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A spatial econometric analysis of the regional growth and volatility in Europe

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Abstract Based on a sample of 1,084 European regions (EU15) from 1995 to 2004, we estimate the relationship between the average growth rate of GDP per capita and the volatility of the growth rate allowing for spatial effects. The spatial lag and spatial error models show that the regional per capita growth rate and volatility are significantly positively related on average. However, the inclusion of country interaction terms reveals that the volatility impact is not uniform across countries. In particular, the relationship between growth and volatility is significantly positive for the majority of countries but significantly negative for three countries (namely Finland, Italy, and Ireland).

Keywords Volatility · Regional growth · Spatial dependence

JEL Classification C14 · O52 · R11 · R15

1 Introduction

There is an ongoing debate in the literature about the relationship between volatility and growth. Recently, Imbs (2007) suggests that the growth-volatility connection depends on the level of aggregation of the data. While there is a negative correlation between growth and volatility at the cross-country level, the author finds a positive association between the growth and volatility across sectors within countries. Because growth volatility is significantly higher for small states (Easterly and Kraay 2000; Furceri and Karras 2007), the choice of the level of aggregation plays an important role in this analysis. In general, smaller areas are preferable to larger areas because of the large number of observations and the higher variability of growth

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rates and their volatility. This should lead to more conclusive results. The sign of the relationship between growth and volatility is also important from a policy point of view. A positive relationship would imply that short-run stabilisation policies will reduce the growth rate in the long-run.

In looking at the data, we find that both the growth rates of GDP per capita and their standard deviation exhibit a high degree of variation among European (EU-15) regions at the NUTS 3 level (see Table 2). There are fast growing regions (e.g. regions in Greece, Ireland, Finland und Portugal) that are among the most volatile regions in Europe, but also regions with much lower than average growth rates (e.g. regions in Italy) also show a considerable degree of volatility measured as the standard deviation of growth. Overall, the growth volatility is the lowest in Austria, Belgium and Spain. Based on simple aggregate cross-country correlations there seems to be a negative and weakly significant relationship between volatility and growth when growth volatility is defined as the standard deviation of the average annual growth rate of GDP in current ppp of each region divided by the country's average growth rate (see Graph 1 in the Appendix).

The aim of the present paper is to give new insights into the relationship between the regional growth of GDP per capita and volatility that is based on the regional data at the NUTS 3 level for 14 European countries. In particular, we estimate the determinants of the regional growth of GDP per capita as a function of the initial level of GDP per capita that is measured in purchasing power standards, volatility of growth, share of primary and secondary sectors, as well as population density. The main novelty of this paper is that we investigate the cross-country heterogeneity in the relationship between growth and volatility. It is obvious that country-specific factors may influence the link between growth and volatility. Following previous studies, we use the standard deviation of per capita GDP growth as the primary measure of growth volatility. An alternative measure of volatility is the standard deviation of growth divided by the country's average growth rate. In order to analyse the relationship between the average growth rate of GDP per capita and volatility we used a spatial econometric approach. This technique allows us to measure the extent to which the growth rate of one region depends upon that of its neighbours.

The possible connection between growth and volatility has been the subject of intensive empirical research in recent years. Despite the increasing literature, there is still no consensus on the sign and magnitude of the relationship. The correlation between the average per capita growth rate and its standard deviation at the aggregate level including the data for OECD and Non-OECD countries is often found to be negative (see among others Ramey and Ramey 1995; Imbs 2007; Martin and Rogers 2000). Some studies find an insignificant relationship between the mean growth and its standard deviation based on OECD data (e.g. Norrbin and Yigit 2005). Using cross-section data for a subsample of OECD countries, Ramey and Ramey (1995) find an insignificant relationship between growth and its volatility. Using a similar dataset, Kose et al. (2006) find a significant and positive relationship between growth and its standard deviation but wherein the positive coefficient turns into a significantly negative one when control variables such as investment in human capital and initial GDP are accounted for. Other studies also find a positive relationship between the average growth rate of output and the standard deviation of output growth (e.g. Kormendi and Meguire 1985; Grier and Tullock 1989).

The relationship between regional economic growth and volatility has not received much attention in the literature (for the summary of previous studies using regional data see Table 6 in the Appendix). Using regional data for 48 US States from 1970 to 1988, Dawson and Stephanson (1997) find a negative relationship between growth and its standard deviation but the coefficient is only significant at the 10% level. Using a similar data set, Chatterjee and Shukayev (2006) find a negative relationship between the average per capita growth rate and its standard deviation but the coefficient is only significant at the 5% level when the growth rates are calculated as log changes but are not significant based on percentage changes. Using regional data for 10 Canadian provinces from 1961 to 2000, Dejuan and Gurr (2004) find a positive but statistically insignificant relationship. Chandra (2003) investigates the impact of the GDP growth rate and its squared term on the standard deviation of growth. Using regional data for the EU-15 at the NUTS 2 and NUTS 3 levels from 1980 to 1995, the author finds that regions with very high and very low growth rates are accompanied by high volatility. The estimates suggest a U-shaped relationship between volatility and growth.[1] This means that for regions with low growth rates there is a negative relationship between the standard deviation and the growth rate while for regions with high growth rates there is a positive relationship. Martin and Rogers (2000) find a significant negative association between the per capita growth rate and its standard deviation based on regional data on 90 European regions from 1979 to 1992. Thus, the impact of volatility on regional growth seems to be less clear-cut at the regional level than at the aggregate level.

To summarise, the empirical studies differ widely in terms of the aggregation level (aggregate, industry, or regional levels), the time period over which volatility is measured, country coverage, measurement of volatility (standard deviation of the growth rate, standard deviation of the GDP gap or standard deviation divided by the growth rate), definition of the growth rate (i.e. log changes or percentage changes), as well as the empirical specification and estimation technique (cross-section versus panel data methods using the time variation). Most empirical studies that are based on aggregate cross-country data find a negative relationship between volatility and growth, in particular in middle-income and poorer countries. However, the relationship seems to be somewhat less robust when the sample of OECD countries is used. Studies based on disaggregated data (i.e. at the regional or industry levels) also give no clear-cut evidence on the relationship between growth and volatility (see Table 6 in Appendix). Using various data sets at the country and regional levels as well as different time periods, Chatterjee and Shukayev (2006) conclude that there is no robust relation between the average growth rate of GDP per capita and its standard deviation.

2 Empirical model

There are two empirical approaches to investigate the relationship between growth and volatility. The first approach relates the average annual growth rate on its

[1] It is far beyond the scope of the study to analyse the functional form of the relationship between growth and the standard deviation of growth.

standard deviation using cross-section data. The second approach uses the time series variation and relates annual growth rate of GDP per capita on the standard deviation of the residuals (see for instance Ramey and Ramey 1995 or Stastny and Zagler 2007). We use the first approach that relates the average growth rate over a given sample period to the standard deviation of the growth rate or some other measure of volatility. In addition, we use control variables. Previous studies on the determinants of regional economic growth reveal that initial GDP per capita, degree of urbanisation, and spatial effects are important determinants of regional growth of GDP per capita and/or labour productivity (see, among others, Armstrong 1995; López-Bazo et al. 2004; Badinger et al. 2004; Carrington 2003; Ertur et al. 2006; Ciccone 2002; Fingleton 2001). The empirical growth model is extended by the inclusion of spatial effects. Spatial dependence has been used extensively in studies of regional growth (see Abreu et al. 2005a, for a recent literature review). Other scholars find that country dummies reflecting aggregate country specific factors also play an important role for regional economic growth. For instance, using data on European regions, Attfield et al. (2000) find that spatially correlated growth is explained by country specific dummy variables and initial incomes but that geographical proximity per se does not matter. Given the findings in the literature, the empirical model explaining regional growth can be described as follows:

$$\bar{\Delta}Y_i = \beta_0 + \beta_1 \log(Y_{1995,i}) + \beta_2\sigma_i + \beta_3 shagr_i + \beta_4 shind_i + \beta_5 \log(density_i) + \sum_{j=1}^{J} \theta_j co_{ij} + e_i,$$

where i denotes the region at the NUTS 3 level. $\bar{\Delta}Y_i$ denotes the average annual growth rate of GDP per capita in purchasing power standards from 1995 to 2004. Y_{1995} denotes the initial level of per capita GDP in pps for the year 1995, σ_i denotes volatility measured as the standard deviation of growth of GDP per capita in current ppp for the period 1995–2004. Alternatively, we use the standard deviation of growth of GDP per capita in current ppp, 1995–2004 divided by the aggregate average country specific growth rates. *Shagr* denotes the share of value added in the primary sector (NACE A and B) as a percentage of total value added. *shind* is the industry share of value added (NACE C to E). Population density, *density,* is measured as regional population per square kilometres, e_i is the error term that is $N(0,\sigma^2)$ and co_{ij} is a set of dummy variables taking the value of 1 if the region is in part of country j and zero otherwise zero. Furthermore, we investigate whether the impact of volatility differs across countries. This can be done by the inclusion of interaction terms between the volatility and country dummy variables:

$$\bar{\Delta}Y_i = \beta_0 + \beta_1 \log(Y_{i,95}) + \beta_2\sigma_i + \beta_3 shagr_i + \beta_4 shind_i + \beta_5 \log(density_i) + \sum_{j=1}^{J} \varphi_j co_{ij}\sigma_i + e_i,$$

The OLS estimation of the parameters can be biased or inefficient in the presence of spatial dependence. Spatial autocorrelation occurs when the dependent variable or error term in each region are correlated with the dependent variable or the error term in the neighbouring region. In order to account for spatial effects we first use the spatial error model, in which the spatial dependence affects the error term. The growth equation accounting for spatial error dependence can be written as:

$$\bar{\Delta}Y_i = \beta_0 + \beta_1 \log(Y_{i,95}) + \beta_2\sigma_i + \beta_3 shagr_i + \beta_4 shind_i + \beta_5 \log(density_i) + \sum_{j=1}^{J} \theta_j co_{ij} + u_i,$$

and

$$u_i = \lambda W \varepsilon_i + \varepsilon_i^*,$$

where parameter λ is a coefficient of the spatially correlated errors indicating the extent of the spatial correlation between the residuals. W denotes a distance based weight matrix. ε^* is the error term that is normally distributed with the mean zero and variance $\tilde{\sigma}^2$. A negative parameter, λ, implies that the errors of the opposite sign are clustered together geographically.

An alternative way to incorporate the spatial effects is to use the spatial lag model, which accounts for the spatial dependence by including the serially autoregressive term of the dependent variable (Anselin and Bera 1998). Positive spatial dependence indicates that the growth in neighbouring regions affects a region's growth rate positively. Negative spatial dependence occurs if regions with high growth rates are located side by side with those of low growth rates or vice versa. This is commonly referred to as the existence of the so-called checkerboard pattern (Anselin and Bera 1998). The equation including the spatially dependent growth rate (i.e. the weighted average of the growth rates of neighbouring regions) can be written as:

$$\bar{\Delta}Y_i = \beta_0 + \rho W\bar{\Delta}Y_i + \beta_1 \log(Y_{i,95}) + \beta_2\sigma_i + \beta_3 shagr_i + \beta_4 shind_i + \beta_5 \log(density_i) + \sum_{j=1}^{J} \theta_j co_{ij} + \varepsilon_i,$$

where W again denotes a distance based weight matrix and ρ is the spatial lag parameter. The specification of the weight matrix is the sensitive point of the spatial econometric modelling (Anselin and Bera 1998). There are various ways to define the spatial weight matrix. In this study, we used an inverse distance function to calculate the weights in the spatial weight matrix, $w_{ij} = 1/d_{ij}$, where d_{ij} is defined as the shortest Euclidean distance in kilometres between the centroids of region i and that of region j. In the next step, the elements of the spatial weight matrix have been row standardized so that the elements of each row add to unity. Beyond some distance, the growth rate of region j should no longer affect those in region i. For this reason, an upper distance is typically chosen beyond which all weights are equal to zero. In this analysis, we select the mean distance as the upper distance above which the spatial weights is assumed to be zero. Values above the upper distance are replaced by an infinite value. The parameters of both spatial models can be estimated by the maximum likelihood. In the case of spatial autocorrelation, OLS is still unbiased, but no longer efficient. However, OLS is biased in the presence of spatial lag effects, in turn resulting from the misspecification of omitting a significant explanatory variable in the regression model.

3 Data and descriptive statistics

We employ data on the EU-15 NUTS 3 regions (excluding Luxembourg) from the Eurostat database REGIO, which contains information on GDP per capita in purchasing power standards, total population, square kilometres, and the share of the primary and secondary sectors in GDP. The growth rate is calculated as the average annual change in per capita GDP per capita. Following the literature (e.g. Armstrong 1995; López-Bazo et al. 2004) we employ per capita GDP expressed in purchasing power standards (pps). Alternatively, one can use GDP at the current market prices expressed in EUR. Note that the purchasing power standards are based on national price differences but do not account for differences in the GDP deflator within countries. However, unreported estimates show that the estimation results are not sensitive when GDP is expressed in EUR rather than in purchasing power standards. Ertur and le Gallo (2003) also suggest that the empirical results on the spatial effects are not sensitive with respect to the conversion method into a common currency.

Table 1 shows the average annual growth rate of GDP per capita, its standard deviation of growth and standard deviation of growth divided by the country's average growth rate. The average annual growth rate (in current ppp) from 1995 to 2004 was 4.1%. The standard deviation of growth is 3.7 on average. Table 2 shows the country averages and medians for the annual growth rate, standard deviation, and the control variables. Since the standard deviation of growth tends to be higher for high-growth regions than for regions with low growth rates, we used an additional measure of volatility. This measure was calculated as the ratio of the standard deviation of growth of GDP per capita for each region divided by the mean

Table 1 Descriptive statistics

	Means	Median	Std. dev	Min	Max
Average annual growth of GDP in per capita in current EUR ppp, 1995–2004 in %	4.1	3.9	1.4	0.8	11.6
GDP per capita in current EUR ppp, 1995	15,672	14,843	5,748	5,718	68,604
Standard deviation of per capita GDP growth	3.7	3.2	1.9	1.1	21.6
Volatility of per capita GDP growth[a]	0.93	0.85	0.43	0.22	4.43
Population density (population in 1,000 divided by km^2)	494	160	1,079	2.0	20,529
Share of agriculture in GDP in %	3.4	2.3	3.9	0.0	28.4
Share of industry in GDP in %	28.2	27.7	9.4	4.0	75.2

[a] Volatility of growth is calculated as the standard deviation of the average annual growth rate of GDP per capita in current ppp of each region divided by the country's average growth rate. Data are multiplied by 100 except population density and GDP per capita. *Source*: New Cronos, own calculations

Table 2 Descriptive statistics for growth and volatility by country

	# of regions	Average annual per capita growth rate (current ppp)		Standard deviation of the per capita growth rate		Volatility of growth[a]	
		Mean	Median	Mean	Median	Mean	Median
Austria	35	4.3	4.2	2.8	2.7	0.66	0.64
Belgium	43	4.2	4.2	2.9	2.8	0.71	0.67
Denmark	15	3.9	3.9	3.1	3.2	0.80	0.81
Finland	20	4.7	4.8	5.3	4.9	1.12	1.03
France	96	3.7	3.7	3.4	3.3	0.91	0.90
East Germany incl. Berlin	113	4.6	4.8	3.6	3.2	0.83	0.72
West Germany	326	3.4	3.3	3.2	2.7	0.91	0.77
Greece	51	4.9	4.7	6.6	5.3	1.36	1.09
Ireland	8	8.0	7.9	5.5	4.7	0.69	0.59
Italy	103	2.8	2.8	3.4	3.3	1.20	1.16
Netherlands	40	4.8	4.8	3.7	3.5	0.77	0.73
Portugal	30	4.1	4.1	5.3	5.1	1.29	1.24
Spain	50	5.5	5.4	2.8	2.6	0.51	0.47
Sweden	21	3.7	3.7	3.5	3.3	0.94	0.87
United Kingdom	133	4.9	4.8	5.1	4.9	1.03	0.99

[a] See Table 1 for the definition of volatility of growth

country's growth rate. Based on the standard deviation, we find that Greece and Ireland exhibit the largest standard deviations of growth. For the second volatility measure (i.e. standard deviation divided by the country's specific growth rates), we find that the volatility of growth is higher than average in Greece, Portugal, and Italy. Spain, Austria, Belgium, and Ireland are characterised by a low degree of volatility.

In order to provide some first evidence on the relationship between per capita GDP growth and the standard deviation of growth, we present simple pairwise correlation coefficients (see Table 3). We find that the correlation coefficients between per capita GDP growth and its standard deviation are significantly positively related at the 5% level in only 4 out of 15 countries. For further two countries we find positive correlations coefficients that are significant at the 10% level. However, for 4 countries we find a negative correlation but in no case is the negative correlation statistically significant. In order to test the robustness of the results, we provide regression coefficients based on the robust regression method. The main advantage of the robust regression method is that it reduce the impact of outliers or atypical observations that may result from errors in the regional growth rate. Again, we find that positive and significant correlation coefficients in 6 out of 15 countries. For West Germany and Italy we find negative correlation coefficients that are only marginally or not significant (p-values of 0.08 and 0.15). However, the bivariate correlation coefficients should be interpreted with caution because important omitted factors such as initial GDP per capita and spatial dependence

Table 3 Correlation coefficient between growth and its standard deviation

	Correlation coefficient		Coefficient based on the robust regression method	
	Coeff	*p*-value	Coeff	*p*-value
Austria	−0.03	0.85	0.04	0.85
Belgium	0.10	0.52	0.35**	0.04
Denmark	0.56**	0.03	0.41*	0.06
Finland	−0.16	0.49	−0.08	0.49
France	0.25**	0.02	0.20**	0.01
East Germany incl. Berlin	0.35***	0.00	0.35**	0.00
West Germany	0.10*	0.08	−0.05*	0.08
Greece	0.30**	0.03	0.16*	0.06
Ireland	−0.43	0.29	0.38	0.34
Italy	−0.06	0.58	−0.12	0.15
Netherlands	0.02	0.89	0.00	1.00
Portugal	0.33*	0.08	0.30*	0.10
Spain	0.17	0.24	0.01	0.94
Sweden	0.26	0.25	−0.06	0.80
United Kingdom	0.04	0.66	0.02	0.84

Notes: The correlations for Denmark and Ireland should be interpreted with caution as our sample size is very small

may also play a role in explaining regional growth. In fact, regression analysis controlling for other factors is the proper tool for determining the relationship between growth and its standard deviation.

4 Empirical results

Table 4 shows the estimation results of the spatial lag and spatial error model of the determinants of regional economic growth where volatility is measured as the standard deviation of per capita GDP growth.[2] The estimation results are based on the spatial weight matrix with no upper bound distance.[3] For the sake of comparison we also provide the OLS results. The estimation results for the alternative volatility measure (i.e. the standard deviation of per capita growth rate divided by the country's average per capita growth rate) produce similar sign and significance of the volatility coefficient and are therefore not reported.[4]

In order to detect the appropriate form of spatial autocorrelation, we used the specific to general search approach as described in Anselin et al. (1996). We used

[2] We also conducted spatial autocorrelation tests that are available upon request. Unreported results show a significant negative spatial autocorrelation for all the variables.

[3] Estimations results using the spatial weight matrix with the mean distance as the upper limit lead to similar results and are available upon request.

[4] Estimations results using the alternative volatility measure are available upon request.

Table 4 Estimates of the impact of the standard deviation of growth on regional growth

	Spatial error model		Spatial lag model		OLS	
	Coeff.	z	Coeff.	z	Coeff.	t
Log GDP per capita in current ppp, 1995	−0.007***	−4.19	−0.007***	−4.00	−0.007***	−3.86
Standard deviation of growth rate	0.117***	2.95	0.116***	2.91	0.115***	2.85
Log population density	0.001***	2.79	0.001**	2.15	0.001**	2.07
Share of the agriculture in total GDP	−0.034*	−1.80	−0.039**	−2.07	−0.040**	−2.12
Share of the industry in total GDP	0.005	0.89	0.005	0.88	0.005	0.96
Country effects (reference category France)						
Austria	0.004**	2.04	0.005***	3.45	0.006***	4.05
Belgium	0.009***	4.39	0.003	1.61	0.003*	1.78
Denmark	0.009***	4.57	0.002	1.48	0.002	1.51
Finland	0.013***	5.63	0.010***	5.33	0.010***	5.08
East Germany including Berlin	0.010***	3.68	0.005***	2.93	0.005***	3.52
West Germany	0.000	−0.22	−0.005***	−4.97	−0.004***	−4.53
Greece	0.003	0.77	0.009***	2.49	0.009***	2.49
Ireland	0.043***	8.08	0.040***	7.72	0.039***	7.49
Italy	−0.014***	−8.95	−0.010***	−9.96	−0.009***	−9.89
Netherlands	0.016***	7.90	0.009***	5.74	0.009***	5.90
Portugal	−0.003	−1.01	0.001	0.31	0.000	−0.01
Spain	0.015***	9.36	0.019***	14.34	0.018***	14.23
Sweden	0.007***	3.42	0.002	1.14	0.001	0.93
United Kingdom	0.013***	6.57	0.009***	5.35	0.008***	4.93
Constant	0.097***	5.89	0.070***	3.50	0.095***	5.78
Spatial error parameter, λ	−3.540***	−18.43				
Spatial lag parameter, ρ		−18.43	0.664**	1.96		
Tests for spatial effects	chi2(1)	p-value	chi2(1)	p-value		
LM test of $\lambda = 0/\rho = 0$	4.94	0.026	1.19	0.275		
Robust LM test of $\lambda = 0/\rho = 0$	23.2	0.000	19.3	0.000		
Log likelihood	3398.6		3382.0			
Pseudo R^2/Adj. R^2	0.33		0.40		0.40	
# of obs	1,084		1,084		1,084	

Notes: The dependent variable is the annual average growth rate of GDP per capita in current ppp for the period 1995–2004. t-values are based heteroscedasticity-consistent standard errors. ***, ** and * denote significance at the 1%, 5%, and 10% levels. The Pseudo R^2 is calculated as the squared value of the correlation between the observed and predicted growth rate

Lagrange Multiplier (LM) tests and their robust versions. The robust LM error test and robust LM lag test indicate the presence of spatial dependence in the data. Since the LM spatial lag statistics is lower than the LM error lag statistics the interpretation of the regression results is based on the spatial error model (Table 5).

We find a significant positive relationship between growth and volatility across European regions. This is also the case when the control variables are excluded (see

Table 5 Estimates of the impact of the standard deviation of growth on regional growth (with interaction effects)

	Spatial error model		Spatial lag model		OLS	
	Coeff	*z*	Coeff	*z*	Coeff	*t*
Log GDP per capita in current ppp, 1995	−0.007***	−4.02	−0.007***	-3.81	−0.007***	−3.66
Standard deviation of growth of per capita GDP in current ppp	0.260***	2.98	0.214**	2.26	0.221**	2.36
Log population density	0.001***	2.75	0.001***	2.09	0.001**	2.01
Share of the agriculture in total GDP	−0.034*	−1.79	−0.039**	−2.06	−0.040**	−2.10
Share of the industry in total GDP	0.006	1.05	0.006	1.01	0.006	1.09
Interaction terms country—volatility (ref. category France)						
Standard deviation of growth—Austria	−0.324*	−1.67	−0.272	−1.35	−0.282	−1.34
Standard deviation of growth—Belgium	−0.186	−1.01	−0.130	−0.70	−0.139	−0.71
Standard deviation of growth—Denmark	0.165	0.67	0.250	1.10	0.240	1.07
Standard deviation of growth—Finland	−0.318**	−2.26	−0.278**	−2.06	−0.288**	−2.15
Standard deviation of growth—East Germany including Berlin	−0.186*	−1.85	−0.148	−1.37	−0.159	−1.45
Standard deviation of growth—West Germany	0.044	0.31	0.091	0.63	0.082	0.84
Standard deviation of growth—Greece	−0.090	−0.76	−0.041	−0.33	−0.049	−0.31
Standard deviation of growth—Ireland	−0.534**	−2.22	−0.483**	−2.00	−0.493**	−2.04
Standard deviation of growth—Italy	−0.334***	−2.69	−0.269***	−2.04	−0.277***	−2.01
Standard deviation of growth—Netherlands	−0.232	−1.41	−0.189	−1.15	−0.202	−1.24
Standard deviation of growth—Portugal	−0.017	−0.08	0.033	0.16	0.024	0.19
Standard deviation of growth—Spain	−0.083	−0.56	−0.036	−0.22	−0.042	−0.21
Standard deviation of growth—Sweden	−0.174	−1.54	−0.133	−1.09	−0.134	−0.97
Standard deviation of growth—United Kingdom	−0.238**	−2.16	−0.181	−1.57	−0.189	−1.58
Country effects (reference category France)						
Austria	0.014**	2.35	0.013**	2.18	0.014**	2.34
Belgium	0.015***	2.68	0.007	1.23	0.007	1.34
Denmark	0.004	0.49	−0.006	−0.73	−0.005	−0.67
Finland	0.027***	3.88	0.023***	3.61	0.023***	3.56
East Germany including Berlin	0.009	1.63	0.001	0.26	0.002	0.47
West Germany	0.006*	1.65	0.000	−0.10	0.001	0.23
Greece	0.005	0.68	0.009	1.34	0.009	1.38
Ireland	0.069***	7.09	0.064***	6.75	0.064***	6.63
Italy	−0.003	−0.71	−0.001	−0.16	0.000	0.00
Netherlands	0.025***	4.33	0.016***	2.81	0.016***	2.92
Portugal	−0.005	−0.50	−0.003	−0.28	−0.003	−0.32
Spain	0.018***	4.11	0.021***	4.45	0.020***	4.31
Sweden	0.013***	2.98	0.006	1.41	0.006	1.34
United Kingdom	0.023***	4.88	0.016***	3.46	0.016***	3.33
Constant	0.088***	5.36	0.065***	3.16	0.088***	5.35
Spatial error parameter, λ	−3.541***	−19.01				

Table 5 continued

	Spatial error model		Spatial lag model		OLS	
	Coeff	z	Coeff	z	Coeff	t
Spatial lag parameter, ρ			0.61*	1.72		
Tests for spatial effects:	chi2(1)	p-val.	chi2(1)	p-val.		
LM test of $\lambda = 0/\rho = 0$	5.24	0.022	1.25	0.263		
Robust LM test of $\lambda = 0/\rho = 0$	23.19	0.00	19.25	0.00		
Log likelihood	3419.0		3401.1			
Pseudo R^2/Adj. R^2	0.39		0.42		0.41	
# of obs	1,084		1,084		1,084	

Notes: The dependent variable is the annual average growth rate of GDP per capita in current ppp from 1995–2004. t-values are based heteroscedasticity-consistent standard errors. ***, ** and * denote significance at the 1%, 5%, and 10% levels

Table 7 in the Appendix).[5] These findings are consistent with Imbs (2007) that also find that growth and volatility are significantly positively related based on the industry data from 22 OECD countries for the period 1970–1992, while the results using specifications that are based on aggregate cross-country data reveal that growth and volatility are significantly negatively related. Our results also indicate that the relationship between growth and its standard deviation is significantly positive when disaggregated data are used. Thus, the same reasoning that applies to growth-volatility link at the industry level may apply also to link at the regional level. One explanation is that regional data may allow to capture a part of aggregate volatility that is region specific and tends to be positively associated with growth. Balderston and Within (1954) have already recognized the importance of the aggregation problems (cited in Lahr and Stevens 2002). In particular, Balderston and Within (1954) suggest that the "process of aggregation may obscure important relationships between the components of aggregates".

The convergence coefficient shows the expected negative sign and is significant at the 5% level. The speed of convergence is approx. 0.7% per year, which is in line with earlier studies.[6] Margini (2004) in summarizing the previous literature suggest that the process of regional convergence is very slow in the EU compared to other areas. Estimates of the convergence rates based on cross-country instead of regional data Lead to substantially higher rates of convergence. According to the meta-analysis based on cross-country data of Abreu et al. (2005b) find an average rate of convergence of about 2% per year.

Agglomeration, as measured by population density, has a positive and significant effect on the growth of regional GDP per capita. Furthermore, the share of agricultural GDP is negative but only marginally significant. The negative effect is in line with previous findings based on NUTS 2 data (see, for instance, Cappelen

[5] When we use the standard deviation of the per capita growth rate divided by the country's average per capita growth rate, we also find a positive relationship. These results are available upon request.

[6] The speed of convergence is calculated as $\ln(1 - T\beta_1)/T$ where T is the length of the period.

et al. 2003; and Fagerberg and Verspagen 1996). Finally, we find that country effects are jointly significant indicating that growth rates differ between countries. In particular, we find that regions in Ireland, Spain, and the United Kingdom have significantly higher growth rates, while regions in Italy and West Germany (excluding West-Berlin) have significantly lower growth rates than the reference category, namely France.

In order to investigate whether the relationship between the average growth rate and the standard deviation of growth differs across EU countries, we re-estimated the spatial lag and error models including the interaction terms between the standard deviation of growth and the country dummy variables (see Table 6). Again, we focused on the interpretation of the regression results based on the spatial error model because the robust LM spatial lag statistics is lower than that of the LM spatial error statistics. Furthermore, the Wald test rejects the null hypothesis that interaction terms have no significant effects (p-value of 0.00). This indicates that the strength of the relationship between growth and volatility is not uniform across countries. In particular, we find that the impact of the standard deviation of growth is significantly negative in 3 out of 14 EU countries. The magnitude of the impact (calculated as the sum of the coefficient on the country dummy variable and the overall volatility coefficient) is −0.274, −0.074, and −0.058 for Ireland, Italy, and Finland, respectively.[7] The negative relationship between growth and its standard deviation for Italy, Ireland and Finland is quite interesting, since the Italian regions are characterised by low growth, while Irish and Finish regions show high growth rates during the sample period.

5 Conclusions

Based on a sample of 1,084 European regions (EU15) from 1995 to 2004, we investigated the relationship between regional per capita growth and volatility. As control variables we used the initial level of GDP per capita measured in (current) purchasing power standards, share of primary and secondary sectors, and population density (measured as regional population in working age per km^2). The empirical growth model accounts for the spatial dependence. Furthermore, we explored the cross-country heterogeneity in the impact of volatility on economic growth.

We find that the relationship between volatility and growth is significantly positive on average. However, the inclusion of country interaction terms indicates that the relationship between volatility and average growth is not uniform across countries. We find a significant and positive relationship between growth and volatility for the majority of countries. However, there is a significantly negative relationship between growth and its standard deviation for Italy, Finland, and Ireland.

The study suggests the need for further studies at the regional level on the relationship between growth and volatility. In particular, a longer period should be used, but such data is only available at the NUTS 2 level. Another important issue

[7] The results based on the alternative volatility measure are quite similar as expected and, therefore, not reported.

that needs to be addressed is the role of the differences in the data quality across regions. To model the link between growth and volatility one should also use employment growth and its standard deviation as an alternative measure of volatility.

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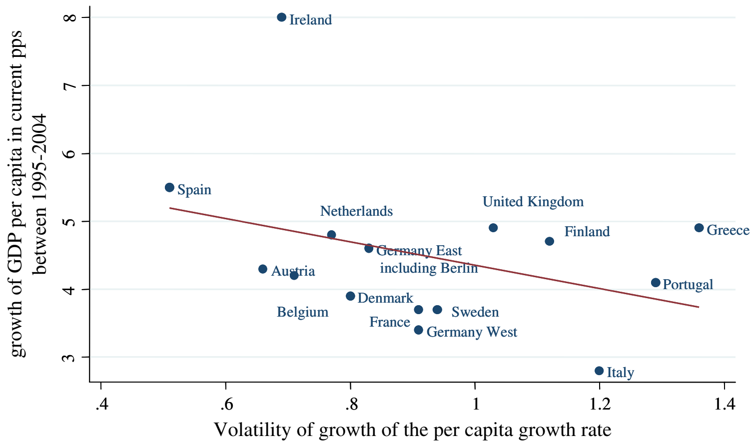
Appendix



Graph 1 Correlation between the median volatility and median growth rate across countries. *Note*: Volatility of growth is calculated as the standard deviation of the average annual growth rate of GDP per capita in current ppp of each region divided by the country's average growth rate

Table 6 Summary of previous studies using the cross-sectional approach and regional data

	Sample countries (*N*) and time (*T*)	Measure of growth	Measure of volatility	Sign and significance of the coefficient	Control variables
Chatterjee and Shukayev (2006)	$N = 48$ US states, $T = 1963–1989$	Per capita growth rate, percentage change and log change	Standard deviation	Negative but not significant	No
Chatterjee and Shukayev (2006)	$N = 48$ US states, $T = 1977–2001$	Per capita growth rate, percentage change and log change	Standard deviation	Negative and partly significant	No
Chandra (2003)	$N = 266$, $N = 930$, $T = 1980–1995$	Average growth rate	Standard deviation	Non-linear; positive for high-growth regions, negative for low-growth regions	No

Table 6 continued

	Sample countries (*N*) and time (*T*)	Measure of growth	Measure of volatility	Sign and significance of the coefficient	Control variables
Dawson and Stephanson (1997)	$N = 48$ US States, $T = 1970–1988$	Average annual growth state product per worker	Standard deviation	Negative and significant at the 10% level	No
Dejuan and Gurr (2004)	$N = 10$ Canadian Provinces, $T = 1961–2000$	Average annual	Standard deviation	Positive and significant at the 10% level	Yes
Martin and Rogers (2000)	$N = 90$ European Regions, $T = 1979–1992$	Coefficient of the regression of the logarithm of GDP per capita on time	Standard deviation	Negative and significant at the 5% level	Yes

Table 7 Estimates of the impact of the standard deviation of growth on regional growth

	Spatial error model		Spatial lag model		OLS	
	Coeff	*z*	Coeff	*z*	Coeff	*t*
Standard deviation of per capita growth	0.11***	2.92	0.11***	2.85	0.11***	2.82
Constant	0.03***	17.19	0.01	0.52	0.03***	23.27
Spatial error parameter, λ	−3.49***	−15.40				
Spatial lag parameter, ρ			0.62*	1.81		
Country dummy variables	yes		yes		yes	

Notes: The dependent variable is the annual average growth rate of GDP per capita in current ppp between the period 1995–2004. *z*-values and *t*-values are based heteroscedasticity-consistent standard errors. ***, ** and * denote significance at the 1%, 5% and 10% level

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