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ORIGINAL PAPER

The relationship between decentralization and economic growth across regimes

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Abstract

Panel smooth transition regression (PSTR) is applied to obtain thresholds in certain variables to classify the regions into regimes (high or low). Data for the regions of Spain over the period 1986–2010 are used. In general, the results point to a positive (negative) relationship between fiscal (administrative) decentralization and economic growth in regions with low public infrastructure stock per efficient worker and high human capital per worker. In addition, in regions with low (high) total factor productivity, expenditure (revenue) decentralization is positively (negatively) correlated with economic growth. The results are fairly robust to different specifications and estimation methods.

JEL Classification R11 · H77 · C33

1 Introduction

The resurgence of economic growth theory and the wave of decentralization in many countries over the past three decades have turned scholars' attention to the relationship between decentralization and economic growth. In fact, Oates (1999) pointed out that the main results of his early work on fiscal federalism should be valid in the dynamic setting of new models of economic growth, which has been supported by the theoretical article of Brueckner (2006). Moreover, the theoretical literature points to a hump-shaped relationship between fiscal decentralization and economic growth (Xie et al. 1999; Akai et al. 2007; Ogawa and Yakita 2009). The empirical

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evidence seems to be in line with this, since positive and negative relationships, as well as non-significant relationships, have been found to depend on the countries, sample period, methodology and variables capturing decentralization, as collected in surveys by Martínez-Vázquez and McNab (2003), Baskaran et al. (2016) and Martínez-Vázquez et al. (2017). Additionally, for OECD countries, Gemmell et al. (2013) found that spending decentralization was associated with lower economic growth, while revenue decentralization was associated with higher growth. Moreover, Thießen (2003) and Carniti et al. (2019) found hump-shaped relationships using total expenditure measures of fiscal decentralization for panels of countries. However, Carniti et al. (2019) also found an inverted hump-shaped relationship using a measure based on public infrastructure investment.

The fact that the empirical results are heterogeneous raises the question of whether there are some other aspects that condition the relationship between decentralization and economic growth, such as institutions and culture, which are very difficult to quantify and test, as pointed out by Stansel (2005). The level of development itself could also be a factor that conditions such a relationship as suggested by Sato and Yamashige (2005) in their theoretical work, and empirically tested by Davoodi and Zou (1998), who found a negative relationship for developing countries and no relationship for developed countries.

In any case, one of the main conclusions of the both theoretical and empirical literature is that the relationship between decentralization and economic growth is non-monotonic.

Another issue that can be drawn from the empirical literature is that most of the previous evidence considered one facet of decentralization (fiscal decentralization) and therefore neglected administrative decentralization. In addition, most of the articles focused on just one dimension of fiscal decentralization, either revenue decentralization or expenditure decentralization, while few works considered both jointly.

This article addresses the three main issues in the empirical literature as pointed out above. Therefore, (i) we consider that the relationship between decentralization and economic growth is non-monotonic and, in particular, we contribute to the literature that claims that such a relationship depends on the state of the economy. Inspired in this literature, it is hypothesized that the correlation between decentralization and economic growth could depend on the regimes of some relevant economic variables. Additionally, (ii) we address the multifaceted dimension of decentralization by considering both fiscal and administrative decentralization and (iii) deal with the multidimensional aspects of fiscal decentralization by considering expenditure and revenue measures.

In the empirical strategy, a novel methodology is implemented to test the relationship between decentralization and economic growth. Thus, to achieve our objective, we use panel smooth transition regression (González et al. 2005; Fok et al. 2005), a nonlinear estimation approach that has the additional advantage of nesting the linear estimation commonly used in the literature. This econometric technique allows estimating the threshold levels of variables to determine regimes; for example, a high regime or low regime, in a given time, if the value of the variable is above or below the threshold. Therefore, we are able to test statistically the relationship between decentralization and economic growth rates across the determined regimes.

The candidate variables to generate thresholds are called transition variables and, in principle, any variable could be a candidate. Therefore, we consider variables related not only to the decentralization process itself, but also, control variables or any other key variable of the economy.

Even though it is too risky to predict which variables could generate different correlations between decentralization and economic growth, a strand of the above theoretical and empirical literature has shown that this relationship is conditioned on the level of economic development. Therefore, we might expect a priori that fundamental economic variables, such as output per capita, inputs of the production function and the indicator of technology, are the main candidates to generate regimes.

This article focuses specifically on Spain; one of most decentralized countries of Europe alongside Switzerland, Germany and Belgium. Despite the mixed results found in the empirical literature on the relationship between fiscal decentralization and economic growth, on the whole, positive relationships have been found for single-country studies. As Baskaran et al. (2016) pointed out, this may be due to the common institutional framework. In recent years, the evidence biased toward a positive relationship has been rectified with the findings of Lozano and Julio (2016) for Colombia; Park et al. (2019) for South Korea; Mendoza-Velázquez et al. (2022) for Mexico; Ding et al. (2019) for China and Thanh and Canh (2020) for Vietnam. Even for cross-country analysis, recent literature has found a positive relationship between decentralization and economic growth as shown by Canavire-Bacarreza et al. (2020) and Huynh and Nguyen (2020). In the particular case of Spain, the empirical evidence provided by Carrión-i-Silvestre et al. (2008), Cantarero and Pérez-González (2009), Gil-Serrate et al. (2011) and Aray (2018) found positive relationships. However, Aray (2018) also found a negative relationship between administrative decentralization and economic growth.

Following the literature on the effects of institutions on the economy (North 1990; Hall and Jones 1999; Rodrick, Subramnian and Trebbi, 2004 and Dixit 2009), it is assumed that variables, which capture decentralization, are collected by the total factor productivity (*TFP*). Therefore, we follow the approach of Aray (2018), who specified an equation for the *TFP* growth rate including explanatory variables that capture fiscal and administrative decentralization and the control variables suggested in the literature. However, this article goes further than Aray (2018) since it provides evidence across regimes generated by relevant economic variables. In addition, we also show evidence using measures of the *TFP* growth rate obtained from estimating translog production functions and stochastic frontier models.

Data for the period 1986–2010 are used for the Spanish autonomous communities (NUTS2). We are aware that by focusing on regions of a single country, the institutions and culture are more homogenous than when using a panel of countries. Precisely, we are more interested in the different correlations between decentralization and economic growth that might be conditioned by economic variables such as development level, as suggested in the theoretical literature.

As pointed out by Aray (2018), this topic is very suitable for Spain because of the Catalan government's recent disputed call for independence and the usual political debate of going forward or backward in the decentralization process based on efficiency arguments. Thus, we are able to provide a wide methodology that can give some insight into the direction to follow regarding the decentralization process based not only on a criterion of economic growth, but also on the levels of some key economic variables. In addition, the objective of this article might also be of great interest for European regional policy, which seeks to promote the reduction of structural differences between regions of the Union, the balanced development of the Community, and ensure equal opportunities for individuals.

The article is organized as follows: The empirical strategy is presented in the next section and estimation issues are described in Sect. 3. Section 4 shows the robustness check, while Sect. 5 discusses policy implications. Conclusions are drawn in Sect. 6.

2 Empirical strategy

2.1 Specification of the TFP

Let the final output of region i in year t, Y_{it}, be given by a Cobb–Douglas production as follows:

$$Y_{it} = B_{it} K_{it}^{\alpha_{it}} L_{it}^{\beta_{it}}, \tag{1}$$

where Y_{it} is the constant value added at a factor cost; K_{it} is the stock of non-residential productive physical capital and L_{it} is the number of efficient workers (human capital stock). α_{it} and β_{it} are the elasticities of output respect to the inputs. Therefore, B_{it} is the *TFP* when labor is adjusted for human capital.[1]

Following Aray (2018), let *TFP* evolve over time according to a function as follows[2]:

$$\begin{aligned} \frac{B_{it}}{B_{it-1}} = & \frac{Z_{it}}{Z_{it-1}} \left(\frac{S_{it}}{S_{it-1}}\right)^{\theta_1} \left(\frac{k_{it}^{pu}}{k_{it-1}^{pu}}\right)^{\theta_2} \left(\frac{k_{it}^{hc}}{k_{it-1}^{hc}}\right)^{\theta_3} \left(\frac{k_{it}^{s}}{k_{it-1}^{s}}\right)^{\theta_4} \left(\frac{k_{it}^{rd}}{k_{it-1}^{id}}\right)^{\theta_5} \\ & \times \left(\frac{T_{it}}{T_{it-1}}\right)^{\theta_6} \left(\frac{F_{it}}{F_{it-1}}\right)^{\theta_7} \left(\frac{I_{it}^{pu}}{I_{it-1}^{pu}}\right)^{\theta_8} \left(\frac{I_{it}^{eh}}{I_{it-1}^{eh}}\right)^{\theta_9} \left(\frac{R_{it}}{R_{it-1}}\right)^{\theta_{10}} \end{aligned} \tag{2}$$

where S_{it} is a specialization index as specified by Álvarez (2007) that accounts for the different economic structure of the regions with respect to the whole country.[3]

[1] Base year 2005 was used.

[2] More details on the definitions of variables are in Table 1.

[3] The index is defined as follows

$$S_{it} = \sum_{j=1}^{5} \left(\frac{Y_{it,j}}{Y_{it}} - \frac{\mathbf{Y}_{t,j}}{\mathbf{Y}_t}\right)^2$$

Being $Y_{it,j}$ the gross value added of sector j in region i in year t. The sectors are classified as follows: agriculture, industry, energy, construction and services. Y_{it} is the total gross value added of region i in year t as defined above and $\mathbf{Y}_{t,j}$ and $\mathbf{Y}_t$ stand for values added referring to whole country, Spain. S_{it} is zero when the regional productive structure is equal to that of the whole country, and increases with the level of specialization.

Table 1 Description of the variables

Variable	Description referred to community *i* in time *t*	Source
Y_{it}	Gross value added	Spanish Statistical Office (INE)
B_{it}	Total factor productivity (*TFP*)	Own calculations. Data from INE, BBVA Foundation-Ivie and Bancaja Foundation-Ivie
K_{it}	Stock of non-residential productive physical capital	BBVA Foundation-Ivie
L_{it}	Efficient workers: Number of workers adjusted by human capital	Bancaja Foundation-Ivie
$\hat{K}_{it}$	Combined input for growth accounting	Own calculations. Data from INE
y_{it}	Gross value added per efficient worker	Own calculations. Data from INE and Bancaja-Ivie
k_{it}	Stock of non-residential productive physical capital per efficient worker	Own calculations. Data from BBVA-Ivie and Bancaja-Ivie
K^{*}_{it}	Stock of non-residential productive capital without including public infrastructure	BBVA-Ivie
S_{it}	Specialization index	Own calculations. Data from INE
$Y_{it,j}$	Gross value added of sector *j*	INE
$\mathbf{Y}_{t,j}$	Gross value added of sector *j* at national level	INE
$\mathbf{Y}_{t}$	Gross value added of the country	INE
K^{pu}_{it}	Public infrastructure stock	BBVA Foundation-Ivie
k^{pu}_{it}	Public infrastructure stock per efficient worker	Own calculations. Data from BBVA-Ivie and Bancaja-Ivie
K^{hc}_{it}	Healthcare public capital stock	BBVA Foundation-Ivie
k^{hc}_{it}	Healthcare public capital stock per efficient worker	Own calculations. Data from BBVA-Ivie and Bancaja-Ivie
k^{s}_{it}	Index of social capital per capita	BBVA Foundation-Ivie
K^{rd}_{it}	R &D capital stock	BD.MORES
k^{rd}_{it}	R &D capital stock per efficient worker	Own calculations. Data from BD.MORES and Bancaja-Ivie
T_{it}	Own taxes collected by regional government/total taxes collected by the central and regional governments in region *i*	Own calculations. Data from BADESPE
F_{it}	T_{it} plus the part of the VAT and income taxes transferred/Total non-financial resources of the regional government	Own calculations. Data from BADESPE
I^{pu}_{it}	Investment in infrastructure of the subnational governments/total public investment in public infrastructure in region *i*	Own calculations. Data from BBVA-Ivie and Bancaja-Ivie

Table 1 (continued)

Variable	Description referred to community *i* in time *t*	Source
I_{it}^{eh}	Infrastructure spending in education (E) and health (H) of the subnational governments/total public investment in E and H	Own calculations. Data from BBVA-Ivie and Bancaja-Ivie
R_{it}	Number of royal decrees issued for the region/regional average of royal decrees issued by the state	Own calculations. Data from the Ministry of Territorial Policy
D_{it}	$D_{it} = 1$, If the same party holds office in the central and regional government with majority in the central government	Own calculations. Data from RULERS, World Statesmen.org

k_{it}^{pu} is the regional public infrastructure stock per efficient worker.[4] k_{it}^{hc} is a variable accounting for public healthcare capital stock per efficient worker. k_{it}^{s} is an index of social capital per capita of region i in time t. k_{it}^{rd} is the R &D stock per efficient worker.

To capture decentralization, the five explanatory variables suggested by Aray (2018) are considered. T_{it} is the tax autonomy and F_{it} refers to financial autonomy.[5] I_{it}^{pu} is the investment autonomy indicator for public infrastructure[6] and I_{it}^{eh} is the investment autonomy indicator for education and health.[7] R_{it} captures the administrative decentralization, that is, the political, legal, administrative and economic decision-making power of the regions, which can be collected by competencies assumed by the autonomous communities and proxied by the ratio between the number of royal decrees on the transfers of competencies issued for the autonomous community i and the regional average of royal decrees issued by the state in year t.

Finally, $\frac{Z_{it}}{Z_{it-1}}$ is assumed to capture deterministic and random shocks, such as

$$\frac{Z_{it}}{Z_{it-1}} = e^{\left(\delta_i+\tau_t+\sum_{p=0}^{2}\theta_p D_{it-p}+\varepsilon_{it}\right)} \tag{3}$$

where δ_i captures specific regional characteristics, τ_t captures time effects that equally affect all the regions, D_{it} is a dummy variable that takes the value one whenever the same party holds office in the central and regional government simultaneously and with majority in the central government, and zero otherwise. It was constructed as suggested by Aray (2016)[8] and ε_{it} is a random disturbance.

Substituting (3) in (2) and taking the natural logarithm, the growth rate of *TFP* is given by:

$$\begin{aligned}\triangle Log\left(B_{it}\right) =& \delta_i + \tau_t + \sum_{p=0}^{2} \theta_p D_{it-p} + \theta_1 \triangle Log\left(S_{it}\right) + \theta_2 \triangle Log\left(k_{it}^{pu}\right) \\ &+ \theta_3 \triangle Log\left(k_{it}^{hc}\right) + \theta_4 \triangle Log\left(k_{it}^{s}\right) + \theta_5 \triangle Log\left(k_{it}^{rd}\right) \\ &+ \theta_6 \Delta Log\left(T_{it}\right) + \theta_7 \triangle Log\left(F_{it}\right) + \theta_8 \triangle Log\left(I_{it}^{pu}\right) \\ &+ \theta_9 \triangle Log\left(I_{it}^{eh}\right) + \theta_{10} \triangle Log\left(R_{it}\right) + \varepsilon_{it}\end{aligned} \tag{4}$$

[4] It includes roads and highways, water systems, railways, airports, ports and other urban infrastructures provided by local governments.

[5] Equivalent measures were calculated for the autonomous communities under the special regime (Basque Country and Navarre).

[6] It includes items 102, 103, 202 and 203 of the public investment series of the BBVA foundation-Ivie.

[7] It includes items 702, 703, 802 and 803 of the public investment series of the BBVA foundation-Ivie.

[8] Aray (2016) found evidence only for this dummy variable with majority in the central government. For that reason, we just included it.

2.2 Measuring the TFP

2.2.1 Growth accounting approach

The variable $\triangle Log(B_{it})$ is a non-observable variable that it is initially calculated by performing a growth-accounting exercise as Aray (2016). For the calculation, constant returns to scale are assumed, that is, the constraint $\beta_{it} = 1 - \alpha_{it}$ is imposed. Thus, the growth rate of *TFP* is calculated through the Divisia–Tornqvist index as follows:

$$\Delta Log(B_{it}) = \Delta Log(Y_{it}) - \Delta Log(\hat{K}_{it})$$

where

$$\Delta Log(\hat{K}_{it}) = \frac{\alpha_{it} + \alpha_{it-1}}{2} \Delta Log(K_{it}) + \frac{(1 - \alpha_{it}) + (1 - \alpha_{it-1})}{2} \Delta Log(L_{it})$$

α_{it} is calculated with data from INE.

2.2.2 Cobb–Douglas production function

A Cobb–Douglas production function without imposing constant returns to scale is proposed as follows

$$Y_{it} = B_{it} K_{it}^{\alpha_i} L_{it}^{\beta_i} \tag{5}$$

The two-step approach by Cole and Neumayer (2006) is followed. However, this article goes further by considering that elasticities of output with respect to the inputs vary across regions.[9] Fortunately, panel data are very useful to overcome this problem since it is possible to estimate α_i and β_i, for $i = 1, 2, ...17$. Therefore, the following equation is estimated in the first step

$$\triangle Log(Y_{it}) = \alpha_i \triangle Log(K_{it}) + \beta_i \triangle Log(L_{it}) + \upsilon_{it}, \tag{6}$$

where $\upsilon_{it} = \triangle Log(B_{it})$. Therefore, a measure of the *TFP* growth rate can be obtained through an econometric approach by estimating a production function as an alternative to the growth accounting methodology. Thus, the estimation $\hat{\upsilon}_{it}$ can be used as the dependent variable in Eq. (4) in the second step of the procedure. Notice, however, that with this procedure we are assuming constant elasticities of output respect to inputs over time. In addition, we dot not include individual and time effects, and therefore, they are included in $\hat{\upsilon}_{it}$ as assumed in Eq. (4).

2.2.3 Stochastic frontier approach: Cobb–Douglas production function

Let us rewrite production function in Eq. (5) as follows

[9] Barro (1999) already stressed the disadvantage of considering static factor shares.

$$Y_{it} = e^{v_{it}} \xi_{it} K_{it}^{\alpha_i} L_{it}^{\beta_i} \tag{7}$$

where $\xi_{it} \in (0, 1]$ is the level of efficiency for region i at time t. If $\xi_{it} = 1$, the region is achieving the maximum output with the available technology. v_{it} is a random shock. In analogy with Eq. (5), notice that $B_{it} = e^{v_{it}} \xi_{it}$ in Eq. (7).

Taking natural logarithm in Eq. (7), the following stochastic frontier model can be estimated

$$Log\left(Y_{it}\right) = \alpha_i Log\left(K_{it}\right) + \beta_i Log\left(L_{it}\right) + v_{it} - \omega_{it} \tag{8}$$

where $\omega_{it} = -Log\left(\xi_{it}\right)$, which is assumed to follow a half-normal distribution, that is, $\omega_{it} \sim |N\left(0, \sigma_{it}^2\right)$. Again, we expand on the traditional empirical literature on the stochastic frontier models by considering that elasticities of output with respect to the inputs vary across regions.

We estimate the stochastic frontier model given by Eq. (8) using maximum likelihood estimation. Thus, we are able to construct the estimation of the *TFP* growth rate as follows

$$\triangle Log\left(B_{it}\right) = \left(\hat{v}_{it} - \hat{\omega}_{it}\right) - \left(\hat{v}_{it-1} - \hat{\omega}_{it-1}\right) \tag{9}$$

And, in a second step, Eq. (4) is estimated.

2.2.4 Stochastic frontier approach: translog production function

Since the translog production function is the Taylor approximation of the CES function, it has become very popular in empirical implementations. Therefore, we obtain a measure of the *TFP* growth rate by estimating the following stochastic frontier model[10]

$$\begin{aligned} Log\left(Y_{it}\right) =& \alpha_i Log\left(K_{it}\right) + \beta_i Log\left(L_{it}\right) + b_1\left(Log\left(K_{it}\right)\right)^2 + b_2\left(Log\left(L_{it}\right)\right)^2 \\ &+ b_3 Log\left(K_{it}\right) Log\left(L_{it}\right) + \psi_{it} - \varphi_{it} \end{aligned} \tag{10}$$

With ψ_{it} and φ_{it} similar to v_{it} and ω_{it}, respectively. The procedure to obtain $\triangle Log\left(B_{it}\right)$ is the same as above. Therefore,

$$\triangle Log\left(B_{it}\right) = \left(\hat{\psi}_{it} - \hat{\varphi}_{it}\right) - \left(\hat{\psi}_{it-1} - \hat{\varphi}_{it-1}\right) \tag{11}$$

[10] As a potential alternative to our approach, Almanidis et al. (2019) proposed a stochastic frontier model with thresholds along the lines of Hansen (1999). This model allows the fixed effects to vary over time smoothly and the variation pattern to depend on thresholds.

3 Estimation issues

Annual data over the period 1986–2010 are used.[11] All the regions of Spain (autonomous communities, NUTS2) are included: Andalusia, Aragon, the Principality of Asturias, the Balearic Islands, the Basque Country, the Canary Islands, Cantabria, Castile-La Mancha, Castile and Leon, Catalonia, Extremadura, Galicia, La Rioja, Madrid, Murcia, Navarre and Valencia.[12]

We estimate panel smooth transition regression (PSTR) models taking as a baseline Eq. (4) and for each of the four measures of *TFP* growth rate as dependent variables.[13] All the variables of the model in log and increments of log, as well an index for the TFP, were considered as candidates to generate regimes. The reported standard errors are adjusted by heteroskedasticity *à la* White (1980).[14]

According to the procedure described above, only three variables generate regimes: the public infrastructure stock per efficient worker, an index of *TFP* relative to Spain (the whole country) and the human capital stock per worker. The results obtained for the four measures of *TFP* growth rate are described below. Thus, case (1) refers to the growth accounting measure, cases (2), (3) and (4) use the *TFP* growth rate calculated from Eqs. (6), (9) and (11), respectively.

Table 2 shows the results for the four measures of *TFP* growth rate with the public infrastructure stock per efficient worker as the transition variable, whose threshold in log is 9.35–9.36 (11,500-11,600 constant euros per efficient worker). It is observed that about 83–84% of the observations classify the communities as low regime and 16–17% as high regime. As can be noticed at the bottom of Table 2, linearity hypotheses are rejected in most of the cases at the 1% level of significance and they are all rejected at the 10% level. We are aware of the issue of endogeneity. However, we cannot test for this properly under nonlinearity and, therefore, exogeneity is assumed.[15]

In the low regime, regarding the control variables, the results are quite robust for the specialization index and for the public infrastructure stock per efficient worker since they remain significant at the 1% level independently of the measure of *TFP*

[11] When the database was constructed, data on physical capital at regional level were available until 2010.

[12] Fortunately, the disaggregated data available at NUTS2 level for the variables needed for the empirical implementation are not unique to Spain. Certainly, most OECD countries have similar available data. Therefore, our methodology can be applied in these countries.

[13] Details on the econometric approach are provided in Appendix.

[14] Estimations with clustered robust standard errors using the panel units as the cluster yield the same results.

[15] Since conventional exogeneity tests are not valid under nonlinearity, a large number of articles merely assumes the issue does not exist. Other articles assume potential endogeneity and estimate using instrumental variable approaches (Fouquau et al. 2008; Lee and Chiu 2011; Kinfack and Bonga-Bonga 2022). Endogeneity in the context of the threshold panel data framework is still developing. Seo and Shin (2016) extended the panel threshold model of Hansen (1999; 2000) to account for endogenous regressors using GMM. However, to our knowledge, such an extension and the corresponding asymptotic theory for the PSTR have not still been developed. In addition, GMM works when the number of individuals is larger than the time periods, $\mathbf{N} > \mathbf{T}$, and we have that $\mathbf{T} > \mathbf{N}$. PSTR with GMM becomes a formidable task beyond the scope of this article.

Table 2 PSTR with the public infrastructure stock per efficient worker as the transition variable

Transition variable:	Public infrastructure stock per efficient worker							
	(1)		(2)		(3)		(4)	
Threshold	9.3629		9.3475		9.3475		9.3475	
Gamma	20		20		20		20	
	Low	84%	Low	83%	Low	83%	Low	83%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	0.0044	0.0047	0.0044	0.0043	0.0033	0.0043	0.0033	0.0044
D_{t-1}	− 0.0061	0.0046	− 0.0048	0.0038	− 0.0050	0.0043	− 0.0050	0.0042
D_{t-2}	− 0.0047	0.0029	− 0.0041	0.0027	− 0.0004	0.0029	− 0.0006	0.0027
$\Delta Log(S_{it})$	**0.0121**	0.0025***	**0.0114**	0.0021***	**0.0114**	0.0021***	**0.0114**	0.0022***
$\Delta Log(k_{it}^{pu})$	**0.3393**	0.0726***	**0.1677**	0.0556***	**0.1991**	0.0542***	**0.1896**	0.0540***
$\Delta Log(k_{it}^{hc})$	0.0378	0.0253	0.0139	0.0184	− 0.0067	0.0192	0.0001	0.0172
$\Delta Log(k_{it}^{s})$	− **0.0261**	0.0149*	− 0.0158	0.0144	− 0.0103	0.0139	− 0.0087	0.0138
$\Delta Log(k_{it}^{rd})$	**0.0774**	0.0390*	0.0461	0.0306	**0.0561**	0.0204**	**0.0579**	0.0188***
$\Delta Log(T_{it})$	− 0.0040	0.0063	− 0.0027	0.0055	− 0.0020	0.0059	− 0.0021	0.0063
$\Delta Log(F_{it})$	**0.0117**	0.0059*	**0.0109**	0.0053*	0.0082	0.0051	**0.0091**	0.0052*
$\Delta Log(I_{it}^{pu})$	**0.0139**	0.0042***	**0.0103**	0.0038**	**0.0101**	0.0037**	**0.0098**	0.0037**
$\Delta Log(I_{it}^{eh})$	− **0.0054**	0.0028*	− 0.0043	0.0025	− 0.0050	0.0030	− 0.0051	0.0032
$\Delta Log(R_{it})$	− **0.0459**	0.0157***	−**0.0398**	0.0150**	− **0.0446**	0.0209**	− **0.0449**	0.0204**
	High	16%	High	17%	High	17%	High	17%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	**0.0936**	0.0079***	**0.0853**	0.0087***	**0.0638**	0.0080***	**0.0674**	0.0082***
D_{t-1}	− **0.0529**	0.0102***	− **0.0497**	0.0112***	− **0.0405**	0.0099***	− **0.0432**	0.0102***
D_{t-2}	0.0042	0.0092	0.0032	0.0070	− 0.0072	0.0072	− 0.0046	0.0077
$\Delta Log(S_{it})$	0.0134	0.0089	**0.0163**	0.0073**	0.0091	0.0098	0.0093	0.0098
$\Delta Log(k_{it}^{pu})$	**0.2114**	0.1185*	0.0466	0.0909	0.0978	0.0850	0.1028	0.0930
$\Delta Log(k_{it}^{hc})$	0.0807	0.1195	0.0745	0.0910	0.0255	0.0972	0.0263	0.0994
$\Delta Log(k_{it}^{s})$	− **0.0328**	0.0169*	− 0.0225	0.0176	− 0.0123	0.0143	− 0.0096	0.0150
$\Delta Log(k_{it}^{rd})$	**0.1092**	0.0495**	0.0805	0.0463	**0.0895**	0.0502*	**0.0878**	0.0501*
$\Delta Log(T_{it})$	0.0651	0.0399	**0.0623**	0.0356*	0.0561	0.0326	0.0564	0.0326
$\Delta Log(F_{it})$	**0.0172**	0.0080**	**0.0117**	0.0067*	**0.0194**	0.0104*	**0.0189**	0.0094*
$\Delta Log(I_{it}^{pu})$	− 0.0019	0.0061	− 0.0026	0.0050	0.0037	0.0066	0.0032	0.0067
$\Delta Log(I_{it}^{eh})$	− 0.0004	0.0035	0.0001	0.0029	− 0.0009	0.0032	− 0.0006	0.0033
$\Delta Log(R_{it})$	− 0.0034	0.0492	− 0.0295	0.0435	− 0.0380	0.0393	− 0.0422	0.0405

Table 2 (continued)

	High	16%	High	17%	High	17%	High	17%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
No. of observations	388		388		388		388	
No. of individuals	17		17		17		17	
R^2	0.6179		0.5769		0.5536		0.5418	
Linearity tests	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*
Ho: $\delta_1 = ... = \delta_m = 0$	1.8090	0.0087	1.9087	0.0046	1.4115	0.0854	1.4729	0.0621
Ho: $\pi_1 = \pi_2$	56.1251	0.0000	21.4761	0.0000	71.2688	0.0000	75.8510	0.0000

$***, **, *$ Significant at 1%, 5% y 10%, respectively

growth rate. In addition, a positive and significant coefficient is found for the R &D capital stock per worker in three cases, while weak evidence is found for social capital. For the variables capturing fiscal decentralization, in the case of revenue decentralization, the estimates of the parameters of financial autonomy are positive and significant across three cases at the 10% level, while no evidence was found for tax autonomy. In relation to the variables that capture expenditure decentralization, strong evidence is found for the estimate of the parameter of the variable capturing autonomy in public infrastructure investment, which is positive and significant for the case of the the growth accounting measure of *TFP* at the 1% level and at the 5% level in the other three cases, while very weak evidence was found for the variable capturing autonomy of investment in education and health infrastructure, whose estimated coefficient is negative and significant at the 10% level only when the dependent variable is obtained from the growth accounting exercise. As regards administrative decentralization, the estimate of the parameter of the indicator of transferred competencies is found to be negative and significant at the 1% level in the first case and at the 5% level in the other three cases.

In the high regime, regarding the control variables, the coefficients of the political dummies are significant at the 1% level across the four cases and with positive signs for the contemporary value and negative signs for the one lagged period value. In addition, weak evidence was found for specialization and public infrastructure, which have positive signs in one out of the four cases and are significant at the 5 and 1% levels, respectively. The results for R &D capital stock and social capital are similar to those found in low regime. In relation to the variables that capture decentralization, it is observed that the results are weaker than in the low regime. In fact, statistical evidence is only found for the variables that capture revenue decentralization. Thus, the estimated coefficient of tax autonomy is positive and significant at the 10% level in one out of the four cases, while the estimated coefficient of financial autonomy is positive and significant at the 5% level in the first case and at 10% in the other three cases.

Summarizing, revenue decentralization seems to be weakly and positively correlated with economic growth regardless of the level of public infrastructure stock per efficient worker, although the evidence is a little stronger in the high regime. However, in the low regime of public infrastructure stock per efficient worker, there is a strong positive relationship between autonomy in public infrastructure investment and economic growth, while it is negatively correlated with the variable that captures administrative decentralization.

Table 3 shows the results for the four measures of *TFP* growth rate with the transition variable *TFP* index, whose threshold is 102-105. Recall that this transition variable is a relative index of TFP with respect to the whole country, which is normalized to 100. As can be seen in the four cases, the observations are more balanced across the low and the high regimes than in Table 2. Again, linearity hypotheses are rejected in most of the cases at the 1% level of significance.

Notice that, as in Table 2, the results of the control variables in the low *TFP* regime are quite robust for the specialization index and the public infrastructure stock per efficient worker, whose estimated coefficients remain significant at the 1 and 5% levels depending on the cases. Moreover, weak evidence was found for the political factors, while the estimated coefficient of R &D capital stock is positive and significant at the 1% level in cases (1) and (2). For the fiscal decentralization variables, it is obtained for revenue decentralization that the coefficient for financial autonomy is positive and significant at the 5% level in the first case and at the 10% level in the second case, while the coefficient of tax autonomy is positive and significant at 10% in case (3). For expenditure decentralization, the coefficient for autonomy in public infrastructure investment is positive and significant in all cases. Regarding administrative decentralization, only cases of measures *TFP* growth rate using stochastic frontier functions, estimates show negative and significant signs at the 5% level.

In the high *TFP* regime, the coefficients of the specialization index and public infrastructure stock per efficient worker are also positive and significant in all cases, most of them at the 1% level. In relation to the decentralization variables, the results are very different: the coefficient of tax autonomy is negative and significant at the 5% level when *TFP* growth rate is obtained from the residuals of the estimations of Cobb–Douglas production functions, regardless of the method.

Similar to the case with public infrastructure stock as a transition variable, when the *TFP* index is the transition variable, the results are stronger in the low regime.

Table 4 shows the results for the four measures of *TFP* growth rate with the transition variable human capital stock per worker, whose threshold in log is 0.82–0.86, being 2.3–2.4 per worker, which can be interpreted as an educational and skill multiplying factor of the number of workers. The results for the third and fourth measures of *TFP* growth rate must be taken with caution because it leaves very few observations (5%) in the low regime. Linearity hypotheses are rejected in most of the cases.

In the low regime, the results for the control variables are quite robust again for the specialization index since it is positive and significant at the 1% level for the first and second measures of *TFP* growth rate, while it is significant at the 10% level for the third measure. Moreover, the coefficients of public infrastructure stock per efficient worker and public capital health per efficient worker are positive and

Table 3 PSTR with an index of TFP as the transition variable

Transition variable:	Index of TFP							
	(1)		(2)		(3)		(4)	
Threshold	102.0824		103.2639		103.4499		104.7521	
Gamma	5		20		14		20	
	Low	58%	Low	66%	Low	29%	Low	45%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	0.0160	0.0103	0.0142	0.0083	**0.0235**	0.0133*	0.0200	0.0125
D_{t-1}	− 0.0099	0.0071	− 0.0087	0.0057	− 0.0110	0.0093	− 0.0126	0.0074
D_{t-2}	**− 0.0085**	0.0036**	**− 0.0061**	0.0033*	− 0.0065	0.0054	− 0.0063	0.0041
$\Delta Log(S_{it})$	**0.0085**	0.0036**	**0.0124**	0.0020***	**0.0174**	0.0047***	**0.0118**	0.0031***
$\Delta Log(k_{it}^{pu})$	**0.3647**	0.0943***	**0.1679**	0.0706**	**0.2657**	0.1217**	**0.2019**	0.0732**
$\Delta Log(k_{it}^{hc})$	0.0287	0.0465	0.0160	0.0382	0.0462	0.0664	0.0028	0.0468
$\Delta Log(k_{it}^{s})$	− 0.0122	0.0122	0.0020	0.0104	0.0098	0.0130	− 0.0053	0.0129
$\Delta Log(k_{it}^{rd})$	**0.1380**	0.0377***	**0.0892**	0.0237***	0.0441	0.0413	0.0954	0.0578
$\Delta Log(T_{it})$	− 0.0013	0.0172	0.0039	0.0119	**0.0337**	0.0193*	0.0002	0.0135
$\Delta Log(F_{it})$	**0.0140**	0.0059**	**0.0104**	0.0055*	− 0.0025	0.0097	0.0045	0.0051
$\Delta Log(I_{it}^{pu})$	**0.0201**	0.0083**	**0.0157**	0.0069**	**0.0507**	0.0145***	**0.0199**	0.0108*
$\Delta Log(I_{it}^{el})$	− 0.0016	0.0052	0.0000	0.0040	− 0.0064	0.0085	0.0009	0.0068
$\Delta Log(R_{it})$	− 0.0321	0.0297	− 0.0262	0.0282	**− 0.0638**	0.0289**	**− 0.0778**	0.0273**
	High	42%	High	34%	High	71%	High	55%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	0.0040	0.0054	0.0066	0.0057	0.0038	0.0048	0.0049	0.0057
D_{t-1}	− 0.0045	0.0077	− 0.0043	0.0066	− 0.0052	0.0054	− 0.0039	0.0058
D_{t-2}	− 0.0091	0.0071	**− 0.0104**	0.0051*	− 0.0017	0.0034	− 0.0021	0.0037
$\Delta Log(S_{it})$	**0.0192**	0.0035***	**0.0151**	0.0033***	**0.0084**	0.0041*	**0.0124**	0.0040***
$\Delta Log(k_{it}^{pu})$	**0.3185**	0.0789***	**0.1354**	0.0459***	**0.1657**	0.0515***	**0.1705**	0.0503***
$\Delta Log(k_{it}^{hc})$	0.0398	0.0322	0.0235	0.0232	− 0.0139	0.0251	0.0001	0.0250
$\Delta Log(k_{it}^{s})$	**− 0.0319**	0.0122**	− 0.0189	0.0110	− 0.0098	0.0088	− 0.0060	0.0099
$\Delta Log(k_{it}^{rd})$	0.0302	0.0261	− 0.0105	0.0171	0.0375	0.0222	0.0296	0.0222
$\Delta Log(T_{it})$	− 0.0122	0.0083	**− 0.0148**	0.0053**	**− 0.0128**	0.0056**	− 0.0084	0.0054
$\Delta Log(F_{it})$	0.0032	0.0059	0.0071	0.0055	0.0047	0.0054	0.0085	0.0059
$\Delta Log(I_{it}^{pu})$	0.0032	0.0049	− 0.0006	0.0032	0.0033	0.0033	0.0031	0.0040
$\Delta Log(I_{it}^{eh})$	− 0.0024	0.0023	− 0.0020	0.0014	− 0.0011	0.0033	− 0.0016	0.0032
$\Delta Log(R_{it})$	− 0.0453	0.0336	− 0.0266	0.0192	− 0.0194	0.0195	− 0.0298	0.0199
No. of observations	372		372		372		372	
No. of individuals	17		17		17		17	
R^2	0.4771		0.4127		0.5285		0.4597	

Table 3 (continued)

Linearity tests	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*
Ho: $\delta_1 = \ldots = \delta_m = 0$	1.8256	0.0026	1.5786	0.0181	2.1647	0.0001	1.5298	0.0257
Ho: $\pi_1 = \pi_2$	19.9701	0.0000	12.6854	0.0000	13.0061	0.0000	13.3317	0.0000

***, **, * Significant at 1%, 5% y 10%, respectively

significant at the 5 and 1% levels, respectively, and only in the case of the growth accounting measure of *TFP* growth rate. In addition, considering up to a 10% level, the contemporary value of partisan alignment has a positive and significant coefficients in two cases, while the first lag shows a negative and significant coefficient in all cases. Moreover, a negative and significant coefficient is also obtained for social capital in three out the four cases. Regarding the variables that capture decentralization, a negative and significant coefficient was only found at the 1% level for autonomy in education infrastructure and health investment and in all cases. Since Spanish regions hold almost all powers over education and health, no significant coefficient for autonomy in education infrastructure and health investment was expected. However, in this case, the negative coefficient could be indicating that in a region with a very healthy, educated and skilled workforce, higher investment in education and health by the central government compared to the regional and local governments could be associated with higher TFP growth rates.

In the high regime, the coefficients of the specialization index and the public infrastructure stock per efficient worker are significant at 1% in most cases, while weak evidence is found for the political factors. In addition, a negative and significant coefficient at the 5% level is also obtained for social capital in the first case. For fiscal decentralization, the estimates of the parameters for financial autonomy and autonomy in public infrastructure investment are positive and significant at the 5% level in all cases, while the variable capturing administrative decentralization shows a negative coefficient, which is significant at the 10% level in cases (1) and (2) and at the 5% level in cases (3) and (4).

The results found for the high regime in human capital regarding the variables that capture decentralization are quite striking because they mostly coincide with those found for the low regime in public infrastructure stock.

Table 4 PSTR with the human capital per worker as the transition variable

Transition variable:	Human capital stock per worker							
	(1)		(2)		(3)		(4)	
Threshold	0.8542		0.8633		0.8185		0.8185	
Gamma	20		19		5		5	
	Low	13%	Low	14%	Low	5%	Low	5%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	**0.0086**	0.0042*	**0.0154**	0.0043***	0.0171	0.0114	0.0152	0.0132
D_{t-1}	– **0.0201**	0.0088**	– **0.0193**	0.0072**	– **0.0312**	0.0158*	– **0.0307**	0.0159*
D_{t-2}	– 0.0005	0.0065	0.0020	0.0052	– 0.0025	0.0131	– 0.0038	0.0137
$\Delta Log(S_{it})$	**0.0537**	0.0154***	**0.0404**	0.0134***	**0.0743**	0.0400*	0.0724	0.0424
$\Delta Log(k_{it}^{pu})$	**0.3475**	0.1534**	0.2065	0.1342	0.1196	0.2111	0.1731	0.2258
$\Delta Log(k_{it}^{hc})$	**0.2698**	0.0856***	0.1141	0.0818	0.0938	0.1509	0.1124	0.1693
$\Delta Log(k_{it}^{s})$	– 0.0721	0.0422	– **0.0894**	0.0363**	– **0.1140**	0.0515**	– **0.0934**	0.0517*
$\Delta Log(k_{it}^{rd})$	0.0008	0.0893	– 0.0587	0.0864	0.1669	0.1286	0.1561	0.1350
$\Delta Log(T_{it})$	0.0517	0.0496	0.0442	0.0452	0.0925	0.0761	0.0868	0.0793
$\Delta Log(F_{it})$	0.0284	0.0254	0.0278	0.0249	0.0207	0.0430	0.0179	0.0416
$\Delta Log(I_{it}^{pu})$	0.0211	0.0253	0.0198	0.0234	0.0017	0.0427	0.0003	0.0424
$\Delta Log(I_{it}^{eh})$	– **0.0256**	0.0073***	– **0.0253**	0.0080***	– **0.0594**	0.0135***	– **0.0579**	0.0134***
$\Delta Log(R_{it})$	– 0.1088	0.0805	– 0.0799	0.0635	0.1430	0.1741	0.1073	0.1786
	High	87%	High	86%	High	95%	High	95%
	Coef	S.E	Coef	S.E	Coef	S.E	Coef	S.E
D_t	0.0118	0.0078	0.0103	0.0079	0.0067	0.0075	0.0069	0.0078
D_{t-1}	– 0.0060	0.0069	– 0.0051	0.0064	– 0.0035	0.0063	– 0.0039	0.0064
D_{t-2}	– **0.0067**	0.0035*	– **0.0069**	0.0034*	– 0.0034	0.0029	– 0.0033	0.0029
$\Delta Log(S_{it})$	**0.0122**	0.0023***	**0.0115**	0.0024***	**0.0111**	0.0026***	**0.0112**	0.0025***
$\Delta Log(k_{it}^{pu})$	**0.3871**	0.0868***	**0.1971**	0.0712**	**0.2426**	0.0552***	**0.2351**	0.0561***
$\Delta Log(k_{it}^{hc})$	0.0206	0.0237	0.0070	0.0188	– 0.0092	0.0207	– 0.0037	0.0189
$\Delta Log(k_{it}^{s})$	– **0.0297**	0.0135**	– 0.0183	0.0126	– 0.0095	0.0135	– 0.0083	0.0136
$\Delta Log(k_{it}^{rd})$	0.0536	0.0422	0.0242	0.0346	0.0218	0.0276	0.0243	0.0270
$\Delta Log(T_{it})$	– 0.0006	0.0065	0.0029	0.0053	0.0029	0.0062	0.0024	0.0066
$\Delta Log(F_{it})$	**0.0079**	0.0031**	**0.0066**	0.0027**	**0.0084**	0.0036**	**0.0090**	0.0035**
$\Delta Log(I_{it}^{pu})$	**0.0127**	0.0048**	**0.0095**	0.0043**	**0.0113**	0.0047**	**0.0110**	0.0046**
$\Delta Log(I_{it}^{eh})$	– 0.0021	0.0032	– 0.0013	0.0028	– 0.0013	0.0032	– 0.0016	0.0033
$\Delta Log(R_{it})$	– **0.0390**	0.0222*	– **0.0354**	0.0202*	– **0.0482**	0.0194**	– **0.0486**	0.0197**
	388		388		388		388	
	17		17		17		17	
	0.5458		0.4991		0.5011		0.4699	

Table 4 (continued)

Linearity tests	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*
$Ho: \delta_1 = ... = \delta_m = 0$	1.3947	0.0633	1.3199	0.1010	1.4261	0.0515	1.4405	0.0468
$Ho: \pi_1 = \pi_2$	26.0682	0.0000	26.1462	0.0000	18.0798	0.0000	17.0686	0.0000

***, **, * Significant at 1%, 5% y 10%, respectively

4 Robustness checks

An extended Cobb–Douglas production function accounting for public infrastructure is also proposed without imposing constant returns to scale in the spirit of Aschauer (1989). Thus, let us assume a production function as follows:

$$Y_{it} = B_{it}\left(K_{it}^{*}\right)^{\alpha_i}\left(L_{it}\right)^{\phi_i}\left(K_{it}^{pu}\right)^{\lambda_i} \tag{12}$$

where K_{it}^{*} is the stock of non-residential productive capital without including the public infrastructure stock.[16] K_{it}^{pu} is the stock of public infrastructure. Departing from Eq. (12), the following equation is estimated:

$$\triangle Log\left(Y_{it}\right) = \alpha_i \triangle Log\left(K_{it}^{*}\right) + \phi_i \triangle Log\left(L_{it}\right) + \lambda_i \triangle Log\left(K_{it}^{pu}\right) + \mu_{it}, \tag{13}$$

where $\mu_{it} = \triangle Log\left(B_{it}\right)$ is the disturbance. Again, the two-step approach by Cole and Neumayer (2006) is followed.

In addition, we estimate stochastic frontier models by extending Eqs. (8) and (10) to include public infrastructure stock similar to above and use the residuals to calculate *TFP* growth rates. However, in such cases, estimations with varying coefficients and varying efficiency parameters yielded non-concave likelihood functions. Therefore, we have to resort to fixed coefficients and fixed efficiency parameters.

As can be noticed in Table 5, the results are fairly robust across all cases. Interestingly, the negative relationship between tax autonomy and economic growth in regions with high *TFP* is stronger.

5 Policy implications

The evidence provided in the above sections could have policy implications as it shows that the relationship between decentralization and economic growth might be conditioned on levels of key economic variables, which is in line with the theoretical literature, suggesting that the level of development could be a factor that conditions such a relationship. In this regard, for the case of fiscal decentralization, the results are quite striking since they suggest that revenue decentralization could enhance economic growth in regions with low and high public infrastructure stock

[16] Thus, items 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.2.5, and 1.2.6 according to the classification by productive capital assets were taken from BBVA Foundation-Ivie.

Table 5 PSTR with TFP growth calculated from residuals of estimating production functions accounting for public infrastructure

Transition Variable:	Public infrastructure stock per efficient worker						Index of TFP						Human capital stock per worker					
	Cobb-Douglas production function				Translog production function		Cobb-Douglas production function				Translog production function		Cobb-Douglas production function				Translog production function	
	Δ%TFP from OLS residuals		Δ%TFP from SF residuals		Δ%TFP from SF residuals		Δ%TFP from OLS residuals		Δ%TFP from SF residuals		Δ%TFP from SF residuals		Δ%TFP from OLS residuals		Δ%TFP from SF residuals		Δ%TFP from SF residuals	
Threshold	9.3475		9.3475		9.3475		102.3753		98.2262		93.3389		0.8185		0.8633		0.9384	
Gamma	20		20		20		20		20		2		3		20		20	
	Low	83%	Low	83%	Low	83%	Low	60%	Low	36%	Low	5%	Low	5%	Low	14%	Low	43%
	Coef.	S.E	Coef.	S.E	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
D_{it}	0.0045	0.0042	0.0044	0.0043	0.0046	0.0043	0.0142	0.0083	0.0152	0.0092	0.0412	0.0238	0.0254	0.0107 **	0.0150	0.0044 ***	0.0209	0.0115 *
D_{it-1}	-0.0042	0.0037	-0.0049	0.0040	-0.0064	0.0043	-0.0080	0.0055	-0.0062	0.0071	-0.0025	0.0131	-0.0313	0.0150 *	-0.0196	0.0071 **	-0.0191	0.0102 *
D_{it-2}	-0.0035	0.0029	-0.0041	0.0028	-0.0030	0.0028	-0.0073	0.0037 *	-0.0083	0.0033 **	-0.0062	0.0106	0.0011	0.0155	0.0025	0.0051	-0.0071	0.0050
$\Delta Log(S_{it})$	0.0112	0.0019 ***	0.0112	0.0021 ***	0.0126	0.0021 ***	0.0110	0.0025 ***	0.0069	0.0042	0.0282	0.0164	0.0733	0.0384 *	0.0404	0.0136 ***	0.0205	0.0069 ***
$\Delta Log(k_{it}^{pu})$	0.2015	0.0537 ***	0.1358	0.0585 **	0.0928	0.0864	0.2116	0.0711 ***	0.2144	0.1042 *	0.8695	0.4584 *	0.0481	0.3212	0.1893	0.1308	0.2217	0.0736 ***
$\Delta Log(k_{it}^{hc})$	0.0029	0.0170	0.0158	0.0179	0.0189	0.0269	0.0053	0.0406	0.0117	0.0388	-0.1451	0.1528	0.0787	0.1294	0.1103	0.0834	0.0411	0.0457
$\Delta Log(k_{it}^{s})$	-0.0131	0.0142	-0.0150	0.0142	-0.0212	0.0152	0.0032	0.0101	-0.0016	0.0120	0.0658	0.0192 ***	-0.1703	0.0634 **	-0.0858	0.0354 **	-0.0225	0.0107 *
$\Delta Log(k_{it}^{rd})$	0.0340	0.0299	0.0484	0.0312	0.0640	0.0434	0.0676	0.0236 **	0.0623	0.0305 *	0.2161	0.1161 *	0.1113	0.1746	-0.0562	0.0865	0.0598	0.0289 *
$\Delta Log(T_{it})$	-0.0028	0.0053	-0.0029	0.0056	-0.0050	0.0072	0.0001	0.0141	0.0044	0.0182	0.1986	0.0808 **	0.1013	0.0856	0.0435	0.0450	0.0274	0.0138 *
$\Delta Log(F_{it})$	0.0103	0.0052 *	0.0105	0.0053 *	0.0116	0.0058 *	0.0116	0.0059 *	0.0082	0.0051	-0.0067	0.0148	0.0596	0.0397	0.0291	0.0250	0.0107	0.0097
$\Delta Log(I_{it}^{pu})$	0.0097	0.0037 **	0.0114	0.0038 ***	0.0127	0.0042 ***	0.0161	0.0076 **	0.0173	0.0088 *	0.1194	0.0347 ***	0.0223	0.0419	0.0214	0.0234	0.0159	0.0086 *
$\Delta Log(I_{it}^{eh})$	-0.0041	0.0025	-0.0048	0.0025 *	-0.0062	0.0025 **	-0.0003	0.0047	0.0045	0.0036	-0.0541	0.0223 **	-0.0528	0.0159 ***	-0.0257	0.0080 ***	-0.0043	0.0043
$\Delta Log(R_{it})$	-0.0400	0.0154 **	-0.0403	0.0149 **	-0.0549	0.0154 ***	-0.0158	0.0280	-0.0234	0.0222	-0.1256	0.0824	0.0493	0.1374	-0.0861	0.0629	-0.0620	0.0346 *
	High	17%	High	17%	High	17%	High	40%	High	64%	High	95%	High	95%	High	86%	High	57%
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
D_{it}	0.0840	0.0083 ***	0.0840	0.0087 ***	0.0811	0.0090 ***	0.0076	0.0057	0.0044	0.0048	0.0014	0.0048	0.0085	0.0075	0.0103	0.0079	0.0003	0.0042
D_{it-1}	-0.0481	0.0108 ***	-0.0506	0.0110 ***	-0.0550	0.0099 ***	-0.0036	0.0064	-0.0044	0.0054	-0.0032	0.0057	-0.0030	0.0062	-0.0053	0.0065	-0.0009	0.0047
D_{it-2}	0.0000	0.0063	0.0027	0.0068	-0.0053	0.0056	-0.0092	0.0054	-0.0074	0.0047	-0.0051	0.0031	-0.0062	0.0034 *	-0.0071	0.0034 *	-0.0027	0.0038
$\Delta Log(S_{it})$	0.0194	0.0072 **	0.0161	0.0074 **	0.0209	0.0068 ***	0.0152	0.0033 ***	0.0186	0.0039 ***	0.0147	0.0028 ***	0.0114	0.0029 ***	0.0112	0.0026 ***	0.0109	0.0028 ***
$\Delta Log(k_{it}^{pu})$	0.0813	0.0765	0.0315	0.0876	0.0252	0.0585	0.1777	0.0475 ***	0.0950	0.0464 *	0.0342	0.0699	0.2357	0.0645 ***	0.1615	0.0705 **	0.0187	0.0786
$\Delta Log(k_{it}^{hc})$	0.0683	0.0837	0.0643	0.0902	0.0339	0.0739	0.0123	0.0222	0.0100	0.0191	0.0308	0.0332	0.0026	0.0190	0.0091	0.0176	0.0160	0.0334
$\Delta Log(k_{it}^{s})$	-0.0216	0.0180	-0.0233	0.0163	-0.0438	0.0181 **	-0.0131	0.0106	-0.0201	0.0097 *	-0.0267	0.0079 ***	-0.0143	0.0129	-0.0180	0.0122	-0.0240	0.0085 **
$\Delta Log(k_{it}^{rd})$	0.0557	0.0441	0.0844	0.0480 *	0.0760	0.0422 *	-0.0128	0.0198	0.0218	0.0171	0.0376	0.0266	-0.0059	0.0313	0.0280	0.0353	0.0481	0.0410
$\Delta Log(T_{it})$	0.0625	0.0339 *	0.0624	0.0352 *	0.0554	0.0364	-0.0143	0.0061 **	-0.0136	0.0052 **	-0.0157	0.0069 **	0.0024	0.0056	0.0029	0.0053	-0.0061	0.0081
$\Delta Log(F_{it})$	0.0101	0.0069	0.0112	0.0070	0.0114	0.0071	0.0062	0.0043	0.0044	0.0054	0.0055	0.0044	0.0071	0.0027 **	0.0060	0.0028 **	0.0086	0.0040 **
$\Delta Log(I_{it}^{pu})$	-0.0034	0.0044	0.0002	0.0052	-0.0006	0.0050	-0.0006	0.0029	0.0024	0.0033	0.0013	0.0043	0.0090	0.0044 *	0.0110	0.0043 **	0.0097	0.0047 *
$\Delta Log(I_{it}^{eh})$	-0.0008	0.0031	-0.0011	0.0029	-0.0041	0.0039	-0.0016	0.0016	-0.0030	0.0029	0.0000	0.0027	-0.0006	0.0030	-0.0019	0.0029	-0.0061	0.0021 ***
$\Delta Log(R_{it})$	-0.0334	0.0399	-0.0345	0.0418	-0.0221	0.0341	-0.0376	0.0236	-0.0290	0.0202	-0.0283	0.0177	-0.0387	0.0214 *	-0.0361	0.0206 *	-0.0393	0.0295
Nº of observations	388		388		388		372		372		372		388		388		388	
Nº of individuals	17		17		17		17		17		17		17		17		17	
R^2	0.5677		0.5783		0.5769		0.4177		0.4592		0.5703		0.4948		0.5041		0.5523	
Linearity Tests	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*	*Statistic*	*p-value*
Ho: $\delta_1 = ... = \delta_m = 0$	1.9281	0.0040	1.8534	0.0066	2.0504	0.0018	1.4891	0.0342	1.6148	0.0138	1.4643	0.0405	1.3630	0.0775	1.3129	0.1054	1.7980	0.0032
Ho: $\pi_1 = \pi_2$	21.6081	0.0000	24.8087	0.0000	48.3382	0.0000	15.6016	0.0000	148.0603	0.0000	16.9279	0.0000	18.4401	0.0000	28.0182	0.0000	4.2094	0.0040

***, **, * Significant at 1%, 5% y 10%, respectively.

***, **, * Significant at 1%, 5% y 10%, respectively per efficient worker and high human capital per worker, while in regions with high *TFP*, revenue decentralization would be harmful for economic growth. Regarding expenditure decentralization, the evidence suggests that in regions with low public infrastructure stock per efficient worker, low *TFP* and high human capital per worker, increasing the autonomy of investment in hard infrastructure would contribute positively to economic growth.

In relation to administrative decentralization, the negative relationship found with economic growth could be indicating that an increase in the autonomous institutional framework and the corresponding bureaucracy become a drag on economic growth, as Aray (2018) already showed. The empirical evidence provided in this article goes further in associating this result to regions with low public infrastructure stock per worker and high human capital.

Interestingly, the results for regions with low public infrastructure stock per efficient worker and high human capital per worker are very similar. An analysis based on economic theory would indicate that the marginal product of the public infrastructure stock is greater precisely in regions where it is scarce and in regions with larger human capital. Therefore, it might be profitable from an economic standpoint to increase public investment in hard infrastructure in regions with such characteristics. However, for that purpose, and in accordance with the empirical results, such regions might require more financial autonomy and more power to allocate public infrastructure. This argument could also be related to the fact that the public infrastructure investment autonomy is positively correlated with economic growth in regions with low *TFP* growth rates. This allows us to link several relevant fields in the literature, such as empirical economic growth, the fiscal federalism theory, the new economic geography (NEG) and institutional economics.

The seminal paper of Aschauer (1989) marked the beginning of a very active empirical literature on the relationship between public infrastructure stock and economic growth, of which a great deal focuses on the indirect channel that accrues through the public infrastructure stock to the TFP. Although there is no full consensus on this topic, the literature might be biased toward a positive relationship. In fact, this article shows a positive and significant relationship in most cases. However, and according to the NEG literature, since public infrastructure investment on a national scale decreases interregional transport costs, which prompts firms and workers to agglomerate into core regions, spatial differences in production between the core and peripheral regions could increase. Albalate et al. (2012) showed interesting evidence on this topic. They pointed out that investment in transport infrastructure (road, railway, ports and airports) in Spain is highly dependent on central institutions and found that national infrastructure investment projects are aimed at favoring the connection with the capital (Madrid). This literature is related to the early work by Hirschman (1958), who already suggested the so-called "leaking by linking" phenomenon, i.e. investment in transport infrastructures at national level could bring gains and losses to regional economies. In this regard, Martin and Rogers (1995) highlighted the positive effects of improvements in local infrastructure on peripheral areas to offset the possible harmful effects of interregional infrastructure. Therefore, and in accordance with the fiscal federalism theory suggesting that regional planners are able to provide goods and services more efficiently because they know citizens' preferences better, greater financial autonomy and more decision-making power of regional governments concerning infrastructure projects could be helpful in proposing and choosing the best projects to increase the intraregional public infrastructure stocks. In turn, this would enhance regional TFP and counteract the negative externalities due to agglomeration economies. In fact, such an argument is related to the organization of a state and the distributions of the responsibilities across government layers, which lay into the institutional framework. Therefore, the institutions play a key role in the economic performance as claimed by the institutional economics. Nevertheless, the results also suggest that it might be recommendable for regions with the characteristics described above to return some other competencies to the central government.

The empirical results of this article could be also useful for making suggestions or recommendations on the direction to follow in the decentralization process based on a criterion of economic growth. More specifically, this proposal can shed light on hot issues in Spain, such as the reforms of the statutes of autonomy and the regional funding law. In addition, the empirical evidence can be useful for the European Union policy. Puga (2002) showed that inequalities among EU regions have increased in spite of the large expenditures funded by the European Union through the regional policy, whose budget of 392 billion euros for the period 2021–2027 is the largest budget item and almost a third of the total long-term EU budget. In this regard, if decentralization is one of the factors that explains differences in per capita income of European regions, as already shown by Ezcurra and Pascual (2008) and Tselios et al. (2012), variations in the degrees of decentralization could be used as an instrument to reduce inequalities in *TFP* productivity levels and per capita income in the European Union regions.

6 Conclusions

This paper presents new evidence on the relationship between decentralization and economic growth. It attempts to shed light on the heterogeneous evidence reported in the empirical literature. Thus, based on the theoretical literature, which has found that this relationship is non-monotonic, it is hypothesized that the relationship between decentralization and economic growth depends on the states of some relevant variables. The paper focuses on the Spanish regions (NUTS2) during the period 1986–2010. PSTR is applied, which allows estimating thresholds for determined variables to sort regions into high regime and low regime.

The results show that three variables produce regimes: public infrastructure stock per efficient worker, an index of total factor productivity and the human capital stock per worker.

In regions that present low levels of public infrastructure stock per worker and high human capital, fiscal decentralization is positively correlated with economic growth, while it is negatively correlated with administrative decentralization.

In regions with low *TFP*, expenditure decentralization is positively related to economic growth, while revenue decentralization is negatively related to economic growth in regions with high *TFP*.

The results are robust to different estimation methods and measures of *TFP*, and independent of the form of the production function and the returns to scale.

The empirical results of this article might have policy implications regarding the direction to follow in the decentralization process considering an economic growth criterion. Among the policy implications that can be drawn from the results, it is suggested that in regions with low public infrastructure stock per worker, high human capital per worker and low TFP, and for the allocation of core infrastructure, greater financial autonomy and more decision-making power for regional governments on infrastructure projects could be helpful in proposing and choosing the best projects to increase the intraregional public infrastructure stocks and consequently enhance TFP. Moreover, administrative recentralization might be an option to enhance economic growth in regions with low public infrastructure stock per worker and high human capital per worker.

Appendix: Econometric approach

The PSTR model

The panel smooth transition regression (PSTR), developed by González et al. (2005) and Fok et al. (2005), may be seen as a threshold regression model in non-dynamics panel with individuals fixed effects (Hansen 1999), in such a way the transition from one extreme regime to the other is not discrete, but smooth, and it is a function of the continuous transition variable.

The PSTR models have several interesting features that make them suitable for our purpose. Since observations in the panel are divided into a small number of homogenous groups or 'regimes', estimated parameters can take different values depending on the value of another observable variable (the transition variable). Therefore, regression coefficients are allowed to change gradually when moving from one group to another.

More specifically, let us denote by V_{it} the dependent variable and write the model as follows:

$$V_{it} = \delta_i + \tau_t + \pi_1' x_{it}[1 - G(q_{it};\gamma, c)] + \pi_2' x_{it} G(q_{it};\gamma, c) + e_{it} \tag{A.1}$$

for $i = 1, ..., N$ and $t = 1, ..., \check{T}$, where N and $\check{T}$ denote the cross-section and time dimensions of the panel, respectively. The dependent variable V_{it} is a scalar, x_{it} is a k-dimensional vector of time-varying exogenous variables included in Eq. (4), δ_i represents the fixed individual effect, τ_t is a time effect, π_1 and π_2 are the vectors of parameters in each regime and e_{it} is a random disturbance. The function $G(q_{it};\gamma, c)$ is a transition function of the observable variable q_{it}, continuous and bounded between 0 and 1. The variable q_{it} known as transition variable may be exogenous or a combination of the lagged endogenous variable (van Dijk et al. 2002). The parameter γ determines the smoothness of the transition, i.e. the speed of transition between regimes, and c denotes the threshold value for the transition variable, that is, the critical level separating two contiguous regimes (location parameter).

Following González et al. (2005), we consider the following logistic transition function

$$G(q_{it};\gamma,c)=\{1+exp[-\gamma(q_{it}-c)/\hat{\sigma}_q]\}^{-1},\qquad \text{with } \gamma>0$$

where $\hat{\sigma}_q$ is the standard deviation of q_{it}.

When $\gamma\rightarrow\infty$, the transition function $G(\cdot)$ tends to be an indicator function and the PSTR becomes a panel threshold model (Hansen 1999). On the contrary, if $\gamma\rightarrow 0$, the transition function $G(\cdot)$ becomes constant and the model collapses into a standard linear panel regression model with fixed effects (the so-called within model). More generally, the value of q_{it} determines the value of $G(q_{it};\gamma,c)$ and its extreme values are associated with the effective regression coefficients $\pi_1[1-G(q_{it};\gamma,c)]+\pi_2 G(q_{it};\gamma,c)$ for individual i at time t.

Testing for linearity

The first step in the procedure is to test whether it is statistically significant to move from a linear model as in Eq. (4) to the nonlinear expression in (A.1) given a transition variable q_{it} capable of generating a threshold between regimes.

As comprehensively discussed in González et al. (2005), linearity can be tested in Eq. (A.1) by considering the hypothesis of linear constraint $H_0:\gamma=0$ or $H_0:\pi_1=\pi_2$. In both cases, the relevant null hypothesis is that there is no difference in the relationship between the explanatory variables and the dependent variable conditioned on any extreme regime. From an econometric standpoint, however, imposing the above constraints results in a non-standard testing problem where under H_0 there are unidentified nuisance parameters, giving rise to the so-called Davies Problem in time series (Davies, 1977; 1987).[17]

In the framework of the PSTR, the identification problem can be solved in two ways. The first approach, proposed by Luukkonen et al. (1988), consists of approximating the transition function $G(\cdot)$ using a m-order Taylor expansion of the nonlinear model around $\gamma=0$. As an equivalent, the following auxiliary regression can be run:

$$V_{it}=\delta_i+\tau_t+\pi x_{it}+\sum_{p=1}^{m}\rho_p x_{it}q_{it}^{p}+\epsilon_{it}$$

Therefore, testing linearity is equivalent to testing $H_0:\rho_1=\cdots=\rho_m$ using a LM-test statistic as Fracasso and Vittucci Marzetti (2014). Under H_0, the test statistic asymptotically follows a χ^2 distribution with m degrees of freedom. As these authors suggest, in small samples the F-version of the LM-test (LM_F) is obtained by dividing the latter by the number of restrictions. As Fracasso and Vittucci Marzetti (2014), a third-order Taylor approximation was chosen. If SSR_0 is the sum of squared residuals under H_0 (linear panel model with fixed effects), and SSR_1 is the sum of squared residuals under H_1 (PSTR model with two extreme regimens), the LM_F statistic is defined as follows:

[17] For more details, see Andrews and Ploberger (1994) and Hansen (1999).

$$LM_F = \left(SSR_0 - SSR_1(\gamma, c)\right) / \left[SSR_0/(TN - N - m - 3)\right]$$

The second approach, proposed by Hansen (1999; 2000) in the context of threshold regression models, consists of imposing a linear constraint and circumventing the identification problem by computing a likelihood ratio (LR) test. Hansen (1999) shows that the LR tests under H_0, with near-optimal power against the null alternatives, is a standard F-statistic based on:

$$LR = \left(SSR_0 - SSR_1(\gamma, c)\right) / \sigma^2$$

Since the fixed effects in Eq. (A.1) fall in the class of models considered by Hansen (1999), a bootstrapping procedure should be considered to simulate the first-order asymptotic distribution of the likelihood ratio test and obtain an asymptotically valid p-value.[18]

Estimation procedure

Even though Eq. (A.1) is nonlinear in the π parameters, the resulting PSTR is conditional on parameters γ and c. Thus, to get consistent estimates we apply nonlinear least squares (NLS) following González et al. (2005) to determine the values of γ and c that minimize the concentrated sum of squared residuals.

$$SSR_1 = \min_{\gamma > 0, c \in \Gamma^n} S_1(\gamma, c)$$

where $S_1(\gamma, c)$ is the sum of squared residuals from estimating Eq. (A.1) for a fixed value γ and c such that $\Gamma^n = \Gamma \cap \{q_1, \dots, q_n\}$. If n is very large, the minimization problem can be solved by a grid search of values for γ and c such that $\gamma > 0$, by taking a certain percentage (η%) of observations out to ensure a minimum number of them in each regime. For some $N < n$, let $q_{(j)}$ denote the (j/N) percentile of the sample $\{q_1, \dots, q_n\}$ and let $\Gamma^n = \Gamma \cap \{q_{(1)}, \dots, q_{(N)}\}$. Then, the value of γ and c that minimizes $S_1(\gamma, c)$ could be considered a good approximation of the starting values of the estimation algorithm used in the NLS estimation problem.

The main advantage of the PSTR estimation technique is that the value of the threshold variable at which a significant change in coefficients occurs is endogenously determined in the estimation procedure.

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[18] For further details on the implementation of the bootstrap procedure, see Hansen (1999).

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