panel ADF	Group rho	Group PP	Group ADF	Statistic	Value	Z-value	Robust P-value
(20a)	Schumpeterian growth model								*Gt*	-1.945	-7.213	0.003
	$lnR_{ijt} = \chi_{0,ij} + 0.49 lnAL_{ijt} + \varepsilon_{ijt}$								*Ga*	-3.433	0.629	0.048
	(3.67)								*Pt*	-13.310	-8.015	0.000
									Pa	-2.551	-4.078	0.015
(20b)	Schumpeterian growth model								*Gt*	-1.386	-3.050	0.003
	$lnR_{ijt} = \chi_{0,ij} + 0.04 lnV_{ijt} + \varepsilon_{ijt}$								*Ga*	-2.218	2.698	0.701
	(0.43)								*Pt*	-9.566	-4.808	0.011
									Pa	-1.705	-1.815	0.089
(20c)	Schumpeterian growth model								*Gt*	-1.378	-2.993	0.013
	$lnR_{ijt} = \chi_{0,ij} + 0.00\, lnN_{ijt} + \varepsilon_{ijt}$								*Ga*	-2.263	2.621	0.505
	(0.00)								*Pt*	-8.575	-3.959	0.015
									Pa	-1.692	-1.781	0.068
(20d)	Schumpeterian growth model								*Gt*	-1.695	0.000	0.000
	$lnR_{ijt} = \chi_{0,ij} - 0.03 lnL_{ijt} + \varepsilon_{ijt}$								*Ga*	-3.279	0.814	0.084
	(-0.15)								*Pt*	-10.958	0.000	0.004
									Pa	-2.285	0.000	0.030

Notes: *A* denotes *TFP*, *R* is R&D expenditure; *R/A* is productivity-adjusted R&D expenditure; *AL* is the TFP adjusted for hours; *V* is the sectoral value added; *N* is total employment and *L* is the number of hours worked. Annual data over the period 1979-2001. Number of observations: 1320.a) The Pedroni statistics are described in detail in Pedroni (1999). *NPT 1.3* was used in the estimation as Chiang and Kao (2002) developed it. The numbers in parentheses are *p*-values. All of them indicate the rejection of the null hypothesis of non-cointegration. b) The Westerlund statistics are described in Persyn and Westerlund (2008). The *xtwest* command with the *bootstrap* option was used. Number of bootstraps to obtain p-values which are robust against cross-sectional dependencies set to 800.

As to the extended semi-endogenous growth model, the tests by Pedroni (1999) and Westerlund (2007) show that the null hypothesis of non-cointegration between *lnA* and the two explanatory variables (*lnR* and *lnAL*) can be rejected only in the case of estimate (19a). Both coefficients are statistically significant. By contrast, estimates (19b) to (19d) do not yield the expected results.[12]

The results for Schumpeterian growth theory show the existence of a cointegrating relationship in estimates (20a) to (20d), using the Pedroni (1999) and Westerlund (2007) tests.[13] However, only one coefficient of these variables (*AL*) is statistically significant and, contrary to the Schumpeterian hypothesis, is different from 1.[14]

In summary, the hypothesis of non-cointegration is rejected in the estimates of the semi-endogenous and Schumpeterian models. Additionally, good results in terms of the value of the coefficients are obtained when *R* is the proxy of technological capacity and *AL* is the proxy of product proliferation.

D. Explanatory model of TFP growth

The existence of a cointegrating relationship between the variables *A*, *X* and *Q* is a necessary but non-sufficient condition to conclude that TFP can be explained by either of the two models.

Therefore, the stochastic version of equation (10) is estimated by OLS in the present section, with different specifications of the equation representing TFP growth. The model is based on Howitt's (2000) theoretical proposal that nations which undertake R&D will converge in growth rates whereas those that do not will have no long-term growth. In addition to domestic technological variables,

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[12] In these estimates product proliferation is assessed by sectoral value added (*V*), total employment (*N*) or sectoral hours worked (*L*). The hypothesis of non-cointegration cannot be rejected (by Westerlund's tests), V is not statistically significant and N and L show negative signs.

[13] According to Ha and Howitt (2007), in the absence of statistical significance in the parameters, it is enough to test the stationarity of *ln R/AL* and *ln R/V* to support the Schumpeterian model. In our case, as can be seen in online Appendix, the variables *R/AL* and *R/V* are not stationary but they are I(0) in differences. Given this result, the next step, in line with the suggestion of Madsen (2008), is to assess whether there is a cointegrating relationship between them.

[14] This result is also obtained by Madsen (2008) but he did not believe that this evidence was sufficient to deny the validity of the fully-endogenous growth model, given the difficulty of capturing product proliferation in its entirety.

we can introduce technology transfer as a source of productivity growth, which extends the model in two ways. Firstly, following the abundant literature related to the work of Coe and Helpman (1995), we include the acquisition of technology through international technology spillovers which are transmitted through trade. Secondly, and following Griffith et al. (2004), the model is augmented with a distance to the frontier variable which represents the capacity to grow and catch up with the leader countries, independently of the international economic relations which are established via foreign direct investment or international trade.

$$\Delta \ln A_{ijt} = \beta_{0ij} + \beta_1 \Delta \ln X^{d}_{ijt} + \beta_2 \Delta \ln X^{f}_{ijt} + \beta_3 \ln\left(\frac{X}{Q}\right)^{d}_{ijt} + \beta_4 \ln\left(\frac{X}{Q}\right)^{f}_{ijt} + \beta_5 DF_{ij} + \varepsilon_{ijt}\,. \qquad (21)$$

Expression (21) nests the second generation growth models and includes these additional explanatory factors. International technology spillovers are approximated by two measures whose construction has been detailed in Section III.B: to test semi-endogenous theory we include ΔX^f, and to test Schumpeterian theory, $(X/Q)^f$. Finally, the distance to the technological frontier for each sector-country is defined by the two alternative variables *DF1* and *DF2*. The Schumpeterian prediction is $\beta_1 = \beta_2 = 0$, $\beta_3 > 0$, $\beta_4 > 0$, and $\beta_5 > 0$. The semi-endogenous growth hypothesis predicts $\beta_1 > 0$, $\beta_2 > 0$, and $\beta_3 = \beta_4 = \beta_5 = 0$.

The dependent variable, TFP growth, and the growth of domestic and foreign expenditure in R&D, are measured in 5-year differences to filter out the influences of the business cycle and transitional dynamics on TFP growth. Research intensity variables are measured as the five-year average within the same period that is covered by the differences and, finally, distance to the frontier is measured at the beginning of each quinquennium (t-5). In this way, the sample is reduced to 240 observations for the 1979–1999 period.

As seen in Section III.C, the variable *AL* appears to offer good results as a proxy of product proliferation. Given that we do not possess information about the value of *A* in all the trade partners of our sample of sector-countries, foreign research intensity cannot be calculated by the quotient $(R/AL)^f$ and V^f has to be used. Table 2 presents the results of two specifications of equation (21). In both of them foreign research intensity is assessed by $(R/V)^f$, although domestic research intensity is calculated either by $(R/AL)^d$— in columns 1 to 5 — or by $(R/V)^d$ — in columns 6 to 10. Since the second specification offers a better adjustment of the model, we focus our discussion on the latter five columns.

Table 2. Parameter estimates of equation (21) in five-year differences

X/Q	$(X/Q)^d=(R/AL)$					$(X/Q)^d=(R/V)$				
	Pooled		Fixed effects			Pooled OLS		Fixed effects		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ΔX^d	0.03	0.02*	0.01	0.02*	0.01	0.05**	0.03**	0.01	0.03**	0.01
	(3.14)	(1.70)	(0.80)	(1.65)	(0.94)	(2.02)	(2.00)	(1.04)	(1.95)	(1.20)
ΔX^f	0.07	0.09**	0.07**	0.09***	0.07**	0.15**	0.09***	0.07**	0.09***	0.06**
	(0.03)	(2.59)	(2.13)	(2.63)	(2.08	(2.48)	(2.57)	(2.08)	(2.59)	(2.02)
$(X/Q)^d$	-0.02	-0.08***	(-0.06) ***	-0.07***	-0.07***	0.03	-0.09***	-0.08***	-0.09***	-0.08***
	(0.03)	(-6.09)	(-5.31)	(-6.03)	(-5.39)	(0.17)	(-6.56)	(-5.73)	(-6.50)	(-5.83)
$(X/Q)^f$	-0.00	-0.02***	-0.03	-0.02	-0.03	-0.00	-0.01	-0.02	-0.01	-0.02
	(-0.08)	(-0.92)	(-1.23)	(-0.91)	(-1.26)	(0.27)	(-0.58)	(-0.93)	(-0.58)	(-0.95)
$DF1$	0.23	0.64***		0.65***		0.24***	0.66***		0.66***	
	(8.83)	(8.44)		(8.37)		(5.12)	(8.74)		(8.66)	
$DF2$			0.22***		0.22***			0.22***		0.22***
			(9.03)		(9.00)			(9.26)		(9.22)
$CAB1=(R/V)^dDF1$				0.02	0.09				0.02	-0.09
				(0.31)	(-1.12)				(0.27)	(-1.21)
R^2	0.19	0.23	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.25

Notes: a) Variable specifications: A denotes TFP, R is real R&D expenditure; R/A is productivity-adjusted real R&D expenditure; AL is TFP adjusted for hours; V is sectoral value added; N is total employment; L is the number of hours worked; R/AL, R/V, R/L, and R/N are different measures of research intensity $DF1_{iji} = \left(\frac{A_{\max} - A_i}{A_{\max}}\right)_{ijt}$, $DF2_{iji} = \left(\frac{A_{\max}}{A_i}\right)_{ijt}$, $CAB1$ is absorptive capacity. b) Estimation period 1979-2001. Number of observations: 240. c) Figures in parentheses are t values significant at the 1% level (***), 5% level (**) or 10% (*) level.

Column 6 illustrates the results obtained for the pooled OLS estimators. The method assumes that omitted variables are independent of the regressors and are independently and identically distributed. Evidence clearly supports the semi-endogenous hypothesis: the estimated coefficients of growth in domestic and foreign R&D activity are positive and highly significant with respective values of 0.05 and 0.15. By contrast, the results only partially support the Schumpeterian hypothesis. Research intensity is not statistically significant, but distance to the frontier exerts a neatly positive influence on TFP growth.

Pooled OLS estimators can be biased if unobserved sector-country specific effects are correlated with the regressors. Consequently, columns 7 to 10 report the panel estimates when fixed effects for each country-sector individual are included. For semi-endogenous growth theory results do not essentially change. The first obvious result when distance to the frontier is measured by *DF1* (column 7) is the positive and significant effect of the increase in domestic R&D expenditure on TFP growth; furthermore, the growth in foreign technological capacity also exerts a positive influence on TFP growth through imports. As Table 2 shows, the coefficient of the growth in domestic R&D decreases to 0.03, in line with that obtained by Madsen (2008). This scholar interprets this value as significant *excess* social results of investment in R&D because as domestic R&D is included in capital and labour (and then, in the estimates of TFP), estimated elasticities represent the excess — not total effects — of innovative activity on output. The estimated elasticity of the growth of foreign real R&D expenditure is larger, 0.09, also in line with the values obtained by Madsen (2008) for R&D-based research intensity. This result seems to confirm the interdependence existing among the members of the sample and reinforces support for the semi-endogenous approach.

The results give less support to Schumpeterian growth theory. In the fixed effect estimation, the coefficient of the domestic research intensity variable is clearly significant but presents an unexpected negative sign (-0.09). The coefficient of the spillover variable is also statistically insignificant. These results are the opposite of the predictions of fully endogenous growth theory. However, in many empirical studies the research intensity variable has a negative and significant impact on per capita output or on productivity and, in many other papers, it is not statistically significant. Saxena et al. (2008), for instance, also obtained a negative sign for the coefficient of the research intensity variable in India, measured as the ratio between patents and labour force. Ulku (2007a) obtained a negative and non-significant coefficient for the R&D intensity variable (defined as the ratio of real R&D expenditure over output) for one of the four sectors considered in his study (machinery and transport). Ulku (2007b) verified that, in the large market OECD economies, an increase in the share of researchers in the total labour force negatively affects per capita output growth. The author interpreted this as the existence of diminishing returns in the number of researchers in terms of per capita output in these countries. Islam (2009) verified that R&D intensity was not a significant variable when it was measured as R/Y, R/AL, PA/L and PG/L.[15] Neither did Madsen (2008) find a clear relationship between research intensity (measured by real R&D expenditure) and TFP growth in OECD countries. This result may be a consequence of multicollinearity, the difficulties presented by an adequate measurement of product differentiation or, *in extremis*, the necessity to relax the assumption of constant returns to scale in research intensity and replace it with the assumption of diminishing returns to research intensity.

Nevertheless, Schumpeterian proposals have some support in our model. The coefficient that accompanies the distance to the technological frontier is, undoubtedly, that which offers the most outstanding results, with a clearly positive and significant influence on TFP growth. As column (7) shows, the estimated coefficient shows the greatest value of all the parameters, 0.66, although when distance is measured by *DF2* (column 8) the coefficient falls to 0.22 and the variable ΔX^d loses its statistical significance. Both results are in the range of 0.2–0.60 obtained by Madsen and, in the case of *DF1*, slightly above the estimated 0.65 obtained by Lucas (2009) for open economies. Whatever the case, the positive value of the estimated coefficient for the distance to the frontier suggests the existence of conditional convergence in the sample studied; as the models by Aghion and Howitt (1998) and Howitt (2000) suggest, the farther a sector is from the technology frontier, the higher is its potential for accelerating productivity

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[15] Where R is R&D expenditure; L is the labour force; Y is GDP; PA are patent applications and PG are granted patents.

growth. Griffith et al. (2003) indicates that this parameter captures cross-country variations in relevant variables. Although distance to the frontier represents autonomous technology transfer because it proceeds independently of R&D activity, its pace varies across countries as a function of institutions, government policy, the level of human capital or trade openness.

Associated with this advantage is absorptive capacity, a concept which refers to the ability of nations to exploit the leaders' knowledge. Two factors have traditionally been considered as major determinants of the ability to absorb and implement foreign technology, namely, human capital, which Abramovitz highlighted in 1986, and national technological capability, considered by Griffith et al. (2003, 2004), among others. Here various measures of absorptive capacity have been examined, all of them based on R&D data, since adequate data for human capital at the sectoral level is not available.

In the last two columns of Table 2, the model is extended to include a variable representative of absorptive capacity (*CAB1*) which is calculated as the interaction between research intensity variable $(R/V)^d$ and distance to the frontier, *DF1*.[16] Column (9) shows the fixed-effect results of the extended model when autonomous technology transfer is measured by *DF1* and column (10) when *DF2* is used. Essentially the results are the same as those obtained without absorptive capacity: TFP growth is positive and significantly affected by growth in domestic and foreign R&D and distance to the frontier whereas domestic research intensity exerts a negative effect. Absorptive capacity does not exert a significant effect on TFP growth. Our results for R&D absorptive capacity are in line with those obtained by Islam (2009) who argues that problems of multicollinearity explain them. Our findings contradict the results of Griffith et al. (2003, 2004) who obtain a positive and significant relationship between this variable and TFP growth in an industry-level analysis.

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[16] For reasons of space in this section and in the rest of the paper the results obtained when the absorptive capacity is calculated by the interaction for a distance to the frontier variables and research intensity measured by $(R/AL)^d$ have not been included. They are very similar to those obtained with $(R/V)^d$.

IV. Sensitivity analysis

In this section we summarise the sensitivity of our results to the use of different indicators of research intensity and absorptive capacity. Research intensity is measured by three alternative measures. The first is that used in the preferred specification in Table 2, $(R/V)^d$. Additionally, in the denominator, two proxies for product differentiation, hours worked (L) and total employment (N), were incorporated to obtain alternative proxies of research intensity, $(R/N)^d$ and $(R/L)^d$ which have their foreign counterparts $(R/N)^f$ and $(R/L)^f$. To avoid problems of multicollinearity the absorptive capacity variable is also calculated by the interaction of one of these measures of research intensity and one of the two alternative measures of distance to the frontier, *DF1* and *DF2*. So the interaction between a measure of research intensity and two specifications of the distance to the technological frontier, *DF1* and *DF2*, allows us to obtain five additional proxies of absorptive capacity: *CAB2*, *CAB3*, *CAB4*, *CAB5*, and *CAB6*.

Table 3 presents the results of all the estimations in which autonomous technology transfer is measured by *DF1*. The first five columns contain the result of the extended model with (R/V) as the research intensity variable and different measures of absorptive capacity. Columns 6 to 11 show the results when (R/N) is included as the research intensity variable. The results of the estimations which include (R/L) as research intensity variable and *DF2* as autonomous technology transfer are similar. They are presented in the online Appendix.

The results from Table 3 confirm those of Table 2. In nine of eleven regressions the variable of growth in domestic real R&D expenditure shows a positive and significant coefficient. In relation to the values observed in Table 2, these increase to approximately 0.04 when R/V is the research intensity variable and fall to around 0.02 when research intensity is measured by (R/N). Similar results are observed for growth in foreign R&D. This variable is highly significant in all the estimations, with values of the coefficient ranging from 0.07 to 0.10.

For all specifications domestic research intensity is found to exert a highly significant negative impact on TFP growth and foreign research intensity obtains no significant coefficients whatever research intensity or absorptive capacity indicators are employed. As in previous specifications, the inclusion of R/V increases the value of the coefficient to -0.11, but when research intensity is measured by R/N the coefficient falls to -0.04.

Table 3. R&D intensity, distance to the frontier (*DF1*), absorptive capacity and TFP growth (fixed effects)

Estimation	$(X/Q)^d=(R/V)^d$					$(X/Q)^d=(R/N)^d$					
	$(X/Q)^f=(R/V)^f$					$(X/Q)^f=(R/N)^f$					
$X^d=\Delta R^d$	0.03**	0.04***	0.04***	0.04***	0.04***	0.01	0.01	0.02*	0.02*	0.02*	0.02*
	(2.10)	(2.85)	(2.91)	(2.87)	(3.01)	(0.69)	(0.70)	(1.89)	(1.75)	(1.90)	(1.85)
$X^f=\Delta R^f$	0.08**	0.09***	0.10***	0.10***	0.10***	0.07**	0.07**	0.08**	0.08**	0.08**	0.08**
	(2.47)	(2.94)	(2.96)	(3.04)	(3.01)	(2.12)	(2.09)	(2.37)	(2.41)	(2.49)	(2.45)
$(X/Q)^d$	-0.09***	-0.10***	-0.11***	-0.10***	-0.11***	-0.04**	–0.04**	-0.04***	-0.05***	-0.04***	-0.05***
	(-6.50)	(-7.25)	(-7.65)	(-7.22)	(-7.79)	(-2.48)	(-2.31)	(-3.03)	(-3.41)	(-2.93)	(-3.51)
$(X/Q)^f$	-0.01	0.01	0.01	0.00	0.02	-0.02	–0.02	-0.05	-0.02	-0.05	-0.02
	(-0.52)	(0.35)	(0.60)	(0.31)	(0.74)	(-0.70)	(-0.76)	(-1.52)	(-0.74)	(-1.67)	(-0.80)
DF1	0.64***	0.70***	0.65***	0.70***	0.64***	0.59***	0.60***	0.61***	0.56***	0.61***	0.54***
	(8.00)	(9.49)	(8.90)	(9.55)	(8.79)	(7.40)	(7.07)	(8.05)	(7.25)	(8.11)	(7.07)

Table 3. (continued) R&D intensity, distance to the frontier (*DF1*), absorptive capacity and TFP growth (fixed effects)

Estimation	$(X/Q)^d=(R/V)^d$ $(X/Q)^f=(R/V)^f$					$(X/Q)^d=(R/N)^d$ $(X/Q)^f=(R/N)^f$					
$CAB1=(R/V)^d DF1$						0.06					
						(0.74)					
$CAB2=(R/V)^d DF2$	0.14						-0.19				
	(0.43)						(-0.57)				
$CAB3=(R/L)^d DF1$		-20.76***						-29.13***			
		(-4.30)						(-5.80)			
$CAB4=(R/L)^d DF2$			57.37***						61.73***		
			(3.58)						(3.77)		
$CAB5=(R/N)^d DF1$				-0.01***						-0.01***	
				(-4.50)						(-6.08)	
$CAB6=(R/N)^d DF2$					0.03***						0.04***
					(3.92)						(4.20)
R^2	0.25	0.27	0.27	0.27	0.27	0.19	0.19	0.23	0.22	0.22	0.22

Notes: a) Variable specifications: *A* denotes *TFP*, *R* is R&D expenditure; *R/A* is productivity-adjusted R&D expenditure; *AL* is TFP adjusted for hours; *V* is the sectoral value added; *N* is total employment and *L* is the number of hours worked; *R/AL*, *R/V*, *R/L*, and *R/N* are different measures of research intensity $DF1_{ijt} = \left(\frac{A_{\max} - A_i}{A_{\max}}\right)_{ijt}$, $DF2_{ijt} = \left(\frac{A_{\max}}{A_i}\right)_{ijt}$, *CAB1*-*CAB6* are different measures of absorptive capacity. b) Estimation period 1979-2001. Number of observations: 240. c) Figures in parentheses are *t*-values significant at the 1% level (***), 5% level (**) or 10% .

The central result of a positive and highly significant correlation between TFP growth and distance to the frontier is robust with respect to different absorptive capacity variables. The estimated parameter is close to 0.60 in most specifications. This result is common to all empirical studies that incorporate a proxy for the distance to the frontier and, as stated above, it reflects the advantages, in economies with high levels of integration, of the most backward countries with respect to the leaders.

The results for the absorptive capacity variable are somewhat puzzling, as in other empirical studies such as Madsen et al. (2010) and Islam (2009). Absorptive capacity is not significant when measured by *CAB1* or *CAB2*, but *CAB3* and *CAB5* have a significant negative effect on total factor productivity growth, which prove to be positive when measured by *CAB4* or *CAB6*. The above authors consider that the results for this variable are very sensitive to the model's specification and to the measurement of innovative activity and product variety, as well as to the problems of multicollinearity that are frequent in the models.

Overall, the results do not confirm those obtained by Griffith et al. (2003, 2004), among others, who found a significant and positive relationship between R&D-based absorptive capacity and TFP growth. This is so only in one third of the specifications, those which interact $(R/N)^d$ or $(R/L)^d$ with *DF2*.

V. Conclusions

The purpose of this paper is, firstly, to test whether second generation endogenous growth models are consistent with the data from ten productive sectors in six developed economies during the period 1979-2001. Secondly, it aims to examine the capacity of R&D activity international technological spillovers, distance to the frontier and absorptive capacity to explain TFP growth.

The stationarity and cointegration analysis and the growth equations give strong support to semi-endogenous growth theory: domestic innovative activity and international knowledge spillovers transmitted through trade are key drivers of economic growth. This finding has an important implication, namely the transitional effect of investment in R&D.

Nevertheless, the Schumpeterian proposal also enjoys partial support via the positive effect of autonomous technology transfer, as represented by the distance to the technological frontier. This implies that countries that are far behind the technological frontier experience high productivity growth and that it is possible to achieve TFP growth if the right policies are in place. The Schumpeterian paradigm considers that crucial distinctions in the economic policies should be adopted, depending on the distance between a sector or a country and the technological frontier. No doubt the innovative model requires, firstly, the promotion of R&D investment and, as our results show, this effort must be directed towards the promotion of autonomous technology transfer. As Aghion et al. (2013) state, the closer to the frontier an economy is, the more its growth is driven by innovation-enhancing policies, low entry barriers and research education, while the more detrimental to growth are low degrees of openness and high entry barriers.

The inexistence of sectoral data about the majority of these variables constitutes the principal limitation of the present analysis. Future extensions of the present study will attempt to investigate distance to the frontier and absorptive capacity variables and perform research into the role of other indirect sources of innovation and growth such as competition, investment in tertiary education, trade liberalization, the reduction of credit constraints and increased flexibility in labour markets.

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