

TOTAL FACTOR PRODUCTIVITY CONVERGENCE IN EUROPEAN REGIONS: THE ROLE OF SECTORS AND GEOGRAPHICAL LOCATION.F. J. ESCRIBÁ-PÉREZ^aM. J. MURGUI-GARCÍA^b

Abstract: This paper uses a disaggregated approach to analyse total factor productivity convergence in 121 European regions for 1995-2007. To that end, TFP growth rates and levels are computed, and the role of sectors in aggregate TFP convergence is analysed. Our results show evidence of different trends across the northern and southern regions. Productivity levels in northern regions have improved while the southern regions have shown persistence. The northern regions tend to move closer to the leading region by means of higher within-sector TFP growth rates, specifically in private services and industry, while the southern regions tend to move away.

Keywords: Total factor productivity, structural change, catch-up, European regions.

JEL Classification: O52; R11; R12

1. Introduction

Productivity dynamics is a determining factor in maintaining sustainable regional growth. Since the mid-nineties, there have been signs of weak productivity growth in Europe. In 2007, productivity in the US was 39% higher than in the European Union (EU) in terms of GDP per person employed, and 26% higher in terms of GDP per hour worked. Total factor productivity (TFP hereafter) growth has contributed more to growth in labour productivity than growth of capital per worker has. Indeed, TFP has been the main cause of the different productivity trends in the EU and the US in the period 1995-2007¹. Ever since the studies of Barro and Sala-i-Martin (1991, 1992) and Mankiw, Romer and Weil (1992), the convergence or divergence in regional incomes has been widely studied in the regional science literature. European integration has prompted numerous studies using samples of European regions (EU-12 to EU-27) and a variety of approaches (see Eckey and Türk (2007) for a survey as well as the more recent papers of Le Gallo and Dall’erba (2008) and Bartkowska and Riedl (2012)). All the papers cited analyse the convergence in labour productivity.

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¹ See more details on these statements extracted from the 2007 European Commission report on Competitiveness (SEC, 2007). Easterly and Levine (2001) have previously shown that, at country level, more than 90% of the differences in growth rates are explained by TFP rather than factors accumulation. Many other authors such as Hall and Jones (1999) and Parente and Prescott (2000) also obtained similar results for countries. In fact, in all 121 regions included in this paper for the period under study, we have found a correlation both in growth and in levels of labour productivity and TFP of more than 90%. Boldrin and Canova (2001) previously found, for 101 European regions, that GDP per capita is much more correlated with TFP than with capital-labour ratios. Beugelsdijk et al. (2017) find that 75% of the differences in regional economic development can be attributed to differences in TFP.

Some studies provide evidence of convergence in European regions, while others show evidence of divergence. Moreover, some studies show evidence of polarisation and convergence clubs.

Despite the multitude of existing studies on convergence in labour productivity in European regions, there are few contributions focused on measuring and analysing TFP convergence. The main reason for this is the lack of regional data on capital stock. In existing studies on TFP in European regions by Dettori, Marrocu and Paci (2012) and Ladu (2012), TFP is computed using the capital stock calculated by the authors on the basis of the gross fixed capital formation (GFCF hereafter) series from Cambridge Econometrics. More recent papers, Beugelsdijk et al. (2017) using data from EUROSTAT for 2007 and Escribá and Murgui (2018) where TFP is calculated used BD.EURS database like in our paper. Even more scarce is the literature addressing disaggregate TFP performance. In Schergell, Fischer and Reismann (2007) and Marrocu, Paci and Usai (2013) a disaggregation of 13 industries is used, and the capital stock is calculated from the GFCF series which was replaced by a much lower disaggregation in a later version of the Cambridge Econometrics database due to the lack of robustness of the series.

Our aim in this paper is to analyse TFP convergence in European regions for the period 1995-2007, taking into account the role of sectors in aggregate convergence. Thus, we provide a measure of aggregate TFP for 121 European regions as well as TFP in each of six broadly-defined sectors in those regions. We use cross-sectional techniques to examine the evidence for TFP convergence within sectors and across regions, and take into account spatial interdependence to analyse absolute and conditional β -convergence. Moreover, in order to analyse the role of sectors in convergence, we decompose the regional aggregate TFP growth to measure the relative contributions of within-sector TFP growth and structural change to aggregate convergence and catch-up with the leading region (Brussels).

This paper makes a number of contributions with respect to the analysis of regional convergence. First, TFP is used directly as the variable to be explained. To this end, we calculate TFP levels from the BD.EURS database², using a specific labour and capital income share for each region and sector that are indicative of technological differences. This database is compiled by the Budget General Directorate of the Spanish Ministry of Economic and Financial Affairs. Since the data provided by BD.EURS are mainly based on information supplied by EUROSTAT's regional database, REGIO, so ensuring compatibility with AMECO and EU-KLEMS, they start in 1995. The lack of homogeneous data for the remainder of the European regions, specifically data relating to the GFCF, determined the complete set of regions that are included in this database: 121 regions across the nine European countries of Belgium, France, Germany, Spain, Netherlands, Austria, Italy, Portugal, and Sweden.

Second, a disaggregated sectoral approach is used to analyse the convergence in TFP. A decomposition of aggregate regional TFP is performed to analyse the relative contributions of within-sector TFP growth and structural change to a region's

² See Escribá and Murgui (2014a).

aggregate TFP growth. These contributions or effects are compared with the leading region to analyse the sources of catch-up. This paper contributes to the debate with a disaggregate analysis of TFP for a sample of 121 regions in the European Union. Among the few studies that analyse TFP behaviour at the regional level, there are some authors, such as Esteban (2000) and Ezcurra et al. (2005), who argue the irrelevance of disaggregated approaches. Conversely, Batog and Batog (2007), Fiaschi and Lavezzi (2007), Le Gallo and Dall'erba (2008), Bah and Brada (2009), Henze (2015) and O'Leary and Webber (2015) advocate the use of disaggregated approaches and the importance of structural change to capture the regional dynamics of productivity.

Our results show that TFP growth and levels differ greatly between the northern and southern regions in this period. The northern regions have improved, with their productivity levels growing at positive rates, while the southern regions have shown persistence in TFP levels. Low TFP growth rates in the southern regions are a consequence of the marked structural change towards sectors such as construction, private services, and financial and real estate, which have strongly negative growth rates in these regions. In fact, the structural change effect dominates in TFP growth in southern regions. In northern regions, it is the within-sector growth effects—mainly in the industry sector—which explain the regional TFP growth. The industry sector has seen major advances in TFP growth, although it has lost share in both regional groups.³

Regarding the analysis of convergence, when a regional dummy is introduced in the cross-section estimation, our results show that northern regions converge towards a higher steady-state TFP level than the southern regions. This process is also observed in the industry, construction and private services sectors. The northern regions tend to move closer to the leading region by means of higher within-sector TFP growth rates, specifically in private services and industry, while the southern regions tend to move away. The change in the weight of the different sectors has played a smaller (and opposite) role in the catch-up of the northern regions to Brussels. In contrast, structural change plays a positive role in catching up to the leading region but is not enough to offset the strong negative growth of sectors and lead to aggregate catch-up in the southern regions.

The paper proceeds as follows: Section 2 presents the estimation procedure to compute the TFP growth rate and levels, along with growth accounting basic statistics and evidence on regional disparities in TFP levels and growth rates. Section 3 describes the β -convergence model in TFP and the estimation strategy to account for possible spatial effects on regional data. Section 4 analyses the role of sectors in aggregate convergence and provides a measure of the relative contributions of sector TFP growth and sector share to aggregate convergence. The last section outlines the conclusions and some implications for regional development policy.

2. TFP estimation procedure for regions and sectors.

This section includes the procedure to estimate TFP for each industry in each European region. The construction of TFP is more complicated than labour (or capital)

³ The European Commission recently suggested that a strong industrial base will be the key to Europe's economic recovery, productivity and competitiveness. See European Commission (2014).

productivity because we require level comparisons, and not simply growth rate comparisons. We begin by following Solow (1957) in constructing TFP growth rates, where a residual is obtained from a Cobb-Douglas function production with Gross Value Added (Q) and two productive factors (capital (K) and labour (L)), with a Hicks-neutral technical change. Taking logarithms and differentiating, the TFP growth rate can be expressed as:

$$TFP_t = \hat{Q}_t - \alpha \hat{K}_t - (1 - \alpha) \hat{L}_t \quad (1)$$

Under the assumptions of perfect competition and of factor remuneration based on marginal productivity, α and $(1 - \alpha)$ are both the capital and labour income share as well as income elasticities with respect to the factors⁴.

This expression can be written for industries and regions as follows:

$$TFP_{ij,t} = \hat{Q}_{ij,t} - \alpha_{ij} \hat{K}_{ij,t} - (1 - \alpha_{ij}) \hat{L}_{ij,t} \quad (2)$$

where i represents the sectors (agriculture; industry; construction; private services; financial and real estate; and public administration) and j refers to the regions. The information on labour income share $(1 - \alpha_{ij})$ and the rest of the variables—GVA (Q_{ij}), capital stock (K_{ij}) and employment (L_{ij})—is extracted from the accounts available in the BD.EURS database⁵.

This database, in year 2000 euros, is disaggregated into six sectors for 121 regions (NUTS 2) for the period 1995-2007. In accordance with the EUROSTAT disaggregation, each region (NUTS 2) is disaggregated into six major sectors: agriculture and fisheries; industry (manufacturing and energy); construction; wholesale and retail trade services including hotels and restaurants and transport; financial, real estate and other business services; and public administration.

Figure 1 presents the sources of GVA growth for total activities in the 121 European regions. Across all regions, a positive contribution of capital and labour is seen (except in three regions in the former East Germany, whose contribution is zero, or even, in the case of Sachsen-Anhalt, strongly negative), as well as a similarly positive contribution of TFP, with the exception of a few regions, mainly in Spain, Portugal and Italy.

⁴ Implicit in this calculation is assumption of constant returns to scale. This procedure is the most commonly used in the literature. There are other studies which estimate elasticities rather than assuming constant returns to scale. Marrocu, Paci and Usai (2013) calculate the TFP growth rate by applying two procedures. First, they estimate input elasticities (α and β coefficients) for 13 economic sectors in a Cobb-Douglas production function. Second, they apply the Solow methodology: sectoral labour elasticities are computed as the share of wages in value added and assuming constant returns of scale. Their results remain the same regardless of the procedure applied.

⁵ In Appendix 1, more details about the BD.EURS database are provided. This is the only regional database that provides capital stock series, and it is available free on the following web page:

<http://www.sepg.pap.minhap.gob.es/sitios/sepg/es->

<ES/Presupuestos/Documentacion/Paginas/BasededatosBDEURS.aspx>

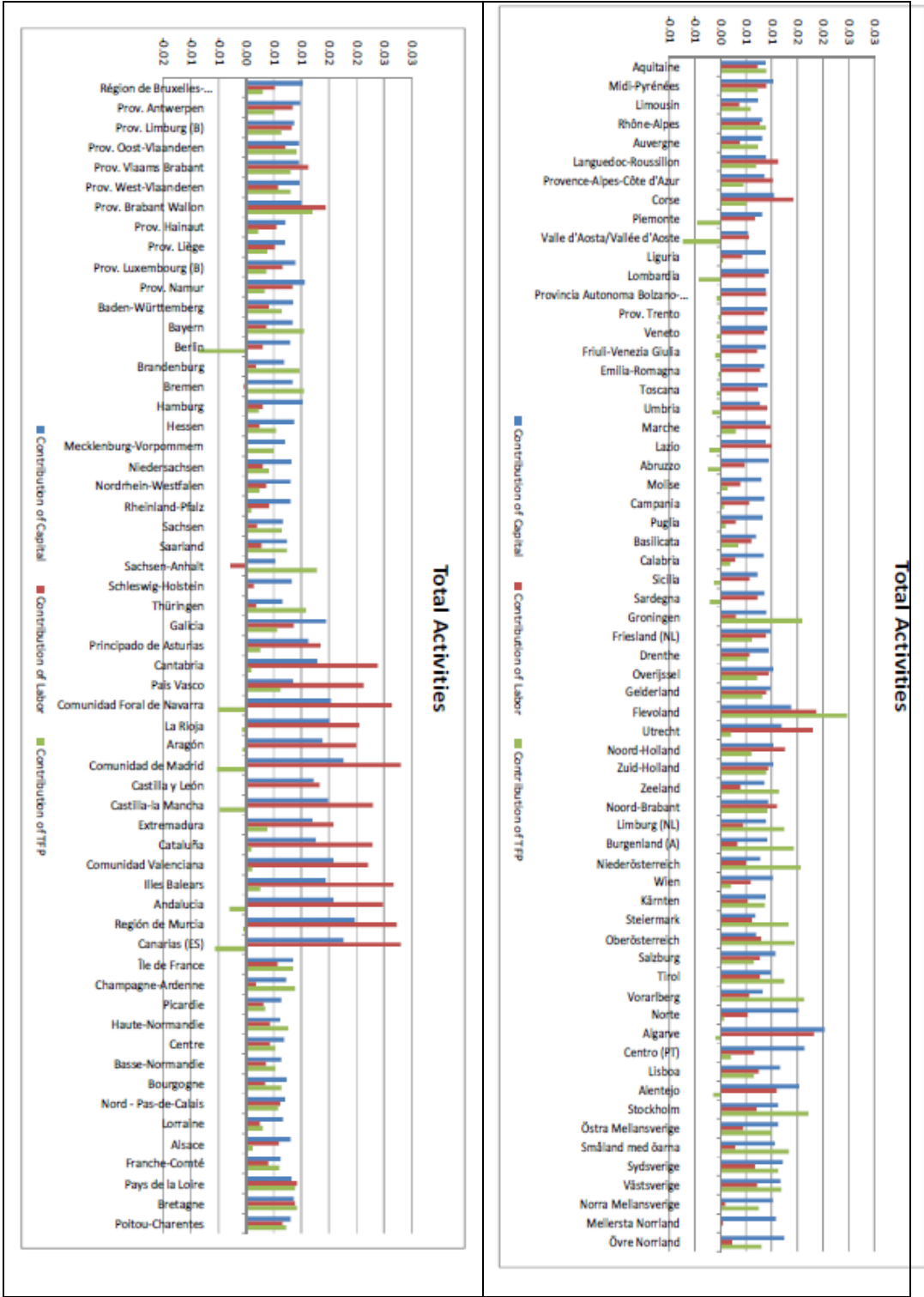


Figure 1. Sources of GVA growth. Total Activities. Average 1995-2007

Focusing on TFP growth, a marked difference in trends across the northern and southern regions can be seen. The contribution of TFP is particularly low (even negative in some regions) in Spanish regions, in southern Italian regions and in Portuguese regions. The opposite behaviour is observed in most northern regions. These results are considerably more pronounced or different for each of the individual sectors.⁶ The causes of these differences in TFP growth will be analysed in section 4.

Once the TFP growth rates have been obtained, we determine the relative levels of TFP in each regional industry and in total activities, following the methodology in Bernard and Jones (1996b) and Harrigan (1999).⁷

Figure 2 shows the relative TFP levels of total activities. The 45-degree line divides the quadrant into two equal parts, so that the regions on the straight line record similar levels of productivity at the beginning (1995) and at the end (2007) of the analysed period. The graph displays the regions with a different symbol according to their country⁸ and shows how most regions in the north (symbols outlined in blue) are located above the straight line. That is, the northern regions have improved their productivity during the period under study. However, most southern regions are close to or below the straight line, indicating a significant persistence in TFP levels during the period considered.

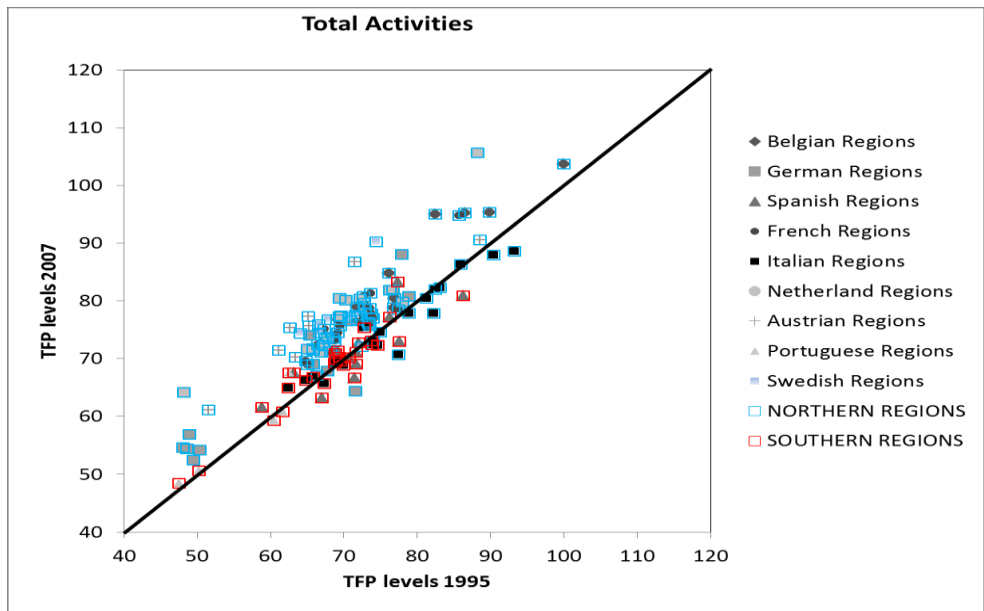


Figure 2. TFP levels in European regions. Total Activities

⁶ For reasons of space, figures and tables corresponding to sectors have not been included, but they are available to the reader upon request to the authors.

⁷ This methodology is used in Escribá and Murgui (2014c) for Spanish regions.

⁸ In Appendix 2, the regional TFP levels are shown at the beginning and at the end of the sample.

3. TFP β -Convergence Analyses.

Having described the differences in the levels and growth rates of total factor productivity in the European regions, in this section we analyse whether the European regions experienced TFP convergence during the period under analysis.

Most research on convergence between European regions has focused on analysing the σ and/or β convergence in labour productivity or in per capita income. In this paper, we go one step further in the analysis of regional convergence in Europe and examine whether there is evidence of TFP convergence between 121 European regions in terms of both aggregate convergence and with respect to individual sectors.

First, a regression model is estimated following Barro (1991) and Barro and Sala-i-Martin (1991). The aim is to show whether the regions that initially had lower TFP values are those with higher growth rates (absolute β -convergence), such that they become closer or converge to the steady-state TFP levels of the most productive regions. Therefore, if all economies are structurally identical, they are characterised by the same steady state and differ only in respect to their initial conditions. The expression that is estimated is as follows:

$$\begin{aligned}\hat{g}_{TFP} &= \alpha + \beta \ln TFP_{1995} + \varepsilon \\ \varepsilon &\rightarrow N(0, \sigma^2 I)\end{aligned}\tag{3}$$

where $\hat{g}_{TFP}$ denotes the annual average growth rate of TFP calculated over the 1995-2007 period and $\ln TFP_{1995}$ is the logarithm of the initial level of TFP. The results of the estimation are presented in Panel (a) of Table 1 for the cross-section of the 121 European regions.

Second, we have introduced a dummy variable for regional group in the estimation. If the assumption of similar steady states is relaxed, conditional β -convergence will be observed. Therefore, if the European regions analysed are not particularly homogeneous (which, based on the empirical evidence of the previous section, appears to be the case), this can lead to bias in the estimation of β by the assumption imposed in expression (3) ($\alpha_i = \alpha$). The constructed variable takes a value of 1 if the regions are located in the north of Europe and a value of 0 otherwise (if the regions are located in the south). Panel (b) of table 1 presents the results.

In Table 1, we present cross-section TFP convergence results for six sectors and for 121 European regions.

We estimate equation (3), in the first instance, using an ordinary least squares regression. The estimates do not suffer from non-normality or heteroskedasticity, as can be observed in the lower part of panel (a) and (b) of Table 1. In panel (a), the estimated β parameter is negative and significant in all cases, which indicates a TFP convergence process during the 1995-2007 period in the 121 European regions. A convergence process is observed for total activities, with a convergence speed of 1.4%; the same is the case for the sectors, although at different convergence speeds. Panel (b) of Table 1 shows the results for conditional β -convergence, while column [1] presents the results for total activities. The regional dummy introduced is positive and

statistically significant⁹. We could therefore conclude that there is evidence of conditional convergence, i.e. the northern European regions converge towards a different (higher) steady-state TFP level than the regions located in southern Europe. The speed of convergence has increased and is closer to 2%. The same is true in the industry, construction and private services sectors: the dummy of the northern regions is positive and significant, indicating the existence of conditional convergence in these three sectors. However, in the agricultural sector as well as in the financial and real estate sectors, the dummy is not significantly different from zero, which shows that the β convergence is absolute, i.e. all the European regions analysed converge to the same long-term TFP level.

Table 1. Estimation Results. OLS Estimation

Dependent variable: Annual average growth rate of TFP 1995-2007.					OLS Estimation	
	TOTAL [1]	Agriculture [2]	Industry [3]	Construction [4]	Private Services [5]	Financial-Real estate[6]
Panel (a): Absolute β -Convergence						
$\hat{\alpha}$	0.064*** (0.015)	0.093*** (0.012)	0.087*** (0.031)	0.073** (0.038)	0.180*** (0.021)	0.114*** (0.015)
$\hat{\beta}$	- 0.013*** (0.003)	-0.020*** (0.003)	-0.015** (0.007)	-0.017** (0.008)	-0.040 *** (0.004)	-0.027*** (0.003)
Convergence speed (<i>b</i>)	0.014	0.023	0.016	0.019	0.051	0.032
R ²	0.12	0.24	0.51	0.035	0.36	0.32
Sample Size	121	121	121	121	121	121
Shapiro-Wilk Test	[0.602]	[0.270]	[0.026]	[0.050]	[0.538]	[0.581]
Breusch-Pagan	[0.519]	[0.480]	[0.103]	[0.010]	[0.022]	[0.653]
Panel (b): Conditional β -Convergence						
$\hat{\alpha}$	0.071 *** (0.012)	0.089*** (0.013)	0.115*** (0.026)	0.099** (0.030)	0.149*** (0.019)	0.116*** (0.015)
<i>D</i> North	0.006*** (0.001)	0.004 (0.004)	0.020*** (0.002)	0.020*** (0.002)	0.010*** (0.001)	0.006 (0.001)
$\hat{\beta}$	- 0.016*** (0.002)	-0.020*** (0.003)	-0.025** (0.006)	-0.026** (0.006)	-0.034*** (0.004)	-0.026*** (0.003)
Convergence speed (<i>b</i>)	0.019	0.023	0.029	0.031	0.043	0.031
R ²	0.38	0.24	0.33	0.38	0.49	0.32
Sample Size	121	121	121	121	121	121
Shapiro-Wilk Test	[0.066]	[0.371]	[0.011]	[0.074]	[0.052]	[0.405]
Breusch-Pagan	[0.090]	[0.481]	[0.304]	[0.564]	[0.016]	[0.580]

Note: Standard errors in brackets. *** Significant at 1%; ** Significant at 5% and * significant at 10%. The null hypothesis for the Shapiro-Wilk test is that the data are normally distributed. Breusch-Pagan/Cook-Weisberg tests the null hypothesis that the error variances are all equal versus the alternative that the error variances are a multiplicative function of one or more variables. The implicit convergence speed is obtained as follows: $b = -\ln(1 - \hat{\beta}T) / T$. Where T is the length of the period.

The basic regression specification (equation 3) assumes that TFP growth rates for different regions are independent. However, there are many studies that

⁹ The significance and importance of the regional dummy also suggests that the basic regression model has left out important factors.

demonstrate the existence of spatial dependence in this type of analysis.¹⁰ Some studies that analyse the β -convergence in labour productivity, taking into account the spatial interdependence between European regions, show differences in the obtained convergence rate.¹¹

Therefore, we present below a brief exploratory analysis of the initial TFP level (exogenous variable) and of the TFP growth rate (endogenous variable). Figures A4a and A4b in Appendix 4 show the maps detailing the TFP levels of the 121 European regions in 1995, as well as their annual average growth rates for the period 1995-2007. They are divided into five quartiles, depicted in colours ranging from light to dark, depending on the initial TFP level (or their growth rates, according to the chart). Thus, regions that appear lighter in colour belong to the lowest initial TFP quartile (or lower growth rate) and those that are darker belong to the higher levels (or rates).

From the figures, it can be deduced that the distribution of the two variables cannot be considered random. Overall, it appears that neighbouring regions have similar values for the two variables, meaning that there seems to be some degree of spatial dependence. Except for northern Italy, the regions that show the highest TFP levels in 1995 tend to be relatively isolated, that is, they have a higher TFP level than their neighbouring regions. In contrast, regions with lower TFP levels are characterised by the fact that they have similar TFP levels to geographically adjacent regions. However, besides the TFP levels, there are more interesting observations to be made concerning TFP growth rates: while it is quite normal for groups of geographically proximate regions to evolve in a similar manner, more remarkable are the opposite trends seen in the less developed regions of the former East Germany (northern regions) and the less developed regions of the south. The German regions started out from the lowest levels and grew at the highest rates.

Thus, as a third step, we estimate the convergence equation taking into account the existing spatial dependence. The model that includes all possible interaction effects—the General Nesting Spatial Model (GNS)—takes the form:

$$\hat{g}_{TFP} = \alpha + \rho W \hat{g}_{TFP} + \beta \ln TFP_{1995} + \theta W \ln TFP_{1995} + \varepsilon \quad (4)$$

$$\varepsilon = \lambda W \varepsilon + u \quad u \rightarrow N(0, \sigma^2 I)$$

where W is the spatial weights matrix, usually containing contiguity relations or functions of distance. A first-order contiguity matrix has zeros on the main diagonal, rows that contain zeros in positions associated with non-contiguous observational units and ones in positions reflecting neighbouring units that are (first-order) contiguous. Parameter ρ captures the “endogenous” effect of a region’s neighbours’ TFP growth rates on its own TFP growth rates. Parameter θ captures the “exogenous” effect of a region’s neighbours’ initial TFP levels on its own TFP growth rates. Parameter λ

¹⁰ See Fingleton and McCombie (1998); López-Bazo et al. (1999); Vayá et al. (2004), Badinger, Müller and Tondl (2004) and Escribá and Murgui (2018) for European regions.

¹¹ See Vayá et al. (2004), Carrington (2003), Baumont, Ertur and Le Gallo (2003) or Le Gallo and Dall’erba (2008), studies which analyse β convergence including spatial dependence in a cross-sectional analysis for European regions.

captures the “correlated” effects of unobserved mean characteristics or factors affecting neighbouring regions (see Appendix 4 for more details).

When spatial interdependence is taken into account (see columns [1], [2], [4] and [6] in panel (a) of Table 2), absolute β -convergence parameters change. The estimated β parameter is negative and significant in all cases although with slightly lower coefficients. For the construction and financial services sectors, the spatial lag of X (SLX) model is used, while the spatial autocorrelation in the error process (SEM) model is used for total activities and agriculture. In other words, these spatial diffusion effects suggest that spatial association patterns influence regional TFP growth. In case of the construction and financial services sectors, the better the starting position in terms of neighbouring regions’ TFP, the greater the regional TFP growth. In estimates for industry and private services all LR tests are accepted, that is, there is no spatial interdependence between regions, and so the OLS model is used (panel (a) of Table 1).

All the estimated variables have highly significant coefficients. The spatial dependence parameter is positive and significant in all cases where it is introduced. Regarding convergence, the estimated β parameter is negative and significant in all cases, which shows evidence that there is a single TFP steady state to which the 121 European regions converge. This convergence process is observed for both total activities, at an annual rate of 0.9%, as well as for the rest of the sectors. Convergence speed differs between sectors: the fastest speeds are found in the private services sector (5.1%) and the construction sector (4.8%), followed by the financial and real estate sector (4.2%).

Regarding the estimation of the conditional β -convergence (when the regional dummy is introduced), the results are presented in panel (b) of Table 2. In total activities, industry, private services and financial and real estate, all LR tests are accepted, and so the OLS model is used (Table 1, panel (b)). In the agricultural and construction sectors the existence of spatial effects is accepted. In the agricultural sector the LR Test ($\lambda = 0$) is not accepted, therefore the SEM model is used as it takes into account spatial dependence in the disturbance process but in this case the dummy is not significantly different from zero, which shows that the β convergence is absolute. The regional dummy introduced is positive and statistically significant in the construction sector, where spillovers effects are associated with the spatially lagged explanatory variable (SLX model). The speed of convergence has increased and is the highest at around 5%.

We can therefore conclude that there is not a single steady state to which all economies converge¹². Northern regions form a group of economies that converge towards the same long-term equilibrium, which is different from that of the southern regions. Convergence towards a different steady-state TFP level occurs at different rates depending on the sector considered. Thus, the fastest speed of convergence takes place in the construction sector (5.3%) and private services (4.3%), followed by the industry sector (2.9%). Conversely, in the agricultural and financial and real estate

¹² This paper does not carry out a rigorous analysis of possible convergence clubs.

sectors, the European regions converge to the same steady state at a rate of 1.6% and 4.2%, respectively.

4. Structural change and productivity growth.

As described in the previous section, an aggregate convergence process has been observed in European regions. The northern European regions converge towards a higher steady-state TFP level than the regions located in southern Europe. To analyse the role of sectors in aggregate convergence, in this section we determine the relative contributions of sector TFP growth and sector share to aggregate convergence. We first perform a decomposition of regional TFP growth and then compare this regional growth with the leading region to analyse the sources of catch-up.

4.1. Sources of regional TFP growth.

Following Bernard and Jones (1996a), we define the TFP of a region – as:

$$TFP_j = \frac{Q_j}{L_j^{1-\alpha_j} K_j^{\alpha_j}} = \sum_i \frac{Q_{ij}}{L_{ij}^{1-\alpha_{ij}} K_{ij}^{\alpha_{ij}}} \cdot \left[\frac{L_{ij}^{1-\alpha_{ij}} K_{ij}^{\alpha_{ij}}}{L_j^{1-\alpha_j} K_j^{\alpha_j}} \right] = \sum_i TFP_{ij} \cdot \omega_{ij} \quad (5)$$

ω_{ij} , that is, $\left[\frac{L_{ij}^{1-\alpha_{ij}} K_{ij}^{\alpha_{ij}}}{L_j^{1-\alpha_j} K_j^{\alpha_j}} \right]$, approximates the relative concentration of factors in sector i ,

with respect to the joint utilisation of resources by that region. Therefore, each ω_{ij} is used to measure the relative participation of sector i in region j . The complete set of ω_{ij} is a proxy of the productive structure of each region j , and the structural change is understood to be the modification of ω_{ij} in the different regions.

Thus, the TFP growth of each region (Total Effect, TE) can be decomposed into a productivity growth effect (PGE) and a structural change effect or share effect (SCE), based on equation (5), as follows:

$$\frac{\dot{TFP}_j}{TFP_j} = \sum_i \left(\hat{TFP}_{ij} \right) \left(\frac{TFP_{ij}}{TFP_j} \right) (\bar{\omega}_{ij}) + \sum_i \left(\dot{\omega}_{ij} \right) \left(\frac{TFP_{ij}}{TFP_j} \right) \quad (6)$$

where the average growth rate for the 1995-2007 period is indicated by the circumflex accent, and the variation by the points.

The first term on the right shows the contribution of within-sector TFP growth to the aggregate for the region, assuming that the initial productive structure does not change. The second term captures the contribution of structural change when there is no within-sector TFP growth. Both effects are calculated for each of the 121 European regions. In order to better present the results, regions are divided into two groups. As can be seen in Table 3, the results show the importance of geographical location (north or south) in regional TFP growth. On average, the group of regions in which TFP grows the fastest during the period are in the north (0.8%, see last row of the table). The southern regions grow at 0.18%.

Table 2. Estimation Results. Spatial regression model.

Dependent variable: $\hat{g}_{TFP,1995-2007}$						
Spatial Regression Model	TOTAL [SEM]	Agriculture [SEM]	Industry	Construction [SLX]	Private Services	Financial-Real estate [SLX]
Panel (a): Absolute β-Convergence						
$\hat{\alpha}$	0.044*** (0.014)	0.083*** (0.012)		0.057 (0.059)		0.079*** (0.019)
$\hat{\beta}$	-0.008*** (0.003)	-0.014*** (0.003)		-0.038*** (0.010)		-0.034*** (0.004)
Convergence speed (b)	0.009	0.016		0.048		0.042
R^2	0.34	0.25		0.20		0.36
$\hat{\lambda}$ $\hat{\theta}$	0.361*** (0.089)	0.426*** (0.072)		0.049*** (0.017)		0.015*** (0.005)
LR Test ($\rho = 0$)	1.431	2.364	0.095	1.047 [0.306]	0.0007[0.97]	0.008
LR Test ($\theta = 0$)	[0.231]	[0.124]	[0.757]	2.916 [0.087]	1.972	[0.925]
LR Test ($\lambda = 0$)	1.090	2.189	0.728	0.220 [0.638]	[0.160]	4.870
	[0.296]	[0.139]	[0.393]		1.457	[0.027]
	12.74	29.10	1.379		[0.227]	0.863
	[0.000]	[0.000]	[0.156]			[0.352]
Panel (b): Conditional β-Convergence						
$\hat{\alpha}$		0.083*** (0.012)		0.004 (0.048)		
$\hat{\beta}$		-0.014*** (0.003)		-0.041*** (0.008)		
$DNorth$		0.004 (0.004)		0.0188*** (0.005)		
Convergence speed (b)		0.016		0.053		
R^2		0.25		0.41		
$\hat{\lambda}$ $\hat{\theta}$		0.426*** (0.074)		0.0373*** (0.014)		
LR Test ($\rho = 0$)	0.288	2.393	0.512	1.47 [0.701]	0.000	0.004
LR Test ($\theta = 0$)	[0.591]	[0.121]	[0.474]	10.26 [0.005]	[0.997]	[0.947]
LR Test ($\lambda = 0$)	0.401	2.351	0.678	0.771 [0.379]	2.683	4.575
	[0.818]	[0.308]	[0.712]		[0.261]	[0.101]
	0.003	29.44	0.018		2.418	0.374
	[0.951]	[0.000]	[0.891]		[0.119]	[0.540]

Note: Standard errors in brackets. *** Significant at 1%; ** Significant at 5% and * significant at 10%. For definitions of λ , ρ and θ see equation (4). The implicit convergence speed (b) is obtained as follows: $b = -\ln(1 - \hat{\beta}T)/T$, where T is the length of the period.

In northern regions, the key role is played by growth effects (87%), while the structural change effects are less relevant. However, in the southern regions, the growth effects are negative (-0.1 %) and only the aggregate TFP grows, due to

structural changes in terms of a shift towards construction, private services and financial and real estate. In other words, within-sector effects outweigh share effects for the northern regions, whereas the opposite is true in the southern regions.

The importance of individual sectors can be seen in Table 3. The disaggregated analysis of within-sector TFP growth and structural change is essential to highlight the importance of the performance of the industrial sector in TFP growth in European regions. The strong positive growth effect of the industrial sector in both regional groups can be observed in second row in Table 3. This is the sector that has seen major advances in TFP growth, although it has lost share in both regional groups, as can be observed in the structural change effect. This loss is much greater in the southern regions, which in part helps to explain the differences between the northern and southern regions in TFP growth. TFP growth rates in private sectors (with the exception of agriculture and industry) are strongly negative and their shares in aggregate TFP have increased in the south.

4.2. Sources of catch-up.

To better understand the role of sectoral TFP growth in aggregate TFP behaviour, we define the TFP growth in the leading region (Brussels has a most TFP level in 1995) in a similar way to equation (6) and we construct a measure of TFP growth for each region relative to Brussels.

$$TFP_j - TFP_{Brus} \quad (7)$$

And then, decomposing into productivity growth effect (PGE) and structural change effect (SCE) and to investigate the relative importance of the two components to aggregate catch-up, we construct measures of within-sector and between-sector catch-up by subtracting the productivity growth effect and structural change effect in Brussels from those in the other regions, for each sector.

$$\sum_i (PGE_j - PGE_{Brus}) + \sum_i (SCE_j - SCE_{Brus}) \quad (8)$$

Table 3. Productivity Growth, Structural Change and Total Effects. Groups of European Regions 1995-2007. Average Percentage Contribution

SECTOR	Northern Regions			Southern Regions		
	PGE	SCE	TE	PGE	SCE	TE
Agriculture	5.53	-4.60	0.93	24.72	-70.98	-46.26
Industry	72.38	-36.35	36.03	84.54	-109.88	-25.34
Construction	-2.26	-6.20	-8.47	-80.77	141.81	61.04
Private serv.	26.81	3.34	30.15	-49.46	68.30	18.84
Fin / Real Est.	-10.18	59.80	49.62	-24.91	133.74	108.84
Public serv.	-4.90	-3.35	-8.25	-9.85	-7.26	-17.11
Total Activity	87.37	12.63	100	-55.73	155.73	100.00
Total Activity	0.0070	0.0010	0.0080	-0.0010	0.0027	0.0018

Note: With the exception of the last row, which shows the value of productivity growth, structural change and total effects, the rest of the table shows percentages that represent each of the effects with respect to the total activity. PGE: Productivity Growth Effect. SCE: Structural Change Effect. TE: Total Effect.

Table 4 presents results on the role of sectors and effects in catch-up to the Brussels region. Since the Brussels region is the most productive region in terms of

1995 aggregate TFP, this means that a positive number indicates a contribution to catch-up to Brussels and a negative number indicates a contribution to divergence in TFP¹³. The northern regions tend to move closer to the leading region, while the southern regions tend to move away. In the north, the convergence of the regions with Brussels is driven by higher within-sector TFP growth rates in all sectors except construction and public services. There has not been an equivalent catch-up process in the south, due to the lower within-sector TFP growth rates in almost every sector. In other words, the productivity growth effect for private services (0.31) and industry (0.18) is the most important factor in overall convergence in the northern regions. In contrast, low TFP growth rates and negative rates in industry and construction have moved the southern regions' productivity further away from that of the leading region.

The shift in sector shares has played a smaller (and opposite) role in the catch-up of the northern regions to Brussels. In the southern regions, structural change plays a positive role, but it is not sufficient to offset the negative productivity growth effect and help southern regions move closer to the leading region.

5. Conclusions and final observations.

In this paper, we provide a measure of aggregate TFP as well as TFP for each of six sectors for 121 European regions over the period 1995-2007. The empirical evidence analysed shows that European regions are not particularly homogeneous in terms of TFP levels and growth rates; a marked difference has been shown in trends across the northern and southern regions.

Table 4. Sources of convergence /catch-up in TFP. Regional group averages in relation to the leading region (Brussels). Values in percentages

REGION	SECTOR	TOTAL EFFECT [1]	PRODUCTIVITY GROWTH EFFECT [2]	STRUCTURAL CHANGE EFFECT [3]
Northern Regions	Agriculture	0.01	0.05	-0.04
	Industry	0.15	0.18	-0.03
	Construction	-0.06	-0.03	-0.03
	Private serv.	0.38	0.31	0.07
	RE & Fin S.	-0.11	0.03	-0.14
	Public Serv.	-0.02	-0.08	0.06
	Total Activ.	0.35	0.45	-0.10
Southern Regions	Agriculture	-0.08	0.05	-0.13
	Industry	-0.19	-0.26	0.07
	Construction	0.12	-0.15	0.27
	Private serv.	0.16	0.00	0.16
	RE & Fin S.	-0.32	0.06	-0.38
	Public Serv.	0.02	-0.05	0.07
	Total Activ.	-0.28	-0.36	0.07

¹³ In Brussels, the productivity growth effect is 0.25 and the structural change effect is 0.20.

We use cross-sectional techniques to examine the evidence for TFP convergence within sectors and across regions, and take into account spatial interdependence to analyse absolute and conditional β -convergence. Our results show that there is not a single steady-state TFP level to which all economies converge. Northern regions converge to a higher long-term equilibrium than that of the southern regions. Convergence towards a different steady-state TFP level for each group of regions occurs at speeds that depend on the sector analysed. The rate of aggregate convergence in European regions is 1.9%, but the rate is higher in the industry sector (2.9%), private services (4.3%) and the construction sector (5.3%). This is not the case in the agricultural and financial and real estate sectors, where European regions converge to the same steady state at a rate of 1.6% and 4.2% respectively.

Moreover, in order to analyse the role of sectors in aggregate convergence, we decompose the regional aggregate TFP growth to measure the relative contributions of within-sector TFP growth and structural change to aggregate convergence or catch-up with the leading region.

Our results are in line with those of Batog and Batog (2007), Fiaschi and Lavezzi (2007), Le Gallo and Dall'erba (2008) Bah and Brada (2009), Henze (2015) and O'Leary and Webber (2015), who advocate using multi-sectoral approaches, analysing TFP levels and growth rates and relating them to each other, for example, by studying convergence.

Industry is the sector that plays the most determinant positive role in regional TFP growth in all the regional groups, and it marks the difference in the dynamic between the northern and southern regions. The manufacturing sector generates significant demand for research and qualified productive services. It is little wonder that the EU executive's 20-20-20 strategy aims to revive the industrial sector in the 27 European countries, such that by 2020 it reaches 20% of total activity.

The northern regions tend to move closer to the leading region by means of higher within-sector TFP growth rates, specifically in private services and industry, while the southern regions tend to move away due to the low TFP growth rates in industry and negative rates in the construction sector. The shift in sector shares has played a smaller (and opposite) role in the catch-up of the northern regions to Brussels. In contrast, structural change plays a positive role in catching up to the leading region, but is not enough to offset the strong negative growth of sectors and lead to aggregate catch-up in the southern regions.

Our results call into question the suitability of the structural change experienced in this period. Indeed, in the south, it has been directed towards those sectors that show poorer TFP behaviour; namely, construction and private services. In the case of the construction sector, the growth effect of TFP is negative in the two groups of regions. However, in private services the growth effect is positive in the north and negative in the south. Within private services sector southern regions tend to produce in relatively low-productivity subsectors. A much higher level of disaggregation might allow us to verify that the activities included in the north are more closely linked to industrial activity and business services, logistics and telecommunications, while activities in the south relate to hotels and restaurants. In the south there is a predominance of a more traditional pattern of specialization and an

absence of incentives to encourage the entry of new companies and activities with greater productivity.

In terms of policy, our findings imply that greater coordination between European regional and national policies is needed to foster the growth of the most productive enterprises and to improve the diffusion of knowledge and technologies. Investment in human, physical and technological capital is necessary, but the public sector should also encourage structural change by promoting the mobility of resources through policies that do not hinder labour mobility and reforms that improve the competitiveness of markets for goods and services.

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APPENDIX of Total Factor Productivity Convergence in European Regions: The role of sectors and geographical location.

APPENDIX 1. BD.EURS Database (NACE Rev. 1)

The basic data for the 121 European regions and the period 1995-2007 are taken from the BD.EURS database (NACE Rev.1) base year 2000. These data were selected on the basis of analysing the quality and consistency of the different statistical sources available on the basic macroeconomic variables—GVA in current and constant prices, employment, gross fixed capital formation and capital stock—for countries and at NUTS-2 level. The level of regional disaggregation corresponds to NUTS 2 in the Eurostat nomenclature of statistical territorial units and the level of industry disaggregation corresponds to six major sectors: agriculture and fisheries; industry (manufacturing and energy); construction; wholesale and retail trade services including hotels and restaurants and transport; financial, real estate and other business services; and public administration.

In this version of the database, only information about 121 regions from nine European countries is presented. These are the regions which provide the highest quality and quantity of information for the period 1995-2007; namely, Belgium, Germany, France, Italy, the Netherlands, Austria, Portugal, Sweden and Spain. The basic source of information is the regional series from EUROSTAT, although the existing information for countries in the AMECO and EU-KLEMS databases was also used as a reference.

The TFP series for European sectors and regions used in this paper were obtained from GVA, employment, capital income share and labour income share data, according to the following criteria:

Gross value added. GVA at current prices from EUROSTAT includes production of goods and services at factor costs produced in the region by the six sectors. GVA deflators are obtained from EU-KLEMS. Series in PPS (purchasing power standard)

Number of employees. National information taken from the series provided by AMECO and EUROSTAT, sectoral disaggregation from EUROSTAT and EU-KLEMS and the regional disaggregation from EUROSTAT.

Gross earnings of each regional industry. The gross earnings of each regional industry is calculated using the EU-KLEMS and EUROSTAT as a reference. Labour shares for each industry are calculated as follows:

$\frac{\text{Employee compensation} * \text{employees}}{\text{GVA}}$. In Table A.2.1 we present the labour share in each region in total activities.

Capital stock. Net stock of capital in the region broken down by the six branches of activity for 121 regions in nine European countries for the period 1995-2007. This figure is calculated using the Perpetual Inventory Method (PIM). Regional GFCF series taken from EUROSTAT are the basic inputs of the estimation, while the

procedure used to ensure regional comparability consists, on the one hand, of using the same sectoral depreciation rates for all the countries and regions in the sample and, on the other, of constructing sectoral regional capital stocks under identical criteria for all the regions in the different countries. Capital stock series provide a sectoral disaggregation similar to that used by EUROSTAT (NACE Rev. 1) for regional GFCF.

APPENDIX 2. European Regions and Groups

Table A.2.1. NUTS 2 Codes and Regional Groupings

Code	Group	Region	Labour shares ($1-\alpha_{ij}$)	Code	Group	Region	Labour shares ($1-\alpha_{ij}$)
Be1	North	Région de Bruxelles	0.675	Fr71	North	Rhône-Alpes	0.635
Be21	North	Prov. Antwerpen	0.673	Fr72	North	Auvergne	0.649
Be22	North	Prov. Limburg	0.689	Fr81	North	Languedoc-Roussillon	0.638
Be23	North	Prov. Oost-Vlaanderen	0.689	Fr82	North	Alpes-Côte d'Azur	0.639
Be24	North	Prov. Vlaams Brabant	0.670	Fr83	North	Corse	0.657
Be25	North	Prov. West-Vlaanderen	0.685	Itc1	North	Piemonte	0.595
Be31	North	Prov. Brabant Wallon	0.680	Itc2	North	Valle d'Aosta	0.619
Be32	North	Prov. Hainaut	0.703	Itc3	North	Liguria	0.600
Be33	North	Prov. Liège	0.702	Itc4	North	Lombardia	0.590
Be34	North	Prov. Luxembourg (B)	0.716	Itl1	North	Bolzano-Bozen	0.614
Be35	North	Prov. Namur	0.719	Itl2	North	Prov. Trento	0.614
De1	North	Baden-Württemberg	0.643	Itl3	North	Veneto	0.599
De2	North	Bayern	0.631	Itl4	North	Friuli-Venezia Giulia	0.606
De3	North	Berlin	0.624	Itl5	North	Emilia-Romagna	0.596
De4	North	Brandenburg	0.667	Itl1	North	Toscana	0.601
De5	North	Bremen	0.648	Itl2	South	Umbria	0.614
De6	North	Hamburg	0.606	Itl3	South	Marche	0.604
De7	North	Hessen	0.608	Itl4	North	Lazio	0.608
De8	North	Mecklenburg-Vorpom	0.669	Itf1	South	Abruzzo	0.620
De9	North	Niedersachsen	0.653	Itf2	South	Molise	0.630
Dea	North	Nordrhein-Westfalen	0.638	Itf3	South	Campania	0.624
Deb	North	Rheinland-Pfalz	0.658	Itf4	South	Puglia	0.619
Ded	North	Sachsen	0.656	Itf5	South	Basilicata	0.630
Dec	North	Saarland	0.637	Itf6	South	Calabria	0.634
Dee	North	Sachsen-Anhalt	0.675	Itg1	South	Sicilia	0.628
Def	North	Schleswig-Holstein	0.639	Itg2	South	Sardegna	0.629
Deg	North	Thüringen	0.668	NI11	North	Groningen	0.629

Es11	South	Galicia	0.629	Nl12	North	Friesland (NL)	0.662
Es12	South	Asturias	0.633	Nl13	North	Drenthe	0.661
Es13	South	Cantabria	0.624	Nl21	North	Overijssel	0.661
Es21	South	País Vasco	0.631	Nl22	North	Gelderland	0.666
Es22	South	Navarra	0.630	Nl23	North	Flevoland	0.656
Es23	South	La Rioja	0.611	Nl31	North	Utrecht	0.652
Es24	South	Aragón	0.624	Nl32	North	Noord-Holland	0.650
Es3	South	Com. Madrid	0.623	Nl33	North	Zuid-Holland	0.661
Es41	South	Castilla y León	0.623	Nl34	North	Zeeland	0.651
Es42	South	Castilla-la Mancha	0.621	Nl41	North	Noord-Brabant	0.645
Es43	South	Extremadura	0.639	Nl42	North	Limburg (NL)	0.648
Es51	South	Cataluña	0.619	At11	North	Burgenland (A)	0.719
Es52	South	Com. Valenciana	0.625	At12	North	Niederösterreich	0.685
Es53	South	Illes Balears	0.628	At13	North	Wien	0.634
Es61	South	Andalucía	0.632	At21	North	Kärnten	0.673
Es62	South	Región de Murcia	0.623	At22	North	Steiermark	0.671
Es7	South	Canarias	0.641	At31	North	Oberösterreich	0.653
Fr1	North	Île de France	0.608	At32	North	Salzburg	0.644
Fr21	North	Champagne-Ardenne	0.642	At33	North	Tirol	0.651
Fr22	North	Picardie	0.647	At34	North	Vorarlberg	0.633
Fr23	North	Haute-Normandie	0.645	Pt11	South	North	0.664
Fr24	North	Centre	0.641	Pt15	South	Algarve	0.702
Fr25	North	Basse-Normandie	0.648	Pt16	South	Centro (PT)	0.697
Fr26	North	Bourgogne	0.643	Pt17	South	Lisboa	0.635
Fr3	North	Nord - Pas-de-Calais	0.647	Pt18	South	Alentejo	0.755
Fr41	North	Lorraine	0.649	Se11	North	Stockholm	0.638
Fr42	North	Alsace	0.638	Se12	North	Östra Mellansverige	0.671
Fr43	North	Franche-Comté	0.648	Se21	North	Småland med öarna	0.677
Fr51	North	Pays de la Loire	0.638	Se22	North	Sydsverige	0.672
Fr52	North	Bretagne	0.644	Se23	North	Västsverige	0.664
Fr53	North	Poitou-Charentes	0.643	Se31	North	Norra Mellansverige	0.682
Fr61	North	Aquitaine	0.638	Se32	North	Mellersta Norrland	0.688
Fr62	North	Midi-Pyrénées	0.641	Se33	North	Övre Norrland	0.694
Fr63	North	Limousin	0.653				

Note: North = Northern Regions; South = Southern Regions.

APPENDIX 3. Regional TFP levels.

The following figures show the TFP level of all activities, ordered from lowest to highest in 1995 in a clockwise direction. The darkest line shows the starting level in 1995 and the lighter line the level reached in 2007, thus the peaks shown in this line indicate changes in the regional TFP ranking. The data are divided into two figures to provide a clearer picture of the 121 European regions: the first figure shows regions with lower levels of TFP while the second shows those with higher levels.



APPENDIX 4. Spatial Dependence Analysis.

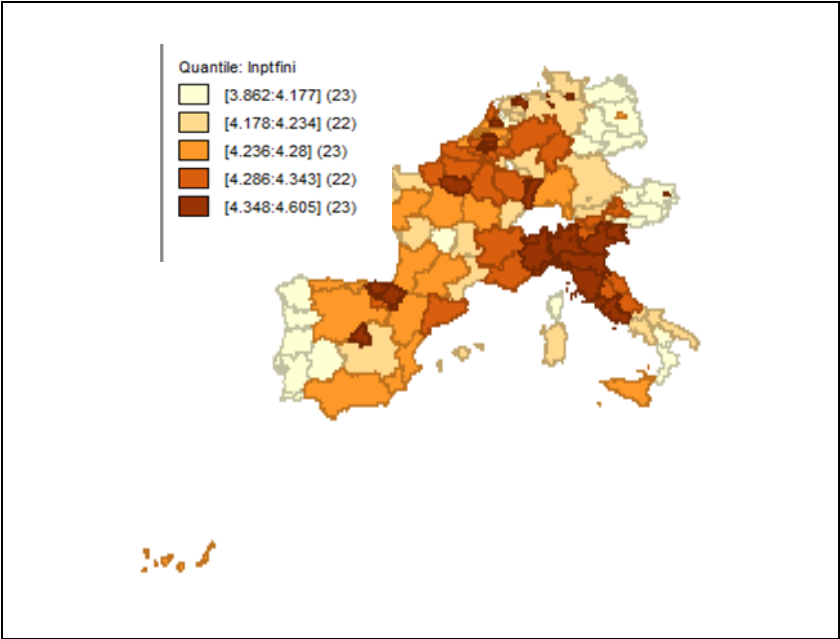
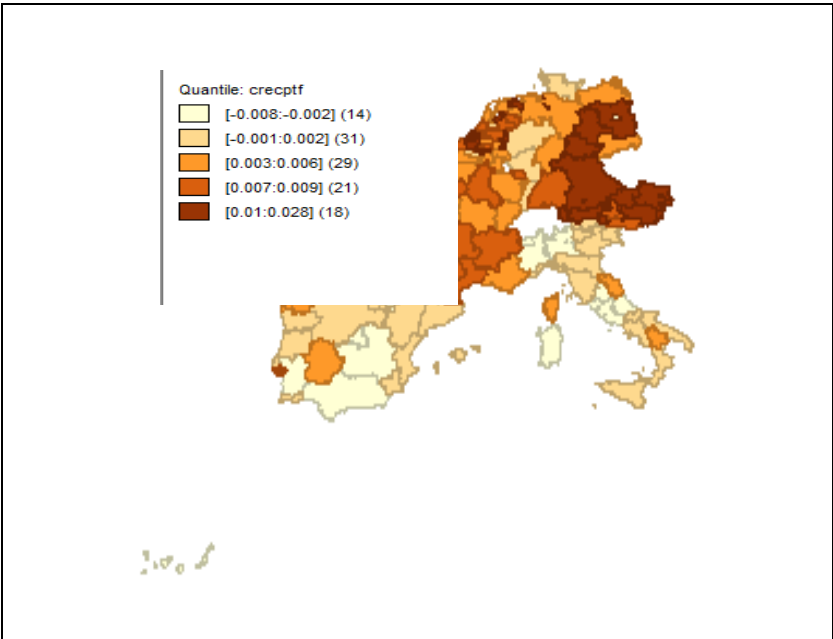


Figure A4a. 1995 TFP levels in European Regions. Total Activities. Source:
Created by authors based on data from BD.EURS



FigureA4b. Average TFP growth rate in European Regions, 1995-2007. Total Activities. Source: Created by authors based on data from BD.EURS

The model that includes all possible interaction effects—the General Nesting Spatial Model (GNS)—takes the form:

$$\begin{aligned}\hat{g}_{TFP} &= \alpha + \rho W \hat{g}_{TFP} + \beta \ln TFP_{1995} + \theta W \ln TFP_{1995} + \varepsilon \\ \varepsilon &= \lambda W \varepsilon + u \quad u \rightarrow N(0, \sigma^2 I)\end{aligned}$$

where W is the spatial weights matrix, usually containing contiguity relations or functions of distance. A first-order contiguity matrix has zeros on the main diagonal, rows that contain zeros in positions associated with non-contiguous observational units and ones in positions reflecting neighbouring units that are (first-order) contiguous. Parameter ρ captures the “endogenous” effect of a region’s neighbours’ TFP growth rates on its own TFP growth rates. Parameter θ captures the “exogenous” effect of a region’s neighbours’ initial TFP levels on its own TFP growth rates. Parameter λ captures the “correlated” effects of unobserved mean characteristics or factors affecting neighbouring regions.

Since the GNS model includes all interaction effects, models that contain fewer interaction effects can be obtained by imposing restrictions on one or more of the parameters¹⁴. The simplest models arise from the following assumptions: First, if $\theta=0$, $\lambda=0$ and $\rho \neq 0$ we are assuming a spatial autoregressive model (SAR). Therefore, the average TFP growth of a region depends on its own initial TFP level and on TFP growth rates of other neighbouring regions through the spatially displaced endogenous variable.

Second, if $\theta \neq 0$, $\lambda=0$ and $\rho=0$ we are assuming that $\hat{g}_{TFP}$ is affected by spatial lags of the explanatory variables, which gives the spatial lag of X model (SLX). The average TFP growth of a region is influenced by its own initial TFP level as well as by the initial TFP level of the contiguous regions, captured by the spatially lagged exogenous variable.

Third, if $\theta=0$, $\lambda \neq 0$ and $\rho=0$ we assume a spatial autocorrelation in the error process (SEM). The average growth of a region is influenced by the anomalous growth (related to random or anticipated shocks) of its neighbouring regions. The residual spatial autocorrelation could be due to the omission of spatially correlated exogenous variables.

Combinations of these imposed restrictions are included in SAC (Spatial autoregressive combined model: $\theta=0$, $\lambda \neq 0$ and $\rho \neq 0$), SDM (spatial Durbin model: $\theta \neq 0$, $\lambda=0$ and $\rho \neq 0$) and SDEM (spatial Durbin error model: $\theta \neq 0$, $\lambda \neq 0$ and $\rho=0$) models.

¹⁴ See Halleck Vega and Elhorst (2015) for a detailed analysis.

Table 2 in the paper presents the estimation results of the convergence equation taking into account spatial dependence. We use the likelihood ratio (LR) or Lagrange multiplier statistics, as is standard practice in the spatial econometric literature. The spatial tests are computed using, as a spatial weights matrix W , a row-normalised binary contiguity matrix, with elements $w_{ij}=1$ if two spatial units share a common border, and 0 otherwise¹⁵. Tests (LR) in the lower part of Table 2 in each column show if the null hypothesis $\theta=0$, $\lambda=0$ or $\rho=0$, respectively, in equation (4) is accepted. To simplify the presentation of the results, only the results of the model according to the LR test are presented. Table 2 is divided into two panels: panel (a) presents results for absolute β -convergence and panel (b) shows results for conditional β -convergence.

References for Appendix

- Anselin, L. (1988): *Spatial Econometrics: Methods and Models*. Dordrecht, Germany: Kluwer Academic Publishers.
- Anselin L., I. Syabri and Y. Kho (2006): GeoDa: An introduction to spatial data analysis. *Geographical Analysis*, 38(1): 5-22.
- Halleck Vega, S. and P. Elhorst (2015) : THE SLX MODEL. *Journal of Regional Science*, 55(3): 339–363.

¹⁵ See Anselin (1988) and Anselin et al. (1996).