ECONOMIC DISCUSSION PAPERS

Efficiency Series Paper 2/2011

Productivity growth and its determinants in the Spanish provinces: Do within-regions differences matter?

María Pérez Urdiales, Luis Orea

Departamento de Economía

Universidad de Oviedo

PRODUCTIVITY GROWTH IN THE SPANISH PROVINCES: DO WITHIN-REGION DIFFERENCES MATTER? *

María Pérez-Urdiales

Oviedo Efficiency Group
Department of Economics, University of Oviedo

Luis Orea

Oviedo Efficiency Group
Department of Economics, University of Oviedo

March 15, 2011

Abstract

We analyze in this paper the productivity growth of the Spanish provinces and its determinants during the period 1986-2006 in order to ascertain whether the heterogeneity in total factor productivity between regions is, as expected, higher than between provinces belonging to the same region. If this is the case, results from previous studies that used regional data can be applied to provinces without losing generality, and multi-province regions can be used as proper references for one-province regions. Our analysis suggests, however, that previous studies that used regional variables may well be subject to specification errors. Moreover, our results suggests that, in order to understand better the productivity growth patterns in Spain, data at province level should be used, and, since this disaggregation is not available for all relevant variables, the private and public institutions that elaborate the traditional regional variables for the Spanish economy should make an effort in the future in order to disaggregate the actual regional variables into variables measured at the province level.

JEL: D24, O47, R11.

Keywords: productivity growth, within-region inequalities, R&D, human capital

---

* Funding: Ministery of Education of Spain (MEC-07-SEJ2007-66979). The authors would like to acknowledge the II Workshop in honour of Geoffrey J.D. Hewings attendees, seminar participants at the Department of Economics of the University of Oviedo and Carlos L. Aparicio-Roqueiro, the Regional Ministry of Economy and Treasury in Asturias, for their helpful comments and suggestions.

1. Introduction

One of the subjects most discussed by economic literature is the analysis of productivity growth and its determinants. The point of departure is Robert Solow’s seminal paper in 1957, in which technical change is measured residually as the growth in outputs not explained by the growth in inputs, under the assumptions of constant returns to scale, perfect competition and full utilization of the inputs. Since then, a vast empirical literature has used the growth accounting approach to analyze changes in productivity and the methodology was extended and applied in large scale empirical studies. An excellent survey of the theory and methods of the measurement of aggregate productivity, as characterized by total factor productivity (TFP), can be found in Diewert and Nakamura (2007).For instance, Denny *et al.* (1981) were the first to disaggregate the Solow residual into terms such as non-constant returns to scale, imperfect competition, and technical change. Other papers controlled later on for other productivity determinants, such us adjustment costs, input utilization, or the existence of external effects.

Since the 70’s, many studies have focused on the evolution of Spain and its regions, especially since IVIE started to construct series of stock of private and public capital, using different methodologies and time periods. The first studies that analyzed the determinants of productivity in the Spanish Regions were Mas *et al.* (1993, 1994 and 1996). Later on, diverse techniques have been used for the calculation of productivity growth. For instance, Maudos, Pastor and Serrano (1998) calculated TFP using Malmquist indexes and studied convergence among Spanish regions. Álvarez (2005) used a stochastic frontier production function for decomposing Spanish regions productivity during the period 1980-1995, and Rodríguez-Vález *et al.* (2009) used the Maximum Entropy method in order to analyze regional production. Other recent papers have examined using data on the Spanish regions or industries the productivity impact of human capital and Innovations (i.e. R&D expenditure), which have been traditionally considered as critical economic growth determinants. For instance, regarding Human Capital, Serrano (1999) studied the effect of Human Capital as an input and as a determinant of TFP. De la Fuente and Domenech (2006) estimated the contribution of schooling to productivity in the Spanish Regions. As for R&D, Huergo and Moreno

(2004) studied the effect of process innovation on TFP. Gumbau Maudos (2006) quantified the effect of the region's own innovation but also innovation spillovers on TFP. López-Bazo *et al.* (2002) discussed the complementarity between Human Capital and Trade and its impact in terms of productivity growth in the Spanish Regions. Moreover, empirical evidence at aggregate level confirms the existence of complementarity between Human Capital and new information technologies and its effect on productivity growth. For instance, De la Fuente and Da Rocha (1996) estimated an extension to Mankiw, Romer and Weil model (1992) in order to analyze the determinants of economic growth for the OCDE countries. The results showed the existence of complementarity between Human Capital and R&D investment.

It is worthy to note that all the papers mentioned previously are regional level studies whilst, the number of studies that analyse productivity at provincial level is certainly small. Among them, Tortosa-Ausina *et al.* (2005) studied the evolution of provincial disparities in terms of productivity growth in order to test the existence of a convergence process, and Greene, Orea and Wall (2010) calculated Total Factor Productivity growth at provincial level using a Fixed Effect Vector Decomposition to illustrate the advantages of this technique However, as far as we are aware, there have been no studies as yet to productivity growth determinants at provincial level.

One of the contributions of this study will be the measurement and decomposition of Total Factor Productivity growth using provincial data. The advantage is not only having more degrees of freedom, but also allowing calculating within-region and between-region deviations in order to analyse differences in terms of TFP. Intuitively, heterogeneity between regions can be expected to be higher, according to similar within-region geo-structural, climatic and socio-economic characteristics. If this is the case, results from previous studies that used regional variables can be applied to provinces without losing generality, and multi-province regions can be used as proper references for one-province regions because they are homogeneous enough. However, higher heterogeneity within regions might be possible in the event of competition within the regions, where particular provinces are able to attract most valued added against other provinces belonging to the same region. The present paper tries to shed light on this issue by explicitly measuring the relative importance of both within and between-region heterogeneity in total factor productivity growth. Our analysis suggests that aggregate measure of the variables fail to provide a proper representation of productivity growth and, therefore, previous studies that used regional variables may well be subject to specification errors. Moreover, our results suggests that, in order to understand better the productivity growth patterns in Spain, data at province level should be used. And, since this disaggregation is not available for all relevant variables, the private and public institutions that elaborate the traditional regional variables for the Spanish economy should make an effort in the future in order to disaggregate the actual regional variables into variables measured at the province level.

The rest of the paper is structured as follows. Based on the growth accounting literature, Section 2 presents the theoretical background and the underlying specifications of the empirical models that are estimated later on. Section 3 describes the data. Section 4 presents the computed productivity growth rates, the parameter estimates and our results. Section 5 concludes.

2. Theoretical background and empirical specification of the model

2.1. Total Factor Productivity measurement

In this paper we apply the growth accounting framework developed by Solow (1957) to measure productivity gains where Total Factor Productivity (hereafter, TFP) is calculated as a residual, i.e. as the difference between the output growth rate and the rate of growth of the inputs involved in the production process (see, also, Jorgenson and Griliches, 1967). In order to measure the contribution of each input to output growth, Solow (1957) imposed the assumptions of constant returns to scale, perfect competition and full utilization of inputs. In this case, the TFP rate of growth can be written as:

$$T\dot{F}P = \dot{y} - \sum_{k=1}^{K} S_k \dot{x}_k \qquad (1)$$

where y is the output, $x=(x_1,...,x_K)$ is the set of inputs, S_k is the share of the k^{th} input in total cost, and a dot over a variable indicates rate of growth. Solow (1957) attributed the computed productivity growth rates to technical change. The productivity (technological) gains computed using equation (1) is traditionally labeled as Solow Residual. As only discrete data is available, in practice a discrete approximation of (1) must be used in order to compute the Solow Residual. As it is customary, the approximation is provided by the Tornqvist Index. In accordance to this index, the productivity growth rate is measured as follows:

$$lnTFP_t - lnTFP_{t-1} = (lny_t - lny_{t-1}) - \sum_{k=1}^{K} 0.5\left(S_{k,t} + S_{k,t-1}\right)\left(lnx_{k,t} - lnx_{k,t-1}\right) \tag{2}$$

2.2. Total Factor Productivity decomposition

Due to data limitations, we will compute the above productivity measures using two aggregated inputs: labour and private capital. As we just consider two inputs, the productivity growth measured as it is customary with the Solow residual cannot longer be interpret as pure technical gains if other inputs, such as public capital, are also relevant inputs of the underlying production function. Following Solow (1957) and Ashauer (1989), the production function can be written in this case as:

$$y = f(x, z, t) \tag{3}$$

where *x* is the set of inputs included in the Solow residual, *z* stands for public capital or other inputs not included in the Solow residual, and *t* is a time trend capturing shifts of the production function over time, i.e. technical change.[1] If we differentiate (3) with respect *t*, we can get the following TFP decomposition after same straightforward manipulations:

$$T\dot{F}P = \dot{y} - \dot{x} = (\varepsilon - 1)\dot{x} + \gamma\dot{z} + \varepsilon_t \tag{4}$$

where ε is the (sum of) output elasticity (elasticities) with respect the *x* inputs, γ is the output elasticity with respect inputs (factors) that have not been taken into account when we first calculated the Solow Residual, and ε_t measures the contribution of technical change to output growth. In accordance with (4), the productivity rate of growth, measured as it is customary by the Solow residual, is a biased measure of technical change (i.e. the “true” productivity growth) because it also captures a scale effect and the effect of other factors not accounted by the Solow residual.

In addition, both labor and private capital are aggregated inputs that might include inputs with different productivity contributions or quality levels, and hence they should have received different weights in the Solow residual. For instance, we expect productive differences between ICT and non ICT capital and between skill and non-skill

---

[1] Hereafter, we will treat *x* as a single input for notational ease.

workers (Hernández and Núñez, 2004; Serrano, 1999). As these different sets of inputs are simply added into a single measure, the weights they implicitly receive in the Solow residual might be wrong. Indeed, assume that x is comprised a mix of high and low-productive capital or labor, i.e. $x=x_1+x_2$. In this case, it is straightforward to show that

$$\dot{x} = \omega_1 \dot{x_1} + \omega_2 \dot{x_2} \tag{5}$$

where $\omega_k=x_k/x$, $k=1,2$. This equation indicates that both high and low-productive inputs are weighted in the Solow residual by their relative importance in the overall composite. The appropriate composite should be constructed taking into account their relative output elasticity that is:

$$\dot{x} = \frac{\varepsilon_1}{\varepsilon} \dot{x_1} + \frac{\varepsilon_2}{\varepsilon} \dot{x_2} \tag{6}$$

where $\varepsilon=\varepsilon_1+\varepsilon_2$. Both input composites (5) and (6) only coincide when the marginal productivity of x_1 and x_2 are of the same magnitude, that might not be the case in a particular application. If this is the case, additional variables should be included as z variables in (4) to control for this problem.

In summary, the above equations, and in particular equation (4), allow us to disentangle technical change (i.e. “true” productivity growth) from other factors associated to scale economies, inputs not included in the Solow residual computation and/or aggregation biases.

2.3. Empirical model

Assume that the stochastic version of the production function (3) can be written as follows:

$$y_{it} = e^{\theta t} f(x_{it}, z_{it}, \beta) e^{\alpha_i + v_{it}} \tag{7}$$

where the subscript i stands for province, v_{it} is the traditional noise term, and α_i captures unobserved differences among provinces that might be correlated with the determinants of the production function $f(\cdot)$. In order to control for this potential endogeneity, we first take natural logs in (6):

$$ln y_{it} = \theta t + ln f(x_{it}, z_{it}, \beta, \gamma) + \alpha_i + v_{it} \tag{8}$$

and, assuming for notational ease that the deterministic production function is a Cobb-Douglas production function, we next take first differences of (7) in order to get the following empirical model:

$$\Delta lny_{it} = \theta + \beta\Delta lnx_{it} + \gamma\Delta lnz_{it} + \Delta v_{it} \tag{9}$$

It is worth mentioning that the first-difference operator allows us to drop the unobserved province effects from the equation and, hence, OLS in (8) is consistent even when the province effects are correlated with the regressors. It is also important to note that θ measures the contribution of technical change to economic growth. Note, in addition, that subtracting Δlnx_{it} from both sides in (9) allows us to write this equation in an alternative, but equivalent, way:

$$\Delta lnTFP_{it} = \theta + (\beta - 1)\Delta lnx_{it} + \gamma\Delta lnz_{it} + \Delta v_{it} \tag{10}$$

where the left-hand side is the output growth not explained by the growth inputs, i.e. a TFP growth measure, and the right hand-side is the empirical counterpart of equation (4) that allows us to control for scale effects, ignored inputs and aggregation issues.[2] The equation (10) is the *basic* specification of the model that is going to be estimated later on. In this specification of the model, the contribution of technical change to economic growth (i.e. θ) is time-invariant and common to all provinces. In order to relax this assumption we extend the basic specification (10) by allowing for both province-specific rates of growth of technical change and technical change determinants, that is

$$:\Delta lnTFP_{it} = \theta_{it} + (\beta - 1)\Delta lnx_{it} + \gamma\Delta lnz_{it} + \Delta v_{it} \tag{11}$$

where

$$\theta_{it} = \theta_i + \delta h_{it}$$

and h_{it} is a vector of “true” productivity growth that might include human capital (Serrano-Martinez, 1999), R&D expenditure, or the existence of external effects (Caballero and Lyons, 1989).

---

[2] The Solow Residual is the dependent variable in many papers using Data from Spain. See, for instance, Hernando and Vallés (1994), Martín-Marcos and Jaumandreu (2004) and Estrada and López –Salido (2004).

3. Data

In this section, we present the variables that are to be used in the empirical analysis. These correspond to 50 provinces of Spain during the period 1986-2006 and are expressed in Euros of 2000.

In a first stage we measure TFP growth using equation (2). To implement this equation we consider Gross Value Added (GVA) as the output and this data is obtained from the National Statistics Institute. The inputs used are Labour and Private Capital. Labour (L) is defined as thousands of people employed and it is obtained from IVIE and Bancaja foundation. Private capital (K)[3] comes from IVIE and BBVA foundation. The inputs are weighted by their shares in total production (S_L,S_K) which come from the National Statistics Institute. In this stage, we do not disaggregate both labor and private capital inputs into several types of labor and capital because we do not have weights at these levels.

In a second stage we decompose the above TFP growth rates into several factors using equation (11). To achieve this aim, we disaggregate Private capital into ICT capital (KICT) and non-ICT capital (KnICT), and we include the ratio between ICT capital and total private capital as an adjustment variable or *z* variable in equation (11). Following Ashauer (1989), public capital (Kpub) is included as explanatory variable in equation (11). This variable also comes from IVIE and BBVA foundation. As determinants variables of “pure” productivity growth, i.e. as h variables, we consider Human Capital and R&D expenditure. Human Capital (HC) is measured by average years of schooling, and it is obtained from IVIE and Bancaja Foundation. Research and Development expenditure (R&D), is obtained from BDMores database, and it is defined as the percentage of R&D expenditure over Gross Value Added. All of these variables are expressed at provincial level, except for the R&D expenditure which is expressed at regional level. Some descriptive statistics are provided in Table 1.

---

[3] In this paper, TFP is calculated using labor and private capital as inputs, following Álvarez (2003). However, a vast empirical literature considers that other inputs must be considered when calculating TFP growth. For instance, De la Fuente and Monasterio (2001) included Public Capital as an input in order to calculate TFP. Since we do not have proper weights for public capital, we have followed a different approach computing our TFP measure without using this input. It is, however, included as a key determinant in the second stage of our procedure.

[Insert Table 1 here]

4. TFP results

In this section we first present the productivity growth rates computed using equation (2), and using GVA as output, and labour and private capital as inputs. The estimation covers the period 1986-2006. The average annual productivity growth rates are shown by regions in Table 2. The rate of growth of valued added, labor and capital are also shown in this table. Rates below the national average are highlighted.

The rate of growth of TFP, valued added, labor and capital shown in Table 2 are comparable with those obtained in previous studies using data of the Spanish regions (see, for instance, BBVA Foundation (2008)). On average, for the whole period, the productivity level in Spain does not change a lot. Moreover, the TFP growth is slightly negative (-0.09%) due to the GVA growth (3.07%) has been less than the average growth of labor and capital (4.54% and 2.37%, respectively).

Regarding the TFP patterns at regional levels, Extremadura and Galicia enjoyed the highest rates of productivity growth, which are 1.48% and 1.28% respectively. It is worthy to note that the abovementioned regions also registered the highest increase in Labour productivity (not shown in Table 2). This situation is not caused by a fast GVA increased, but a slow Labour growth. In the opposite side, Baleares (-1.87%) and Murcia (-1.83%) had the lowest TFP growth rates. The GVA growth rate in these regions was even higher than the average GVA growth in Spain. However, the large increase in GVA had been offset by the high increase of Labour and Capital in those regions. General speaking, the data in Table 2 indicates that TFP is smaller in those regions where labor and capital growth is higher, which is consistent with the existence of non-constant returns to scale in labor and private capital .

[Insert Table 2 here]

Next we try to examine the main issue studied in the present paper, that is, we analyze the relative importance of both within and between-region heterogeneity in total factor productivity growth. For this purpose, we adapt the approach introduced by Plumper and Troeger (2007) and Greene, Orea and Wall (2010). To measure the within-region heterogeneity we compute the standard deviation of the rate of TFP growth of each province with respect to their own regions.[4] This standard deviation is labeled hereafter as within-region standard deviation. To measure the between-region heterogeneity we compute the standard deviation of the rate of TFP growth of each region with respect to the regional TFP growth average. This standard deviation is labeled hereafter as between-region standard deviation. We have chosen this approach to measure regional and provincial heterogeneity because it is very straightforward and it can be computed even with negative growth rates[5].

Table 3 shows the averages of within and between-region standard deviations in terms of Total Factor Productivity. As mentioned in the introduction section, heterogeneity within a region is likely to be lower, according to similar geo-structural, climatic and socio-economic characteristics, thus intra-regional disparities in terms of TFP should be small. However, for this period, the ratio of the within to between deviation in Table 3 is greater than unity. In contrast to the general intuition, this result indicates indicate that the heterogeneity in total factor productivity growth among provinces belonging to the same region is much larger than the traditional heterogeneity among regions. Therefore, our results confirm the existence of a large heterogeneity within regions and the need of provincial-level data in order to provide a proper measure of TFP growth.

[Insert Table 3 here]

The evolution of the overall, between-region and within-region standard deviations is presented in Figure 1.[6] The overall standard deviation exhibited several peaks and troughs along the period 1987-2006. It is also worthy to note the similar temporal patterns that can be observed when comparing the overall and the within-region standard deviation. This behavior suggests that regional variables fail to provide a

---

[4] Regional TFP growth rates are weighted by the province participation in regional GVA.

[5] In principle, regional and provincial heterogeneity can be also analyzed using, for instance, a one-stage Theil decomposition method which distinguishes the within-region component and the between region component. However, the Theil index cannot be applied with negative values, or it is difficult to interpret when negative values are involved in its computation.

[6] It should be noted that overall deviation cannot be additively decomposed into the sum of between-region and within-region deviation. We have just included the overall deviation in Figure 1 as a benchmark that summarizes the overall heterogeneity in total factor productivity growth in Spain.

proper representation of productivity growth and, therefore, data at province level should be used in order to better understand the productivity growth patterns in Spain. On the other hand, the contribution of both between-region and within-region deviations to the overall heterogeneity have been quite different in particular years. For instance, in 1988, between-region standard deviation became a littlerose, while within-region standard deviation became quitedecreased, variations that led to the greater overall regional deviation. On the contrary, the increase of the within-region standard deviation in 1994 contributed most to the rise of the overall standard deviation, as between-region standard deviation exhibited a decrease.

[Insert Figure 1 here]

5. Total Factor Productivity adjustments

Once Total Factor Productivity is calculated using the Solow Residual, it can be decomposed into several components using the empirical model (11) described in Section 2.2. In this model, the Solow Residual is taken as the dependent variable and is regressed on various factors representing TFP adjustments and determinants. To examine the robustness of our results, we have estimated several specification of the model. First we use equation (11) to control for factors associated to the constant scale economies assumption used in equation (2), inputs not included in the Solow residual computation and/or aggregation biases.[7] The productivity growth not explained by the above factors can be labeled as the “true” productivity growth, i.e. genuine technical change. Later on we will try to identify some determinants of the true productivity growth by adding additional variables to the model. In accordance with (11) all models

---

[7] When TFP growth was first calculated, we assumed full utilization rates of both private capital and labor. However, private capital and labor might be considered as quasi-fixed inputs. In this case, the underlying production function depends on the quantities of these inputs *and* the intensity with which they are used. In order to correct for these issues, we introduced other explanatory variables in (11) such as capacity utilization factor, and intermediate inputs, or hours to employment ratio. Since these variables were not statistically significant and other coefficients were robust to the inclusion of capacity utilization factor and intermediate inputs, we do not present these models.

have been estimated using the Fixed Effect estimator where the individual effects can be interpreted as province-specific technical change indices.[8]

It is worthy to note in this moment that using an empirical model where both dependent and most explanatory variables are in first differences allows us to control for unobserved heterogeneity in the production function, but the information that is taken into account to estimate the selected coefficients is just the variation over time of each variable. Since the cross-section information is not used, and most variables are quite persistent or follow common patterns over time, the number of explanatory variables with significant coefficients will be quite limited. This precludes using a large set of explanatory variables in all specifications of equation (11).

Table 4 presents the parameter estimates of the first set of models. Generally speaking, the results obtained are consistent with the empirical evidence. In Model 1, we examine the existence of constant returns to scale in labor and private capital. As expected, the coefficient of the average growth rate of both inputs, *dlnX*, is negative and statistically significant, indicating that constant returns to scale cannot be achieved using only labor and private capital. In other words, the Solow residual tend to underestimate the real technical change if labor and private capital growth increases. If this is the case, it might also register negative values which can hardly be interpreted from an economic point of view.

Next, we estimate Model 2 in order to measure the impact of public capital on productivity growth. When we first calculated TFP growth, private capital and labour were taken as the inputs. However, since Ashauer (1989) a vast empirical literature has attempted to quantify the effect of public capital on TFP as this variable can be considered as an additional input.[9] In our model, this variable is defined as the ratio of public capital to private capital. The coefficient of this ratio is significant and positive, which is consistent with the empirical evidence using regional data, i.e. public capital contributes significantly to productivity growth (De la Fuente, 2008).

---

[8] We have also carried out the estimates using the Random Effect estimator, and the results where quite similar. Given our sample is not a random draw, but the whole population of provinces in Spain, the FE results are presented.

[9] See Straub (2008) and De la Fuente (2010) for two reviews of the empirical literature on Public Capital and Productivity.

In Model 3, the role of ICT capital in productivity growth is analyzed. Information and communication technologies have developed intensively in the past years; therefore, there is a growing interest in studying its contribution to technical change.[10] We include a new variable in order to prove if ICT capital and non ICT capital have the same impact on TFP and it is defined as the ratio of ICT capital to total private capital. This variable has a significant and positive impact on TFP, therefore, we can conclude that productivity growth is higher when ICT Capital increases at the expense of non ICT capital. These results are in line with those found in previous literature (see, for example, Mas and Quesada, 2005).

[Insert Table 4 here]

We can get an "adjusted" productivity growth rate[11] using Model 3 in Table 4 as the productivity growth not explained by the above factors. This adjusted rate can be interpreted as a genuine technical change index. These indexes are shown in Figure 2. Two comments are in order. First, both observed and adjusted TFP growth rates are positively correlated, but, in some cases, there is a large difference between the observed TFP growth and its adjusted counterpart. This outcome suggests that observed TFP growth should be interpreted with caution due to the assumption of constant scale economies fail, some inputs are not included in the computation of the Solow residual and aggregation biases. And second, now, the adjusted productivity growth is positive for every province, which is consistent with the economic theory. This makes our preferred model, i.e. Model 3 in Table 4, a proper starting point to examine closely the determinants of technical change.

[Insert Figure 2 here]

---

[10] First studies of the impact of ICT capital on TFP were Oliner *et al* (1994) and Jorgenson and Stiroh (1995, 1999). In Spain, Hernando and Nuñez (2004) quantified a positive impact of ICT Capital on productivity growth.

[11] Like in the previous section, the relative importance of between and within-region heterogeneity in the adjusted productivity growth rate was also analyzed and the result confirms that the within-region heterogeneity in total factor productivity growth is much larger than the between-region heterogeneity.

6. Technical Change determinants

In this section we extend the model estimated in Table 4 by adding classical determinants of technical change, such as human capital and R&D expenditure. Our aim is to examine the effect on TFP of these variables when using province-level data, instead of regional-level data as it is customary in the literature. Since our aim is to analyze technical change determinants, i.e. θ_{it} in equation (11), these variables are included in the model in levels or in logs, and not in first differences like the previous TFP adjustments. Table 5 shows the results of the extended models.

[Insert Table 5 here]

In Model 4 we add R&D expenditure, which is defined as the logarithm of the ratio of R&D expenditure to Gross Value Added and it is lagged one period to avoid simultaneity biases. Before showing the results, two comments are in order. First, this variable is only available at the regional level. Second, this variable is no available for the whole period, i.e. 1987-2006, and hence only 900 observations are used in Model 4 and next models where R&D expenditure is included as an explanatory variable. Since Griliches (1979), many studies have quantified the impact of R&D investment on productivity growth, especially using Spanish firm-level data (Martín-Marcos and Jaumandreu, 2004; Gumbau-Albert and Maudos, 2002). It is expected R&D expenditure to have a positive impact on productivity. However, the coefficient of this variable in Model 4 is not statistically significant, indicating than, on average, R&D expenditure had not contributed to technical gains during the period 1987-2006.

In Model 5 we add to Model 3 a human capital index as a determinant of technical change. This variable is defined as the average years of schooling and it is entered in levels in order to assess the effect on technical change. Numerous papers provide empirical evidence of a positive effect of educational attainment on productivity growth because it promotes innovation (Pedraja et al, 2002; De la Fuente and Domenech, 2010)[12]. In this model, the coefficient of human capital is significant but negative, which is not consistent with the theory. This unexpected sign might suggest the

---

[12] See De la Fuente (2011) for a broad survey of the empirical literature on Human Capital and Productivity.

existence of an over qualification process, because during this period human capital had a great increased while TFP has been more steady

In Model 6 we add the interaction of human capital and R&D expenditure. Our approach is founded on Nelson and Phelps (1966), who include human capital levels interacted with a technology lag factor. In our model, the interacted variable has a significant and positive effect on TFP. As shown by Model 7, this positive effect is robust to the inclusion of R&D expenditure as a determinant of technical change. Human capital by itself seems to have a negative effect; however, if interacted with R&D expenditure, they seem to reinforce the effect of R&D expenditure. This result is consistent with Nelson and Phelps view of Human Capital. In their own words "educated people make good innovators, so that education speeds the process of technological diffusion".

It is still uncertain using Model 7 whether R&D expenditure, on average, had a positive contribution on technical change. To address this issue we slightly modify the previous model by rewriting human capital as deviation with respect to the sample mean before it is interacted with R&D expenditure. In this case the coefficient of R&D expenditure can be interpreted as the average effect of R&D on technical change. By construction the estimated coefficients are the same as in the previous model, except for the coefficient of R&D expenditure. Since this coefficient (0,2781) is positive and statistically significant in Model 8 we can state R&D expenditure had on average a positive effect on technological improvements.

As mentioned in section 3, all the variables used in our study are expressed at provincial level, except R&D expenditure which unfortunately, the available statistical information is expressed at regional level. In order to analyze the effect of provincial-level innovations on TFP growth, we have provincialized R&D expenditure. To achieve this objective we propose using a two-stage method based on a "complementary" equation that is estimated using data at regional level only, but all explanatory variables in this equation are available at provincial level. Following Guan *et al* (2009), this equation can be obtained from a production function once we have solved out for the R&D expenditure. For instance, if we assume that the underlying production function can be written as:

$$y_{it} = e^{(\theta+\delta h_{it})t} f(x_{it}, z_{it}, \beta) \tag{12}$$

where h_{it} is R&D expenditure. After some algebraic manipulations, h_{it} can be written in as:

$$h_{it} = h_{it}(y_{it}, x_{it}, z_{it}, t, \Theta) = [ln y_{it} - ln f(x_{it}, z_{it}, \beta)]/\delta t - \theta \tag{13}$$

where Θ is a vector of parameters to be estimated. In order to estimate (13), we have used Cobb-Doublas and Translog specifications of $lnf(\cdot)$. The parameter estimates of both complementary regressions are shown in the Appendix. General speaking, the estimated coefficients are reasonable. For instance, accordingly to equation (13), R&D expenditure in the CD specification is, as expected, increasing in outputs (valued added) and decreasing in inputs (labor and capital). Once Θ is estimated with regional data, we can applied the parameters to provincial data to construct R&D expenditure at provincial level. In order to examine the accurateness of our measure we have computed regional R&D expenditures from the estimated provincial levels, and the coefficient of correlation between this regional measure and the original one is about 60%.[13] Since the correlation at regional level is large we expect that the provincial levels are good enough. is correlation is large we expect correlation quite high, In the second stage, once the new variable is created, we re-estimate Model 7 but replacing R&D expenditure at regional level with the variable estimated at provincial level.

[Insert Table 6 here]

As can see in Table 6, the result reveals that by using the constructed variable in the analysis, the coefficient of R&D expenditure becomes smaller compared to that reported in Model 6, however, it remains statistically significant. Similar comments deserve the interaction of human capital and R&D expenditure which has a significant and positive coefficient, but also smaller to the coefficient in Model 7. This result corroborates that innovation has a positive effect on TFP growth if interacted with human capital.

---

[13] See Appendix where we have also plotted both variables. The figure in the Appendix also suggests an strong and positive correlation between the original and estimated R&D expenditure.

7. Conclusions

In this paper we have calculated the Solow residual in the Spanish provinces for the period 1986-2006 and we have found that within-region heterogeneity in terms of TFP is larger than between-region heterogeneity. This result suggests that data at province level should be used in order to provide a proper measure of Total Factor Productivity and, therefore, we encourage private and public institutions to disaggregate the actual regional variables that are not available at province level.

Next, we have adjusted the original Solow residual in order to correct for the bias associated to control for factors associated to the constant scale economies assumption, inputs not included in the Solow residual computation and aggregation biases. The relative importance of between and within-region heterogeneity in the adjusted productivity growth rate was also analyzed and the result confirmed that the within-region heterogeneity in total factor productivity growth is much larger than the between-region heterogeneity.

The effect of human capital and R&D expenditure on TFP growth has also been analyzed and the results of this study show that both variables have not a significant effect on Spanish provinces' TFP, however the interaction of these determinants have a positive and significant effect on productivity growth, that is, innovations require a skilled labor force to contribute to TFP growth. Finally, as a robustness analysis, R&D expenditure was provincialized by using a complementary equation, as this variable was not available at province level, and the result show that the interaction of human capital and the estimated value of R&D expenditure has a significant and positive influence on Spanish provinces' TFP. Therefore, we can corroborate the importance of the existing complementarity between these two determinants.

References

Álvarez, A., Arias, C. and Orea, L. (2003), “A note on the measurement of spatial productivity spillovers from public infraestructura”, *VI Encuentro de Economía Aplicada, Granada.*

Álvarez, A. (2005)” Decomposing Regional Productivity Growth using an Aggregate Production Frontier”, *Economic Discussion Paper, Efficiency Series Paper 02/2005, Departamento de Economía, Universidad de Oviedo.*

Aschauer, D. (1989). "Back of the G-7 pack: public investment and productivity growth in the Group of Seven", *Working Paper Series, Macroeconomic Issues 89-13, Federal Reserve Bank of Chicago.*

Caballero, R. J. and Lyons R. K. (1990): "Internal versus external economies in European Industry", *European Economic Review* 34, 805-830.

De la Fuente, A. (2011) “Human Capital and Productivity”, *BBVA Research Working Papers* 11(3).

De la Fuente, A. (2010) “Infrastructures and productivity: an updated survey”, *Working Papers from BBVA Bank, Economic Research Department* 1018.

De la Fuente (2008).”Inversión en Infraestructuras, crecimiento y convergencia regional”, *UFAE and IAE Working Papers*. 753, 08.

De la Fuente, A. and Domenech, R. (2006b) “Capital Humano, crecimiento y desigualdad en las regiones españolas”, *Moneda y crédito* 222, 13-56.

De la Fuente, A. and Da Rocha, J.M. (1996) “Capital Humano y crecimiento: un panorama de la evidencia empírica y algunos resultados para la OCDE”, *Moneda y crédito* 203, 43-84.

De la Fuente, A. and Monasterio, C. (2001) “Capitalización y crecimiento de la economía asturiana, 1955-1998” *BBVA Foundation*, 169-228.

Denny, M., Fuss, M., and Waverman L. (1981) “The measurement and interpretation of total factor productivity in regulated industries with an application to Canadian telecommunications”, *Cowing T, Stevenson R (eds) Productivity measurement in regulated industries. Academic, New York.*

Diewert, W.E. and A.O. Nakamura (2007) “The measurement of aggregate total factor productivity growth”, *Handbook of econometrics, J. Heckman and E.Leamer (eds)* 6.

Estrada, A., and López-Salido, D. (2004): “Sectoral and aggregate technology growth in Spain” , *Spanish Economic Review* 6, 3-27.

Greene, W., Orea, L. and Wall, A. (2010) “Stochastic Frontiers using a fixed-effect vector decomposition approach with an application to ICT and regional productivity in Spain” *Efficiency Series Paper* 04 2010.

Griliches, Z. (1979). "Issues in Assessing the Contribution of Research and Development to Productivity Growth*", Bell Journal of Economics, The RAND Corporation* 10(1), 92-116.

Guan, Z., Kumbhakar, S.C., Lansink, A.O. (2007) “Excess capital in Agricultural Production”, *American Agricultural Economics Association* 9813.

Gumbau-Albert, M. and Maudos, J.(2006). "Patents, Technological Inputs And Spillovers Among Regions", *Working Papers. Serie EC 2006-11, Instituto Valenciano de Investigaciones Económicas (Ivie).*

Gumbau-Albert,M., Maudos, J. and Cantos, P.(2002). "Transport Infrastructures and Regional Growth: Evidence of the Spanish Case", *Working Papers. Serie EC 2002-27, Instituto Valenciano de Investigaciones Económicas (Ivie).*

Hernando, I. and Nuñez, S. (2004) "The contribution of ICT to economic activity: a growth accounting exercise with Spanish firm-level data", *Investigaciones Económicas* 28 (2), 315-348.

Hernando, I., and Vallés, J. (1994): "Algunas diferencias en la productividad de las empresas manufactureras españolas", *Investigaciones Económicas* 18(1), 117-141.

Huergo, E. and Moreno, L. (2004) "La innovación y el crecimiento de la productividad en España", *Ekonomiaz* 56(2), 208-231.

Jorgenson, D.W. and Griliches, Z. (1967) "The explanation of Productivity Change", *Review of Economic Studies* 34, 249-280.

Jorgenson, D.W. and Stiroh, K. (2000). "Raising the Speed Limit: U.S. Economic Growth in the Information Age", *Brookings Papers on Economic Activity* 1, 125-211.

"Las Fuentes del crecimiento Económico Regional", *Cuadernos de la Fundación BBVA, Capital y Crecimiento, 2008, nº10.*

López-Bazo, E., Serrano, G. and García-Sanchis, J. R. (2002) "Complementarity between Human Capital and Trade in Regional Technological Progress", *Working Papers in Economics83, Universitat de Barcelona.*

Mankiw, N.G. , Romer, D. and Weil, D.N. (1992) "A contribution to the empirics of Economic Growth", *Quarterly Journal of Economics* 107(2), 407-437.

Martín-Marcos, A., and Jaumandreu, J. (2004): "Entry, exit and productivity growth in Spanish manufacturing during the eighties", *Spanish Economic Review* 6, 211-226.

Mas, M., Maudos, J., Pérez, F. and Uriel, E. (1993): "Competitividad, productividad industrial y dotaciones de capital público", *Papeles de Economía Española* 56, 144-160.

Mas, M., Maudos, J., Pérez, F. and Uriel, E. (1994): "Capital público y productividad en las regiones españolas", *Moneda y Crédito* 198, 163-193.

Mas, M., Maudos, J., Pérez, F. and Uriel, E. (1996): "Infrastructures and Productivity in the Spanish Regions", *Regional Studies* 30, 641-649.

Maudos, J., Pastor, J.M. and Serrano, L., (1998). "- Eficiency and Productivity Specialization: The Spanish Regions", *Working Papers. Serie EC 1998-26, Instituto Valenciano de Investigaciones Económicas (Ivie).*

Mas, M. and Quesada, J. (2005): "Las nuevas tecnologías y el crecimiento económico en España", *Bilbao: Fundación BBVA.*

Nelson, R. and Phelps, E. (1966) “Investment in humans, technological diffusion and economic growth”, *American Economic Review: papers and proceedings* 51(2), 69-75.

Oliner, S.D, Sichel, D.E, Troplet, J.E and Gordon, R.J. (1994) “Computers and output growth revisited. How big is the puzzle?” *Brookings Papers on Economic Activity* 2, 273-317.

Pedraja, F., Salinas, M.M. and Salinas, J. (2002): «Efectos del capital público y del capital humano sobre la productividad de las regiones españolas», *Papeles de Economía Aplicada* 93, 135-147.

Plümper, T. and Troeger, V.E. (2007), "Efficient estimation of time-invariant and rarely changing variables in finite sample panel analyses with unit fixed effects," *Political Analysis* 15, 124-139.

Rodríguez-Vález, J., Álvarez Pinilla, A., Arias Sampedro, C., Fernández-Vázquez, E., (2009) “La contribución de las infraestructuras a la producción: estimación por máxima entropía”, *Revista de Economía Aplicada* 50(16), 77-96.

Serrano-Martínez, L. (1999) “Capital Humano, Estructura Sectorial y crecimiento en las Regiones Españolas”, *Investigaciones Económicas*, 23(2), 225-249.

Solow, R.M. (1957) “Technical change and aggregate production function”, *Review of Economics and Statistics* 39,312-320.

Straub, S. (2008) “Infrastructure and development: a critical appraisal of the macro level literature”, *Policy Research Working Paper* 4590, *World Bank, Washington D.C.*

Tortosa- Ausina, E., Pérez, F., Mas, M., Goerlich, F.J. (2005) “Growth and converge profiles in the Spanish provinces”, *Journal of Regional Science* 45(1), 147-182.

Table 1: Descriptive Statistics

Variable	Mean	Stand. Dev	Minimum	Maximum	Observations
GVA	10.166.000	15.618.300	946.641	123.182.000	1050
L	285.703	378.563	295.244	2.977,09	1050
K	24.981.300	34.900.000	2.734.920	306.755.000	1050
S_L	0,6294	0,0280	0,5414	0,7425	1050
S_K	0,3705	0,0280	0,2574	0,4586	1050
KPUB	18.344.500	24.850.900	2.112.320	213.228.000	1050
KICT	1.159.620	2.214.050	51.385,3	24.576.100	1050
HC	262.993	591.340	104.044	640.913	1050
R&D	138.788	204.477	769.760	1.212.120	900

Table 2. TFP, output and input growth rates. Annual averages by region.

Spanish regions	GVA	K	L	TFP
Andalucía	3.33%	5.52%	3.38%	-0.88%
Aragón	2.86%	4.70%	1.67%	0.15%
Asturias	2.20%	2.05%	1.05%	0.83%
Baleares	3.16%	6.58%	4.11%	-1.87%
Canarias	3.17%	5.61%	4.03%	-1.46%
Cantabria	3.27%	2.83%	2.35%	0.74%
Castilla y León	2.53%	3.56%	1.37%	0.36%
Castilla- La Mancha	3.49%	4.21%	2.49%	0.34%
Cataluña	3.44%	4.26%	2.97%	0.03%
Com. Valenciana	3.31%	6.30%	3.23%	-1.06%
Extremadura	3.36%	1.93%	1.87%	1.48%
Galicia	2.57%	3.81%	0.03%	1.28%
Madrid	3.54%	6.79%	3.53%	-1.05%
Murcia	3.33%	6.91%	3.88%	-1.83%
Navarra	3.59%	6.90%	2.78%	-0.69%
País Vasco	2.92%	3.72%	2.42%	0.03%
La Rioja	3.13%	5.88%	2.93%	-1.01%
España	**3.07%**	**4.54%**	**2.37%**	**-0.09%**

Table 3. The ratio of the within to between standard deviation

Period	**σ-Between**	**σ-Within**	**σ-W/σ-B**
1987-2006	1.5922	2.4414	1.5334

Table 4. TFP growth adjustments

	Model 1	**Model 2**	**Model 3**
Variables	Coefficient	Coefficient	Coefficient
	T-ratio	T-ratio	T-ratio
dlnx	-0.6017	-0.6437	-0.5798
	(-22.017)	(-22.726)	(-15.803)
dlnkpubk		0.2019	0.1018
		(4.908)	(2.723)
dlnictk			0.2035
			(4.964)
R^2	0.3686	0.3836	0.3877
Obs.	1000	1000	1000

Table 5. Determinants of technical change

Variables	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
	t-ratio	t-ratio	t-ratio	t-ratio	t-ratio
dlnx	-0,5415	-0,5735	-0,5475	-0,5476	-0,5476
	(-11,75)	(-12,98)	(-11,84)	(-11,87)	(-11,87)
dlnkpubk	0,1006	-0,0155	0,0957	-0,0020	0,0020
	(1,96)	(-0,37)	(1,97)	(-0,04)	(-0,04)
dlnictk	0,1695	0,1199	0,1817	0,1065	0,1065
	(3,43)	(2,79)	(3,62)	(2,59)	(2,59)
lnR&D1	-0,3401			-1,7628	0,2781
	(-1,7)			(-6,47)	(1,42)
lnHC		-5,0070			
		(-7,67)			
lnHCR&D1			0,2766	0,9437	
			(2,73)	(7,67)	
deslnHCR&D1					0,9437
					(7,67)
R-square	0,3277	0,3814	0,3305	0,3508	0,3508
Obs.	900	1000	900	900	900

Table 6. Provincialized determinants of technical change

Variables	Model 7	Model 9
	Coefficient	Coefficient
	t-ratio	t-ratio
dlnx	-0,5476	-0,5546
	(-11,87)	(-13,74)
dlnkpubk	-0,0020	-0,0228
	(-0,04)	(-0,52)
dlnictk	0,1065	0,1092
	(2,59)	(2,55)
lnR&D1	-1,7628	
	(-6,47)	
lnHCR&D1	0,9437	
	(7,67)	
lnR&D1		-1,2966
		(-4,47)
lnHCR&D1		0,3553
		(2,03)
R-square	0,3508	0,3933
Obs.	900	1000

Figure 1. The evolution of overall, between and within standard deviations

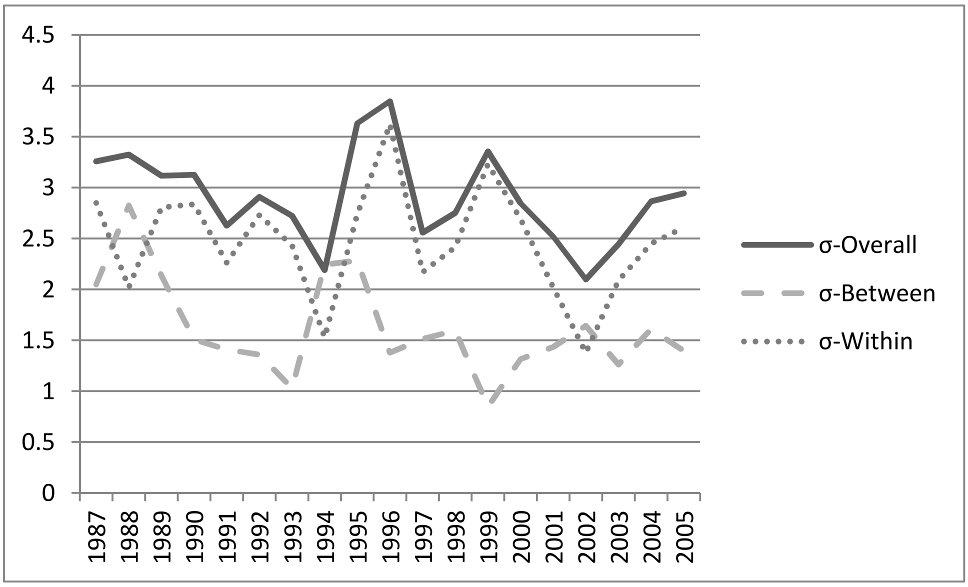
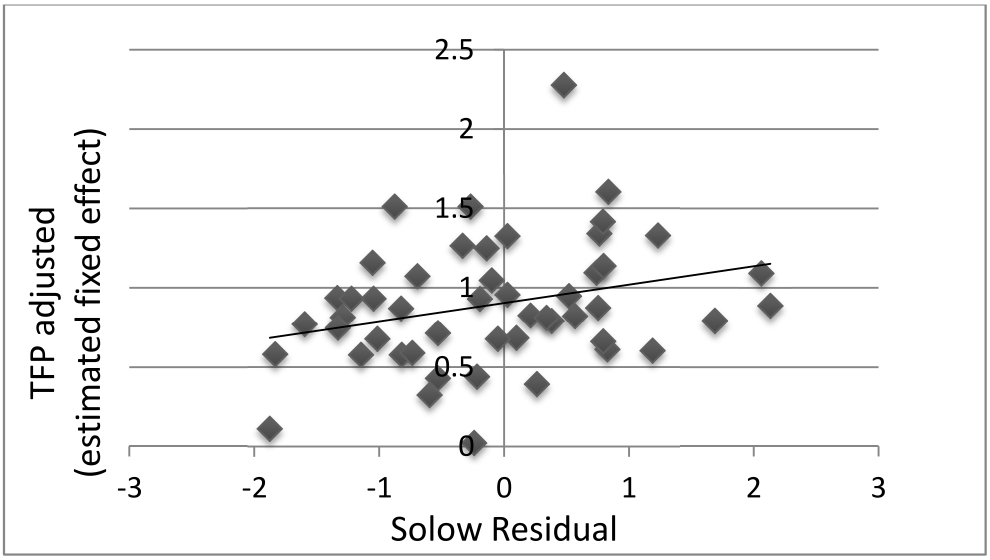


Figure 2. Observed and adjusted TFP growth rates



Appendix

Table A1. OLS parameter estimates of the complementary regression

	Cobb-Doublas		Translog	
Variable	Coef.	t-ratio	Coef.	t-ratio
lny	2.6087	9.10	-38.0612	-1.06
lnL	-3.2199	-11.02	33.6338	1.03
lnK	-2.5415	-6.68	28.1861	0.87
lnictk	-1.1948	-2.25	43.0689	2.49
lnkpubk	3.9930	9.96	-28.9041	-0.86
Lny^2	-	-	4.2556	3.25
lnL^2	-	-	1.5947	1.17
lnK^2	-	-	-13.1470	-7.12
Lnictk^2	-	-	3.1911	2.36
Lnkpubk^2	-	-	-11.0381	-8.81
Lny·lnL	-	-	-7.6486	-3.23
Lny·lnK	-	-	-4.0706	-1.65
Lny·lnictk	-	-	3.9676	2.27
Lny·lnkpubk	-	-	1.2739	0.45
lnL·lnk	-	-	7.3045	2.19
lnL·lnictk	-	-	-0.5939	-0.39
lnL·lnkpubk	-	-	-2.8696	-0.94
lnK·lnictk	-	-	1.3614	1.00
lnK·lnkpubk	-	-	24.3992	8.91
Lnictk·lnkpubk	-	-	-6.7426	-3.84
t	-0.2182	-5.00	-0.1191	-1.89
t2	0.0264	6.71	0.0207	3.94
HC	-0.0135	-5.64	-0.0091	-2.73
cons	-58.9081	-16.37	241.4823	1.19
R-squared	0.5424		0.7813	
Obs	306		306	

Notes: Dependent variable: lnR&D. Both models have been estimated using data at regional level. T-ratios robust to heteroskedasticity.

Table A2. Correlation matrix

Regional variables	Original lnpidi	Estimated lnpidi
Original lnR&D	1	
Estimated lnR&D	0.5922	1

Figure A1. Original and estimated R&D expenditure at regional level.