Entrepreneurship, Total Factor Productivity Growth and Technical Progress: Convergence Towards the Technology Frontier

Brief running title: **Entrepreneurship, Total Factor Productivity Growth and Technical Progress**

Abstract: A firm's set of knowledge processes may be affected by the entrepreneurial culture of the country in which it is located. Total factor productivity, mainly associated with technical progress, accounts for most differences over time and across countries. In the present work we examine the determinants of total factor productivity growth in 26 OECD countries between 1965 and 2010, breaking them down into changes in technical efficiency and shifts in technology over time. Using the U.S. as the technology frontier, different patterns of productivity growth emerge between world technology leaders and countries with low initial levels of productivity. Whereas changes in efficiency seem to be the main result of the evolution in the stock of knowledge in technologically dependent economies, suggesting that less advanced economies can benefit from their relative backwardness, domestic research effort appears to be a relevant factor for technology leaders.

Keywords: Patterns of Productivity Growth, Technical Progress, Technology Frontier, Stock of Knowledge, Panel Data Methods, Entrepreneurship.

1. Introduction

This work is based on the pioneering work by Robert M. Solow and by authors who went deeper into his economic growth model (1956) and technical change in the aggregate production function model (1957) and on the growth model proposed by Jones (2002). Over the past couple of decades there has been increased interest in and analysis of the institutional foundations for economic growth. According to Solow, the key factor for growth is technical progress which, as a consequence of the stock of ideas and knowledge in society, counteracts decreasing yields from capital and determines real wages and per capita income; when nominal and real wages, as an important part of income, are established by institutions (Solow, 1992). Based on the Solow (1956) model, researchers have sought to expand the list of economic factors that may contribute to economic growth. A more recent, and as yet developing field, is the role of entrepreneurship. Jones (2002) argues that 80% of US growth in the post-war period is due to the transition dynamics associated with increases in educational attainment or the increase in world R&D intensity. They seem to rise smoothly, generating an approximate stable growth path.

In any society, the dominant beliefs and basic values or culture (Dauber, Fink and Yolles, 2012; Hatch and Cunliffe, 2006), institutionalise forms of behaviour, ideas of technical and social progress, educational levels and normative frameworks which are either conducive to, or hinder, the stock of ideas and knowledge and technical and social progress; these behaviours and normative frameworks transfer to a society's aggregate production function, forming part of its total factor productivity, through different types of entrepreneurs or entrepreneurship (Schumpeter, 1934, 1950), and their rootedness (or institutionalisation) in society (Aldrich and Zimmer, 1986; Alvarez et al., 2011; Thorton et al., 2011).

Thus although the entrepreneurship literature and Jones and Solow´s studies of economic growth use very different research procedures and methodology, there is necessarily a permeable frontier between them; and furthermore, institutional conditions that guide behaviour and establish normative frameworks are essential for producing one set of outcomes or another in the accumulation of ideas, innovation and growth in the countries examined (see Appendix A), as the technical progress function establishes (i. e. expressions (12) and (13) below, in the formulation). The independent term β_1 ($\beta_{1i} = \beta_1 + u_i$) in the technical progress function (13) reflects the dimension of culture and entrepreneurship in each country.

Some of the conclusions of this present study, apparently quite separate from the entrepreneurship literature, are nevertheless useful for institutional policies on entrepreneurs. One of these conclusions is that the domestic research effort in countries close to the technological frontier (represented by the United States) has positive, significant consequences for those countries, whereas for less advanced countries, greater benefit can come from importing goods which incorporate technical advances and foreign direct investment. A country's culture and entrepreneurs play an important role in both cases, because entrepreneurs discover opportunities (Shane and Venkataraman, 2000) and also create them.

At a macroeconomic level, this article addresses the important question of the factors that determine living standards all over the world, that is, what determines per capita incomes and growth rates of economies over the long run?

From the outset the economic growth literature has shown theoretically and empirically, the predominance of the classical Solow's residual over factor accumulation (i.e. physical and human capital) in the explanation of growth. As a result, total factor productivity (TFP), which is mainly determined by technical progress, appears as the principal component in the description of countries' economic performances over time, and also seems to account for the bulk of the differences in income levels and growth rates.[i] In addition, the empirical literature suggests that technological diffusion matters, and therefore, countries with low initial levels of productivity can benefit from ideas created abroad. This idea is linked to the growing research interest in how organizational knowledge is generated, transferred and implemented (Nonaka, 1991). We think that this knowledge is not simply the sum of all the stages and processes in each firm, the country where the company is located may also have an impact. Moreover, regarding organizational culture, Hofstede et al. (1990) highlight that there is a significant difference between national culture and organizational culture, nevertheless, firms are embedded in societies defined by certain national culture values (Dauber, Fink and Yolles, 2012). For this reason we think that the institutional context of a firm has become important once more.

Thus, the purpose of this paper is to provide evidence of patterns of total factor productivity growth (explicitly including TFP catch-up). With that aim we endogenize and estimate total factor productivity in the framework of an economic growth model. Subsequently, we decompose total factor productivity growth into catch-up and technical change to distinguish diffusion of technology and innovation respectively.

We apply our convergence model to a sample of OECD countries over the period 1965-2010. Each country is compared to the United States, which is considered to be the technology frontier.[ii] We find differential behaviour in countries closer to the frontier with respect to countries with less developed technological knowledge.

The paper is organized as follows. First, in Section 1 we outline the growth model proposed by Jones, 'in which long-run growth is driven by the discovery of new ideas throughout the world' (Jones, 2002, p. 221), which we use to compute total factor productivity. Then we briefly describe the background of the technical progress function evaluated here that incorporates catch-up with the technology frontier, assumed to be the United States, for our sample of industrialized countries. In Section 3 we proceed to the empirical verification of the technology frontier convergence model. Finally, in Section 4 we critically examine some of the assumptions and implications of the model, focusing on the role of human capital and stocks of ideas.

2. The Growth Model and Entrepreneurship

There is a long-standing tradition of belief in the value of entrepreneurship as a factor in economic growth. Smith (1776) recognized the role of profit-seeking entrepreneurs in expanding markets through the ever-increasing division of labour. Holcombe (1998), following Kirzner (1973), believes that entrepreneurship, once included in the standard neo-classical growth model fleshes out the process by which the factors of production interact to create economic growth.

From this point, the theory of economic growth distinguishing production growth is explained by an increase in the primary resources of capital and labor employed in production and the growth of total factor productivity. The theory of economic growth includes institutional, market and company internal factors that explain the differences in welfare between countries at any given moment in time (Solow, 1956; Lucas 1988; Romer, 1990; Barro and Sala -i-Martin, 1991). The initial hypothesis in the economic theory of entrepreneurship is that the economy is endowed with certain factors. Entrepreneurship contributes to production through a combination of productive factors (capital and labour), and therefore more entrepreneurial resource allocation implies higher levels of production and well-being. Lazear (2004) states that entrepreneurs are the single most important players in a modern economy and Henderson (2002) claims that entrepreneurs create economic growth in their communities by forming new firms. To capture that role economic growth models have expanded to incorporate various measures of entrepreneurship.

Incorporating entrepreneurship into a model of economic growth makes it apparent that the engine of economic growth is entrepreneurship, not technological advance or investment in human capital per se and that doing so fills in the institutional details to help make the growth process more understandable (Holcombe, 1998).

Following Jones (2002), the aggregate production function can be represented as

$$Y_t = A_t^{\sigma} K_t^{\alpha} H_{Yt}^{1-\alpha}, \qquad (1)$$

where A_t is the total stock of knowledge available to this economy, K_t is the aggregate capital stock, and H_{Yt} is the total amount of human capital employed to produce output. It is assumed that there are constant returns to scale for physical and human capital factors ($0 < \alpha < 1$), and increasing returns for the equation as a whole ($\sigma > 0$), given that A is considered an additional production factor.

The equation of motion for physical capital is as follows

$$\dot{K}_t = s_{Kt} Y_t - dK_t, \quad K_0 > 0. \qquad (2)$$

the term s_{Kt} represents the investment rate in physical capital, that is, the ratio of investment over output, and $d > 0$ is the constant exogenous rate of depreciation.

The human capital employed to produce output is introduced in the model following the formulation suggested by Bils and Klenow (2000), and is given by

$$H_{Yt} = h_t L_{Yt}, \quad (3)$$

where h_t is human capital per person, and L_{Yt} is the total quantity of labour employed to produce output. Human capital is accumulated through formal education, following the formulation

$$h_t = e^{\psi lht}, \quad \psi > 0 \qquad (4)$$

where lh_t represents the time an individual spends accumulating human capital.[iii]

Finally, the last factor in the production function is the stock of ideas, which is introduced in the model with the generalization proposed by Jones (1995):

$$\dot{A}_t = \delta H_{At}^{\lambda} A_t^{\phi}, \quad A_0 > 0. \qquad (5)$$

the variable H_{At} represents the effective world research effort, which is obtained as the weighted sum of the number of scientists and engineers in each economy, L_{Ai}, following the expression

$$H_{At} = \sum_{i=1}^{M} h_{it}^{\theta} L_{Ait}, \qquad (6)$$

where the weights are given by human capital, with $\theta \geq 0$.[iv]

In the ideas function the coefficient λ represents performance in terms of new ideas from current scientists, whereas ϕ accounts for the impact of past discoveries over new ones. Finally, δ can be considered a measurement of the speed and scope of the transmission of ideas.

The expected value for λ lies between 0 and 1, new discoveries could duplicate so the value of ϕ could be negative if the most fundamental and basic ideas are discovered first. In addition, δ cannot be greater than 1, as it would mean an instant diffusion of new ideas.

As Myro et al. (2008) point out the fact that the technical progress of a country depends on world scientific knowledge without distinguishing between the knowledge obtained in the home country and that obtained abroad, is clearly a limitation on the empirical application of this model. Furthermore, separation of different scientific advances for introduction in the model would require broader theoretical and empirical investigation of their complementary or substitutive nature.

Time invested by each individual can be divided between the production of goods, ideas and human capital. Therefore, the resource constraint can be written

$$L_{At} + L_{Yt} = L_t = (1 - lh_t)N_t, \qquad (7)$$

where L_t is total employment. Furthermore, Myro et al. (2008) define $l_A \equiv L_A / L$ as the part of the labour force that produces ideas ('research intensity ratio'), and $l_Y \equiv L_Y / L$.

Finally, population N_t is assumed to grow at an exogenous and constant rate n>0:

$$N_t = N_0 e^{nt}, \quad N_0 > 0. \ (8)$$

Since all the elements in the model have already been defined an expression for income per worker can be obtained, and thus equation (1) can be expressed in *per capita* terms, multiplying both sides by 1/Lt. The result is

$$y_t = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} l_{Yt} h_t A_t^{\frac{\sigma}{1-\alpha}} \ (9)$$

This equation allows us to work out the value of A. A also has to be both Solow's residual and the estimated stock of ideas if we intend to endogenize technical progress. Therefore, A has to be both the result of equation (9) and of the ideas function.[v]

However, in order to calculate the value of total factor productivity, we first have to give values to some of the parameters that appear in the model. On this matter, we assume that α, the capital's share of income, takes the commonly adopted value of 1/3.[vi]

The ψ parameter is a measure of the impact of education on wages or output per worker. In our work we accept the value of 0.07 employed by Jones and Myro et al. (2008) relying on the estimations of Mincer (1974).[vii]

Finally, we need to find a value for σ which indicates the share of the total stock of knowledge in the economy. Jones normalizes this parameter as σ = 1–α, which implies that A is introduced in the production function as Harrod-neutral technical progress.

3. Technical Progress Function

In 1990, Paul M. Romer proposed the ideas function:

$$\dot{A} = \delta H_A^{\lambda} A,$$

where δ is a productivity parameter (0<δ<1), A is the aggregate stock of ideas (designs) produced in the research sector, and H is the amount of human capital employed in this sector.

Jones (1995) provided a generalization of the function, undoing the linearity in the variables through the inclusion of exponents, and establishing a range of values for them

$$\dot{A}_t = \delta H_{At}^{\lambda} A_t^{\phi}, \qquad (5)$$

where it is assumed that $A_0 > 0$, $0 < \lambda \leq 1$ and $\phi < 1$, and δ is interpreted as the degree of technological diffusion.[viii]

When Jones (2002) estimated this equation for the U.S. economy, he converted it into a technical progress function, since he defined the stock of ideas as the total factor productivity, seeking to measure ideas in production terms. In our application to a broader set of countries we have followed the same approach.

Following the above formulation, Myro et al. (2008) estimated Jones´s specification of the ideas function not only for the US economy, but for several leading European Union countries (i.e. Germany, France and the United Kingdom).

The good results indicated that the specification proposed by Romer and Jones to capture the sources of TFP growth seems to be a good one, but at the same time showed its incapacity to differentiate the influence of ideas from abroad in relation to those generated at home. Likewise, the device used in the model to account for the international diffusion of ideas (i.e. the world research effort in R&D) does not appear to be the right one, which suggests a need for the explicit introduction of alternative ways to take into account the channels through which the international dissemination of knowledge takes place.

Indeed, the technical progress function (5) is valid for the leader country in scientific knowledge, which by assumption is the United States. Nevertheless, as Doménech (2002) points out, the function cannot be applied to countries unless they are at the technology frontier.

Bearing in mind these ideas, the proposed reformulation by De la Fuente (2002) and the work of Coe and Helpman (1995), we propose extending the original equation to explicitly consider ca mechanism of convergence with the technology frontier (i.e. a catch-up term) that can be estimated for economies with less developed technological knowledge (Myro et al., 2008).

3.1. Building a technology frontier convergence model

Following Myro et al. (2008) the following model may be formulated for any technologically dependent country, *i*, taking one country or a group of leading countries as the technology frontier, *l*.

$$\dot{A}_{t,i} = \delta_{t,i} \, H_{t,i}^{\lambda} \, A_{t,l}{}^{\mu+\phi} A_{t,i}^{(1-\mu)} \qquad (10)$$

Where the increase in the stock of ideas for country *i* during period t+1 depends on its value in t and on the value in that same year of the stock of ideas in the country considered to be at the technology frontier, *l*, as well as the number of researchers H in country *i*.

If study country *i* is also the leader in technology (i.e. if $i = l$) the previous expression is simplified and transformed as follows:

$$\dot{A}_{t,i} = \delta_{t,i} \, H_{t,i}^{\lambda} \, A_{t,i}{}^{1+\phi}$$

This is similar to the model suggested by Jones when $1+\phi < 1$ and that of Romer when $\phi = 0$. In terms of variation rates, the above expression adopts this form:

$$\frac{\dot{A}_{t,i}}{A_{t,i}} = \delta_{t,i} \, H_{t,i}^{\lambda} \, A_{t,i}{}^{\phi}$$

Following Romer (when $\phi = 0$), a direct relationship is established between the growth rates of A and H, where the scale effect on H is more evident.

If the country under study does not happen to be the leader, the corresponding expression is:

$$\frac{\dot{A}_{t,i}}{A_{t,i}} = \delta_{t,i} \, H_{t,i}^{\lambda} \left(\frac{A_{t,l}}{A_{t,i}} \right)^{\mu} A_{t,l}{}^{\phi} .$$

where the growth rate of A depends directly on the number of researchers in the domestic economy and on the technological distance from the leader, captured by the ratio $A_{t,l}$ / $A_{t,i}$, where μ becomes a coefficient to measure the speed of convergence towards the technology frontier (i.e. efficiency change). It also depends on the stock of knowledge at the technology frontier (i.e. technical change).

To make it easier to carry out the estimation, equation (10) may be expressed in absolute values of A:

$$A_{t+1,i} = \delta_{t,i} \, H_{t,i}^{\lambda} \, A_{t,l}^{\mu+\phi} \, A_{t,i}^{(1-\mu)} \quad (11)$$

As can be shown, equations (10) and (11) have very similar implications, at least in the long run. The only differences between them concern transition dynamics.[ix]

The main advantage of (11) is that it directly generates a linear equation in logarithms, which is easier to estimate than (10). Thus, taking logarithms in (11) gives:

$$\ln A_{t+1,i} = \ln \delta_{t,i} + \lambda \ln H_{t,i} + \mu \ln A_{t,l} - \mu \ln A_{t,i} + \phi \ln A_{t,l} + \ln A_{t,i}$$

or

$$\ln A_{t+1,i} - \ln A_{t,i} = \ln \delta_{t,i} + \lambda \ln H_{t,i} + \mu \left[\ln A_{t,l} - \ln A_{t,i} \right] + \phi \ln A_{t,l}$$

that can be rewritten

$$\Delta \ln A_{t+1,i} = \ln \delta_{t,i} + \lambda \ln H_{t,i} + \mu \left[\ln A_{t,l} - \ln A_{t,i} \right] + \phi \ln A_{t,l} \qquad (12)$$

The second to last term in the right hand side of equation (12) explicitly introduces the catching up process and therefore accounts for the observed natural long-term pattern of convergence, as countries with low initial levels of productivity exploit the public goods aspects of technology advances.

The value of the elasticity of parameters λ and ϕ no longer coincide with those in Jones' original model, where the dependent variable is the variation of A. But it can be easily proved that the value of λ in Jones' model is equal to that obtained in (12) multiplied by $\left(1 + \frac{1}{\gamma_{A_i}}\right)$, where γ_A is the rate of variation of A.

In the steady state, the growth rate of technical progress is time invariant, and is given by

$$\gamma_{A_i} = \frac{1}{\mu}\left[\gamma_{\delta_i} + \lambda \gamma_{H_i} + (\mu + \phi)\gamma_{A_l}\right]$$

Hence, the technical progress growth rate in the long run is directly proportional to the growth rates of the dissemination parameter, the number of researchers in the analyzed country and technology frontier expansion.

4. Data and Results

Having obtained values for total factor productivity following equation (9), we are now in a position to estimate equation (12) for the group of OECD countries, considering the US as the technology leader.[x]

In this regard, we use panel data methods to estimate the expression of interest. This methodology has several advantages over single use of time series or cross-section techniques.

In our instance we can point out that, according to Gujarati (2003) citation to Baltagi (2001): ‘Panel data enables us to study more complicated behavioral models. For example, phenomena such as economies of scale and technological change can be better handled by panel data than by pure cross-section or pure time series data’ (Gujarati, 2003, p. 638).

In addition, the panel data methodology provides us with a technique that enables us to take advantage of the time series and the cross-sectional dimension of the dataset and identify potential individual effects present in the data. In this respect, the panel data methodology is the most appropriate to test our hypothesis regarding the importance of entrepreneurship for economic growth, since it allows us to test for the presence of individual effects denoting differences in entrepreneurship among the countries considered in our analysis.

Therefore, we rewrite expression (12) to express it more clearly in the context of panel data estimation. Likewise, as we develop the analysis we offer diverse specifications and interpretations of the same formula adapted to the various estimation scenarios or panel data models.

Thus, we can express (12) as

$$\Delta \ln tfp_{it} = \beta_1 + \beta_2 \ln researchers_{it} + \beta_3 \left[\ln tfp_{ust} - \ln tfp_{it} \right] + \beta_4 \ln tfp_{ust} + \varepsilon_{it} \quad (13)$$

where i denotes the cross-section identifier and t the time identifier. Notice that *a priori* we expect a positive relationship between any of the explanatory variables and the dependent variable.[xi] We call $\left[\ln tfp_{ust} - \ln tfp_{it} \right]$ catch-up.

As stated before, the dependent variable is the growth rate of total factor productivity and the explanatory variables can be divided in two groups. The first group consists of the number of researchers in the domestic economy, which allows us to assess the relevance of domestic research effort for productivity growth. The second group contains two regressors, the technology gap with the United States, which accounts for changes in technical efficiency over time, and the total factor productivity of the U.S., which represents the shifts in technology over time.

To the above we add heterogeneity, or individual effect β_1 containing a constant term and a set of individual or group specific variables.[xii] We also include a random disturbance ε_{it}, which has the same characteristics as in a classical regression model (i.e. $\varepsilon_{it} \sim N\,[0, \sigma^2]$).

Our objective is to obtain values for the coefficients of the model, which in this particular case are elasticity parameters because of the logarithmic formulation employed. Consequently, the estimated parameters must be interpreted as the elasticity of the growth rate of the TFP with respect to variations in any of the explanatory variables. Accordingly, and since panel data are available, we follow the subsequent schedule to test for the existence of individual effects in the data (i.e. differences in country growth rates due to individual entrepreneurial characteristics). Thus, first we estimate the *pooled regression* specification, which does not allow for differences among countries, and therefore, would indicate that culture and entrepreneurship have no role in our model. To test for the relevance of country specific effects we use the *F-test for the Significance of Country-Specific Effects,* to help us elucidate which model specification is the more appropriate for our data set. Once the F-test indicates that the classical regression model with a single constant term is inappropriate for these data, and therefore, that entrepreneurship is relevant to determine growth we have to find out if the country specific effects are of a fixed or random nature. For this purpose, we use the *Hausman-test.*

4.1. Pooled Regression

The first step in the panel estimation process requires estimation of the simplest specification of equation (13).[xiii]

Accordingly, in the pooled regression model we assume that the individual effects parameter β_1 only contains a constant term, and also that the coefficients of the other explanatory variables share the same value for every country. This is quite a limiting specification of our convergence model since it does not allow for country differences in β_1, which is the parameter that captures the influence of culture and entrepreneurship.

Therefore, the expression to be estimated is exactly the same as before, but a lag value of the catch-up term has been introduced to avoid the negative sign induced by the presence of the term ln tfp_{it} in the technical progress gap with the technology leader and the growth rate of domestic total factor productivity. As can be observed if both terms are contemporaneous, an increase in TFP in the home economy at time *t* reduces the gap with the technology leader, but at the same time increases the growth rate of TFP in the home country, and so the coefficient for this explanatory variable takes a negative sign.

Table 1 in here

As can be seen in Table I, most of the coefficients have the expected signs. Thus, in column (1), where we have performed the estimation for world technology leaders, apart from the coefficient on the contemporaneous gap with the frontier and the year dummies for 2005 and 2010, the remaining explanatory variables have a positive effect on the growth rate of total factor productivity and all of them appear to be significant at conventional statistical levels. Moreover, R^2 is quite high indicating a remarkable goodness of fit.

The same pattern can be observed in the estimates regarding countries with less advanced technology knowledge presented in column (2). The only noticeable difference is found in the effect of the domestic research effort, which in this case is negative and significant.

Nonetheless, these results are not conclusive as there may be specification errors in the equation due to the restrictive assumptions of this simple model. Therefore we have to make our formulation more flexible to include the specific nature of each country. We do this in the next section allowing the intercept to vary across cross-sectional units.

4.2. Fixed Effects Regression

As stated in Greene (2011) this formulation of the model assumes that differences across units can be captured in differences in the constant term, which in our case is β_1. Therefore, in this scenario we assume that this parameter is different for every country and so needs to be estimated separately for all of them.

Observe that we maintain equal slope coefficients for every country in the sample, but note that in this case we write β_{1i}, adding the subscript *i* to the intercept, and thus pointing out the fact that the constant term may be different for each country in the sample (i.e. the role of culture and entrepreneurship).

The results in Table 2 show the values for the slope coefficients and cross-country specific effects. Likewise, we offer the value for the coefficient of determination and the number of observations for each group.

Table 2 in here

The results remain in line with those obtained previously and therefore most of the elasticity coefficients appear to be significant and have the expected effect on TPF growth. It is worth noticing that the main difference between the group of technology leaders in column (1) and the technologically less advanced countries in column (2) is the impact of domestic research effort on total factor productivity growth. As can be seen, whilst the coefficient on the natural logarithm of the number of researchers remains significant and positive for the technology leaders, indicating that for technologically more advanced countries the domestic research effort has a positive impact on productivity growth, it becomes positive but non-significant for technologically dependent countries.

Moreover, the influence of culture and entrepreneurship as captured by the individual effects term continues to be positive and highly significant and indicates the importance of these factors in determining the pace at which technological knowledge progresses. Additionally, it seems that the influence of entrepreneurship is larger in countries that are technology leaders (the difference is statistically significant).

Additionally, the results indicate that for technology leaders and countries with less advanced technological knowledge, a higher level of technical progress in the United States leads to higher growth in the stock of knowledge. This finding point to the idea that less advanced countries in research terms can benefit from advances in the technology level of the frontier (i.e. technical change in the U.S.).

Likewise, the positive and significant coefficient on the lagged catch-up term indicates that greater distance from the technology leader fosters the advance of domestic total factor productivity, showing that technologically dependent countries can take advantage of their relative technological backwardness by adopting advances from abroad. In fact, the coefficient on the catch-up term seems to be larger for the group of countries situated farther away from the frontier.

The coefficient of determination shows that the goodness of fit of the estimated relation is above 90 percent in both cases, which is indicative of the high explanatory power of the proposed model.

4.2.1. F-test for the Significance of Country-Specific Effects

After estimating the pooled and fixed effects specifications, and then obtained constant term values for every country in our sample, we now want to test whether the cross-section specific effects are statistically different across countries or not. The objective is to elucidate which model specification is the more appropriate for our data set.

To carry out this test, we have to rely on a statistical inference tool, the F statistic, which is based on the coefficients of determination of the pooled and fixed effects. Thus, following Greene (2011) the F ratio can be represented

$$F(n-1, nT-n-K) = \frac{(R^2_{LSDV} - R^2_{Pooled})/(n-1)}{(1-R^2_{LSDV})/(nT-n-K)},$$

where LSDV indicates the least squares dummy variable model (i.e. fixed effects model) and pooled indicates the pooled or restricted model with only a single constant overall term; n denotes the number of cross-sections, T the number of time periods and K the number of regressors not taking into account the constant term.

Under the null hypothesis, all the constant terms are equal among countries and the efficient estimator is pooled least squares.

The statistical software package Stata reports the F-test directly. The same patterns emerge in both groups of countries, as we can in both cases reject the null hypothesis. Therefore, the F-test indicates that the classical regression model with a single constant term is inappropriate for these data. Thus, the F-test concludes that the pooled regression is not appropriate and the result of the test is to reject the null hypothesis in favor of the fixed effects model. It is; however, best to reserve judgment on that, because there is another competing specification that might induce these same results, the random effects model. We examine this possibility in the next section.

4.3. Random Effects Regression

The next step in the estimation of our panel data set involves estimating the random effects model, which assumes that individual effects are uncorrelated with the regressors.

‘If the individual effects are strictly uncorrelated with the regressors, then it might be appropriate to model the individual specific constant terms as randomly distributed across cross-sectional units’ (Greene, 2011, p. 293).

The results of the random effects estimation are displayed in Table 3. The slope coefficients generally have the expected signs, apart from the coefficient on the domestic research effort for less advanced countries which is negative and significant. Moreover, all of them are significant and the coefficients of determination for both models are very high.

Table 3 in here

As can be seen, both groups of countries benefit from their relative backwardness to the technology frontier and the coefficient on the catch-up term is in both cases positive and significant. Note that the coefficient for technologically less advanced countries is larger than the corresponding figure for technology leaders, which is in line with our a priori hypothesis and shows that less advanced countries can largely benefit from their relative delay.

Likewise, it seems that outward shifts in the frontier of knowledge promote the growth rate of total factor productivity in the rest of the world. Thus, the coefficient on the natural logarithm of total factor productivity in the United States is positive and significant for both sets of countries. In particular, the impact appears to be larger for technologically less advanced countries.

After obtaining the random effects estimates of our model of convergence towards the technology frontier, we performed a Hausman test to evaluate if the fixed effects model is more appropriate than the random effects model to characterize our dataset.

4.3.1. Hausman-test

We use the test devised by Hausman (1978), which tests for the orthogonality of the random effects and the regressors (Greene, 2011, p. 301).

The Wald test like the LM test is based on maximum likelihood estimation and can be written

$$W = \left[b - \hat{\beta} \right]' \hat{\psi}^{-1} \left[b - \hat{\beta} \right]$$

where b is the vector of estimated coefficients in the LSDV model, β corresponds to the Generalized Least Squares (GLS) estimates and ψ is the covariance matrix of the difference vector.

As mentioned above, in this instance the null hypothesis is that the individual effects are uncorrelated with the other regressors in the model, and under the null hypothesis, the Wald statistic is distributed as a chi-squared with K-1 degrees of freedom, where K is the number of regressors included in the model.

Hence, the W statistic is 14.25 and 15.56 for technology leaders and technologically less advanced countries respectively. Moreover, the critical value on tables for a chi-squared with six degrees of freedom at 95 per cent significance is 12.59. Therefore, we can reject the null hypothesis of non correlation of the individual effects in our model, and conclude that for the set of countries the fixed effects model fits better than the random effects model.

5. Some Remarks

The above exposition clarifies some of the interesting features of the model under assessment, but it is worthwhile having a deeper look at some of them.

Firstly, we review the more recent literature on returns to schooling and propose a wider range of values for the ψ parameter. Secondly, we examine the implications and differential characteristics of the diverse specifications of the ideas function shown here.

5.1. Returns to schooling

In the work of Jones (2002) for the United States, reproduced for leading European countries by Myro et al. (2008), and in the current work, a value of 0.07 is assigned to the ψ parameter, which represents returns to education following Mincer's (1974) estimations. Nevertheless, more recent estimations give different values for this parameter. The reasons are diverse:

i. The method of estimation. Ashenfelter et al. (1999), worked with a sample of 27 reviews corresponding to 9 countries, and obtained a rate of return of 7.9 per cent, average of the values estimated with Ordinary Least Squares (6.6%) and Instrumental Variables (9.3%).

ii. The range. Bils and Klenow (2000) found an average salary gain associated to an additional year of education of 9.5 per cent, and a range between 5 and 15 per cent for 36 out of 48 countries in their sample.

iii. The trend. The initial estimations on the average returns to schooling were 3.5 per cent in 1974, increasing at a rate of approximately 2 percentage points every decade.[xiv]

iv. The factors. Some works, like Engelbrecht (1997), among others, suggest that there may be significant feedback during growth between human capital and stock of ideas, either in domestic innovation or in the adoption of technology spillovers, not captured with the formal R&D sector. Average years of total schooling therefore may be underestimating the human capital stock.

We therefore need to reconsider the value assigned to the ψ parameter and to the variable used to measure the human capital stock (i.e. the average years of total schooling), as that may have relevant consequences in the calculation of the residual of the production function, a crucial element in our subsequent analysis.

5.2. The Technical Progress Function

Formulations of the ideas function suggest at least three interesting points:

i. The degree of returns to scale on knowledge of the technical progress function. The most common assumption in the theoretical models is $\phi = 1$. More generally, the predictions of models like those of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) are probably consistent with the data only when $\phi \sim 1$. Thus a constant level of research effort leads to a positive and constant rate of technical progress, and consequently sustainable growth in per capita income over a stable growth path.

ii. The ideas function considered in Romer (1990) assumes $\phi = 1$. If increases in the ideas stock are proportional to the existing stock of ideas, as the world research effort has increased to such a great extent in the last forty years[xv], and then the most advanced economies should also have grown at a high rate. This has not been the case, and a way to overcome this prediction is by imposing $\phi < 1$, as in Jones' and Myro's specification.[xvi] The restriction allows that past discoveries could either increase ($\phi > 0$) or decrease ($\phi < 0$) the productivity of contemporaneous ones.[xvii]

iii. Jones uses the total research employment in G-5 countries to represent the world R&D effort. The intention, which comes directly from Romer's model, is to describe the engine of growth of the most advanced countries in the world as a whole. Implicitly, he is assuming:

   a) An instantaneous diffusion of knowledge. People in the developed countries have learnt over the years to employ very advanced capital goods. Implicit in this explanation is the idea that the technologies are available for everybody all over the world.

   b) A strong scale effect, because what it is important is the total research effort. The growth rate of the economy depends on population growth. If this, or the number of researchers, stops, then long run economic growth will do too. Only in the special case that $\phi = \lambda = 1$ can a constant research effort maintain long run growth.[xviii]

In our work we follow Jones' approach, considering that the evidence is clear on this issue, and then we estimate a technical progress function assuming decreasing returns to scale in knowledge. However, relying basically on the results of Myro et al. (2008) and Colino et al. (2013) we consider that the mechanism Jones uses to capture the diffusion of knowledge throughout the world (i.e. total research employment in G-5 countries) is not appropriate and needs to be improved.

6. Concluding Remarks

This work presents a growth model that makes total factor productivity endogenous through the explicit use of a technical progress specification for a set of technologically less developed countries. This formulation is assessed within the framework of panel data methods, which allow us to take advantage of the particular characteristics of this approach, and then improve its results.

The inference procedure reveals the presence of different patterns of convergence towards the technology frontier, considered to be the United States. First, for the group of countries with higher levels of productivity the results indicate that their individual characteristics must be taken into account since they appear to be relevant for determining the pace at which technology advances. Second, the estimation for technologically less advanced countries also seems to indicate the presence of individual effects and that these effects are correlated with the other regressors of the model, providing evidence for the estimation of a fixed effects model.Thus the results indicate that the individual characteristics of both technology leaders and technologically less advanced countries including entrepreneurship are relevant for determining their progress in technology.

Moreover, we have found evidence to support the idea that a higher level of technical progress in the United States leads to higher growth in the stock of knowledge in the rest of the world. Thus, it seems that countries that are farther away in technological terms benefit to a greater extend from shifts in the level of technology at the frontier. In addition, a distinct feature between both groups emerges regarding the importance of domestic research effort. Thus, it seems that for countries closer to the frontier, domestic research effort matters while we have not found any significant effect of this variable for economies considered to be less technologically advanced. This finding suggests that less advanced countries in research terms can benefit from technological advances at the frontier. Likewise, greater distance from the technology leader fosters the advance of domestic total factor productivity, showing that technologically dependent countries can take advance of their relative technological backwardness by adopting advances from abroad. We have also found that the leader's level of technical progress in technology matters for both groups of countries. Thus according to Fare et al. (1994) it seems that the 'United States consistently shifts the frontier over the entire sample period'.

These results shed light on this business phenomenon (brokering knowledge) from an institutional context that has not been analysed by others researchers from this perspective before and also indicates the possibility that more consistent theory can be built upon this empirical base. Furthermore, the technology gap with the leader appears as the main contributor to the evolution of the stock of ideas for both sets of countries in our work. This result is in line with the findings of Dowrick and Nguyen (1989) who point out that 'TFP catching up has been a dominant and stable feature of the pattern of growth in the OECD since 1950'. This clearly shows that technologically dependent countries (in our work all but the United States) benefit from their relative backwardness, and suggests extending the analysis to allow for differences in the speed at which the economies converge at the frontier. Implementation of this idea will require the introduction of the determinants or different channels through which the diffusion of knowledge takes place at world level, that is, a mechanism through which technologically dependent countries in particular can take advantage of technological advances generated abroad. Among the many ways of capturing technology spillovers, the literature proposes beginning with the more obvious, for instance imports of goods or direct international investment in different economies.

Moreover, the existence of significant individual effects in the estimation suggests that some specific characteristics of the countries considered, not taken into account in the proposed model, explain the different performances of these economies in terms of total factor productivity growth over the study period. In the light of this fact, the model can be improved by identifying and subsequently introducing these differential features that determine the adoption of technologies, such as institutional setups, geographic situation, etc. It may be true that this work significantly improves the results previously obtained with this model, but it also certainly suffers from some limitations that we have to address.

The research presented in this paper has implications for scholars and business practitioners. Firstly, we believe that this study contributes to the academic literature on entrepreneurial culture and total factor productivity by examining technical progress which has rarely been analyzed in this context. Our work provides empirical evidence that changes in efficiency are the main component in the evolution of the stock of knowledge in technologically dependent economies and this growth in knowledge can be affected by an entrepreneurial culture. Secondly, we believe that the main managerial implication concerns the different patterns of productivity growth in world technology leaders and countries with low initial levels of productivity, which present many opportunities but also threats for managers, depending on the country they are in. Our results suggest that managers in less advanced economies can benefit from their countries' relative backwardness. Domestic research effort also appears to be a relevant factor for technology leaders, justified at a theoretical level by the principles of the economic growth model.

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Table 1. Ideas Function Estimates, Pooled Regression

Dependent variable: *total factor productivity growth*

	1965-2010	
	(1)	**(2)**
ln *researcher*	0.0030**	-0.0002**
	(0.0009)	(0.0001)
catch-up	-0.2073***	-0.1998***
	(0.0114)	(0.0020)
catch-up (-1)	0.1932***	0.1989***
	(0.0088)	(0.0020)
$\ln tfp_{ust}$	0.1041***	0.1113***
	(0.0081)	(0.0017)
yr1985	0.0140***	0.0146***
	(0.0010)	(0.0003)
yr2005	-0.0158***	-0.0172***
	(0.0009)	(0.0001)
yr2010	-0.0302***	-0.0308***
	(0.0009)	(0.0001)
constant	0.3246***	0.3064***
	(0.0290)	(0.0053)
No. of observations	43	141
R- squared	0.96	0.98

Clustered standard errors in parenthesis.
*** Indicates statistical significance at the 1% level.
** Indicates statistical significance at the 5% level.
* Indicates statistical significance at the 10% level.

Table 2. Ideas Function Estimates, Fixed-Effects Model

Dependent variable: *total factor productivity growth*

	1965-2010	
	(1)	**(2)**
ln *researcher*	0.0072***	0.0007
	(0.0008)	(0.0009)
catch-up	-0.2173***	-0.2026***
	(0.0117)	(0.0022)
catch-up (-1)	0.2004***	0.1958***
	(0.0076)	(0.0028)
ln tfp_{ust}	0.0992***	0.1079***
	(0.0107)	(0.0028)
yr1985	0.0145***	0.0142***
	(0.0010)	(0.0004)
yr2005	-0.0160***	-0.0172***
	(0.0018)	(0.0002)
yr2010	-0.0318***	-0.0313***
	(0.0015)	(0.0005)
constant	0.3767***	0.3051***
	(0.0243)	(0.0074)
No. of observations	43	141
R- squared	0.94	0.97

Clustered standard errors in parenthesis. Standard errors for fixed-effect model clustered by country.
*** Indicates statistical significance at the 1% level.
** Indicates statistical significance at the 5% level.
* Indicates statistical significance at the 10% level.

Table 3. Ideas Function Estimates, Random-Effects Model

Dependent variable: *total factor productivity growth*

	1965-2010	
	(1)	**(2)**
ln *researcher*	0.0030***	-0.0002***
	(0.0009)	(0.0001)
catch-up	-0.2073***	-0.1998***
	(0.0114)	(0.0020)
catch-up (-1)	0.1932***	0.1989***
	(0.0088)	(0.0020)
$\ln tfp_{ust}$	0.1041***	0.1113***
	(0.0081)	(0.0017)
yr1985	0.0140***	0.0146***
	(0.0010)	(0.0003)
yr2005	-0.0158***	-0.0172***
	(0.0009)	(0.0001)
yr2010	-0.0302***	-0.0308***
	(0.0009)	(0.0001)
constant	0.3246***	0.3064***
	(0.0290)	(0.0053)
No. of observations	43	141
R- squared	0.96	0.98

Clustered standard errors in parenthesis. Standard errors for fixed-effect model clustered by country.

*** Indicates statistical significance at the 1% level.

** Indicates statistical significance at the 5% level.

* Indicates statistical significance at the 10% level.

Appendix A: Data Sources

The dataset have been constructed using different sources of international data, to form a group of twenty-seven OECD countries over the period 1965 to 2010 with observations every five years. Nevertheless, data for some countries is scarce and does not cover the whole period; therefore the panel built is not balanced.

The group of countries considered in this work sorted by alphabetical order is: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the USA (considered the technology frontier).

- *Gross Domestic Product*. Data on real GDP per capita in Laspeyres 2010 international dollars (RGDPL) are taken from PWT 7.1. Center for International Comparisons at the University of Pennsylvania (CICUP), June 2011, available on the web at http://pwt.econ.upenn.edu/. We convert this variable into real GDP in Laspeyres 2010 international dollars by means of the population variable offered by the same source.
- *Human Capital*. The data for the average years of total schooling of the population aged 25 or over come from Barro and Lee (2010). The data appendix is available at http://www.barrolee.com/data/dataexp.htm.
- *Scientists and Engineers Engaged in R&D*. The data from 1965 to 1980 are from the National Science Board (1993, 2000). For years after 1980 the source is the OECD. National Science Board is available online at http://www.nsf.gov/statistics/.
- *Total Employment*. Workforce data is calculated from PWT 7.1. We use the value of the real GDP per worker in chained 2010 international dollars (RGDPWOK) to work out the number of workers implicitly defined in it. As stated in the PWT documentation: 'Worker for this variable is usually a census definition based on the economically active population. The underlying data are from the International Labour Organization'.
- *Physical Capital*. Fixed capital stock was calculated using the perpetual inventory method, employing the data for investment at 2010 international dollars calculated from the investment share of RGDPL offered by PWT 7.1. The initial value of the stock of physical capital for 1960 was calculated

following the approach of Harberger and Wisecarver (1977). We use for the growth rate of the real GDP and investment, the mean for the period 1959-1961, and the result was adopted as the initial capital of the intermediate year. The depreciation rate used was 4 per cent.

- *Investment*. Gross Capital Investment at 2010 international prices was calculated from PWT 7.1. The values were calculated using the investment share of RGDPL multiplied by the corresponding real GDP in absolute terms.

NOTES

[i]See for example; Hall and Jones (1999) or Easterly and Levine (2001).

[ii]In this respect we have followed Fare et al. (1994) who noted that: United States is the only country determining the frontier in the constant returns to scale version of technology.

[iii] The exponential form in (4) is consistent with the literature on schooling and wages, following the original work of Mincer (1974). Note that h_t is not a measure of years of schooling, but of the impact of these over wages or output per worker.

[iv]In fact, Jones at this stage, to provide an empirical counterpart of H_A, takes two simplifying assumptions. First, he assumes that only researchers in the G-5 countries (United States, Japan, Germany, United Kingdom, and France) are able to expand the frontier of knowledge. Second, the human capital embodied by the researchers across these countries is assumed to be the same, and constant over time ($\theta = 0$).

[v] Actually, since none of the exponents of the ideas function are known, there is no possibility of estimating A without Solow's residual.

[vi]See for example Mankiw et al.., 1992.

[vii]We offer a wider range of values for this parameter in Section 5.

[viii]In Section 5 we treat in greater detail the different characteristics and implications of Romer's and Jones' approaches.

[ix] For a more detailed explanation see the appendix in De la Fuente (2002).

[x] As a robustness check for our results, we have replicated the same statistical estimation but considering the UK economy as the technological leader. The results are in line with those presented here and available upon request.

[xi] Follow the discussion about the expected sign for the technological catch-up term in the next section.

[xii] See Greene (2011).

[xiii]It is worth noticing that we have run two separate estimations for technological leaders (i.e. Japan, United Kingdom, Germany, France and Italy) and for the rest of countries with low initial levels of total factor productivity to assess the existence of behavioural differences between them.

[xiv]Ashenfelter et al. (1999).

[xv]See Table V.2.

[xvi]Notice that in Myro et al. (2008) specification the discussion refers to the term $1 + \phi$.

[xvii] The same evidence discards values $\phi > 1$, which would generate increasing growth rates, even with a constant population (Jones, 2002).

[xviii] $\frac{\dot{A}}{A} = \delta \frac{H_A^{\lambda}}{A^{1-\phi}} = \delta L_A$. In this case $\dot{A} = \delta L_A A$; research productivity is proportional to the existing amount of ideas.