Infrastructure and Growth in the European Union: an Empirical Analysis at the Regional Level in a Spatial Framework

Chiara Del Bo Massimo Florio

Working Paper n. 2008-37

novembre 2008

UNIVERSITÀ DEGLI STUDI DI MILANO

DIPARTIMENTO DI SCIENZE ECONOMICHE AZIENDALI E STATISTICHE

Via Conservatorio 7
20122 Milano
tel. ++39 02 503 21501 (21522) - fax ++39 02 503 21450 (21505)
http://www.economia.unimi.it
E Mail: dipeco@unimi.it

Pubblicazione depositata ai sensi della L. 106/15.4.2004 e del DPR 252/3.5.2006

Infrastructure and growth in the European Union: an empirical analysis at the regional level in a spatial framework

Chiara Del Bo[a*], Massimo Florio[a]
This Version: November 2008[1]

[a] *Università degli Studi, Milano*
** Corresponding author: chiara.delbo@unimi.it*

Abstract

In this paper we examine the return of public investment in the EU regions. We consider different forms of infrastructure capital by examining the relationship between a set of infrastructure indicators and economic performance at the NUTS2 level with an empirical model derived from the production-function approach. From a social planner's perspective, we want to see which form of infrastructure investment has higher returns, considering structural differences in regions. The main contribution of this paper is to consider the impact of different types of infrastructure on growth, disaggregated at the regional level in the European Union, with an explicit focus on the New Member States, and correcting for spatial dependence and heterogeneity issues. We find that the highest rates of return are associated mainly with TLC, quality and accessibility of the region's transportation network, while endowment of traditional road and railway infrastructure has a positive but slightly lower impact. We also contribute to the debate on convergence, finding that the β-convergence hypothesis holds also when the model encompasses several controls.

JEL: H54, O11, E62, R11
Keywords: infrastructure capital, regional growth, convergence, spatial econometrics.

1. Introduction

The European Union has committed substantial financial resources to regional policy for the 2000-2006 period and a over 350 billion € for the 2007-2013 period, focusing specifically on infrastructure: transport in lagging behind regions accounted for around 26% of total expenditure, while the planned expenditure in the 2007-2013 period will focus mainly in the New Member States (henceforth: NMS), and will support investment in transport, environment, energy, telecommunications, R&D and in other sectors. This strategy is motivated by the theoretical findings according to which public capital is complementary to private capital in promoting growth (e.g. Barro (1990)). However the empirical evidence on the relationship between infrastructure and growth is controversial and still debated. Also, in mature economies, transport infrastructure may be close to its optimal level and suffer from congestion problems. It is therefore important, from a policy-maker's perspective, to understand the returns of investment in different types of infrastructure capital.

In this paper we discuss the link between infrastructure and growth from the theoretical and empirical point of view with a particular attention to how the return is measured and focusing on the European Union regions.

[1] Acknowledgments: This paper has been prepared under the EIBURS research grant to the University of Milan ("Public Investment under Budgetary Constraints in New Member States"). The authors gratefully acknowledge the collaboration in an earlier stage of the research of Cristina Lira, University of Alabama. The authors wish to thank Alberto Bucci, Andrea Caragliu, Marzio Galeotti and participants at the "Conference Developments in Economic Theory and Policy" - Bilbao, Spain, July 10-11 2008, for helpful suggestions and discussions. The usual disclaimer applies.

Chiara Del Bo is the author of Sections 3-6, while Chiara Del Bo and Massimo Florio are the authors of the remaining Sections.

Following the pioneering work of Aschauer (1989), this paper tests the causal relationship between a set of infrastructure indicators and economic performance at the regional NUTS2 level with an empirical model derived from the production-function approach. The main contribution of this paper is to consider the impact of different types of infrastructure capital (namely direct, indirect and TLC components) on growth, disaggregated at the regional (NUTS2) level. The paper's main results are based on a comprehensive database at the European regional level and the focus is explicitly on the recent wave of enlargement, with specific attention to regions belonging to NMS.

The remainder of the paper is organized as follows. Section 2 provides a critical assessment of the concept of infrastructure, and reviews measurement issues and methodologies to assess the returns on GDP growth for this factor, focusing especially on the European Union. The empirical analysis is presented in Sections 3 through 6: the elasticity of output to several dimensions of infrastructure capital is analyzed in levels, in Section 4. Spatial econometric techniques are used in Section 5, while convergence and growth effects of infrastructure are analyzed in Section 6. Finally, Section 7 concludes.

2. Theoretical and empirical background

2.1 The economic relationship between infrastructure and growth

In the economic literature of the last twenty years, the positive relationship between infrastructure and growth received support from a number of studies, both at the theoretical and empirical level. Growth theory suggests that public capital in a broad sense is complementary to private capital in promoting growth (e.g. Barro, 1990; World Bank, 1994) and stimulating household consumption. When considering specifically infrastructure investment, a very lively research agenda stemmed from Aschasuer's pioneering article in 1989, in which he considered a broad set of infrastructure types and found evidence of a significant and consistent output elasticity of public capital, suggesting a relevant growth promoting potential of infrastructure. The surprisingly high elasticity (the estimated elasticity of output was 0.39) and the potential policy implications of the results generated a field of research trying to confirm or disprove the relationship found between infrastructure and growth.[2]

However, in order to correctly interpret empirical results, it is important to understand the channels through which infrastructure may affect growth, and how to measure the actual return of infrastructure. Accurately measuring infrastructure returns is crucial from a policy perspective since the level of estimated returns should be the first guide in deciding how to allocate funds among different programs, while social cost-benefit analysis will be more appropriate for policy evaluation. When considering the rate of return of infrastructure, the main problem is given by the fact that infrastructure economics has the features of imperfect markets: market failures, political objectives and constraints, regulatory and distributional issues move the returns of investment in infrastructure away from the market signals given for them. In addition, in the long term, infrastructures are beneficial to output growth if they are complementary to firms' investment or to household consumption.

For this reason, recent contributions in the field try to find a comprehensive measurement for the return of infrastructure, moving away from the simple output elasticity of infrastructure proposed by Aschauer (1989); several authors have proposed broader sector analysis, specifically considering

[2] For a review of early contributions, including Munnell (1990, 1991) and Morrison and Schwartz (1994), see the comprehensive article by Gramlich (1994) and the book by Sturm (1998).

the contribution of disaggregated infrastructure capital on growth (for example Bennel (1996); Shantayanan et al. (1997); Albala-Bertrand and Mamatzakis, (2007)) and identified the social rate of return of road infrastructure and energy capacity (Canning and Bennathan (2000)).

Focusing on the European Union, it is possible to see that an increasing number of studies specifically consider infrastructure and most of these contributions analyze growth performance at the regional level. One of the most important targets of this field of research is to assess the effectiveness of the European Union Structural Funds on growth and convergence across countries and regions. Recently several papers have focused explicitly on the European Union and on the return of the Structural Funds. Among them De La Fuente (2002) considers an aggregate production function and an employment equation to describe the evolution of employment as a function of changes in factor stocks and wage rates. His findings indicate a high return of infrastructure and direct public investments on output for EU regions. Rothengatter and Schaffer (2004) consider a large set of EU regions and build indexes of infrastructure quantity weighted for their quality. Transport infrastructure networks are considered together with immobile factors of production, i.e. telecommunication, level of education, recreation areas, patent applications. They find different results for high-density and low-density regions: the quality of transport network is important for high density regions while it has a lower role in explaining competitiveness for low density regions.

While these findings support a positive effect of infrastructure capital on growth, some authors disagree. For example, Boldrin and Canova (2003) argue that Structural Funds can distribute income without enhancing the potentialities of the regions which receive them and without producing an impact in the long run. Some authors (Martin, (1997); De Rus et al. (1995)) argue that the construction of transport and telecommunication infrastructure can be harmful in some regions because it can promote the migration of production factors from the poorest area: this result stresses that infrastructure can affect differently the economic performance according to the features of the region where these investments are undertaken. In addition, this field of literature suggests that the infrastructure's effect on growth is not direct, but works through the alteration of the relative prices which define the relative attractiveness of location for firms.

The stress on spatial dimension characterizes other studies that assess the impact of infrastructure on growth and conditional convergence among regions (for example Mas et al. (1995); Kelejian and Robinson, (1997), Lopez-Bano et al. (2004)) and results support the conclusion of convergence towards a middle-rich level for richer regions and convergence towards a lower level for poorer regions (Quah (1996)). At the basis of this result is the assumption that public capital is complementary to private capital in promoting growth and that this effect depends on the degree of substitution between the two factors (Romp and de Haan (2005)). When testing this assumption for the European regions, recent studies find that the economic effect of the investments in infrastructure are stronger in the more developed regions where there is an environment that can exploit them (e.g. Cappelen et al. (2003)).

2.2 Measurement Issues

Gramlich (1994) stresses the importance of an appropriate definition and subsequent measurement of infrastructure, and discusses possible approaches. He defines infrastructure as "the tangible capital stock owned by the public sector". Other authors have tried to provide a broader definition of the concept. Prud'Homme (2004) identifies infrastructure by a set of characteristics that are common to infrastructure capital. Specifically, capital goods that provide services instead of being directly consumed, are lumpy and not incremental, have a long lifespan, are space specific and associated with market failures and consumed by both households and enterprises, can be labeled as infrastructure[3].

In addition to the problem of the definition of public capital and identification of its main components, there is also a problem of measurement. If the first choice is to use data on government spending, these are not always available. Some studies then use some physical measure of infrastructure. Infrastructure capital is considered in terms of quantity, through the introduction of a variable for its physical stock in the econometric models: transports, energy and communications are the most used typologies in the empirical analysis (Canning (1998)). Some authors have proposed to measure infrastructure not only considering the stock component, but also taking into account its quality (Hulten (1996); Calderon and Serven (2004)). Quality is measured by scaling the stock of existing infrastructure with the number of people that potentially can benefit and utilize it, or by dividing it by the square area (Canning (1998)). This measure could take in account the problem of the distinction between the stock of infrastructure and the service they provide.

Different techniques may be used to assess the contribution of infrastructure capital to a country's economic performance. This leads, as Gramlich (1994) showed, to possibly different results, depending on whether results arise from the estimation of a production function instead of a cost function. Sturm (1998)[4] classifies the literature that examines the relationship between infrastructure and growth according to the estimation techniques, and discusses the evidence on the relation between public spending and productivity. The author identifies five main research strategies: the production function approach, which is the most used, the cost function approach, VAR studies, cross-country, or regional cross-section growth regressions and public investment in structural econometric models. The authors find different estimates of the marginal product of public capital in the empirical papers considered, ranging form 0.03 to 0.73: in some contributions the marginal product of public capital is higher than the marginal product of private capital, but in others it is roughly equal (Munnel (1990)) and in some others below (Eberts (1986)). Romp and De Haan (2005) update the classification of Sturm (1998), finding that in the more recent empirical studies there is more agreement about the positive effect of public capital on growth. They discuss the advantages and the shortcomings of the different estimation techniques and in particular, they remark the possibility of reverse causation between public capital and productivity when the production function approach is used. However, according to their evaluation of the different techniques, it is difficult to identify an estimation technique that does not present important drawbacks and it is not clear if the estimation of the production function, with some refinement could not to be a good starting point in the assessment of this relationship.

In the studies that focus explicitly on infrastructure, fixed assets are usually measured by their quantity through the introduction of a variable that accounts for their stock in the econometric models: transports, energy and communications are the most used typologies in the empirical analysis. Most of the empirical studies consider one single infrastructure sector (Roller and Waverman (2001); Fernald (1999); Loyaza et al. (2003)). Sometime an aggregate index of the stock of infrastructure is computed: this choice is motivated by the fact that there is a high correlation among measures of the different kinds of infrastructure (Calderon and Serven (2004)).

In a recent contribution, Bom (2008) proposes an interesting meta-analysis on the empirical results for public capital productivity. By surveying 76 studies that analyze the effect of public capital on

[3] According to this definition, "social infrastructure", such as schools, is excluded, since it does not share some of the features previously listed. This view however does not have general consensus (see for example Chin and Chou (2004)).
[4] For a critical review, see Florio (2000).

growth, with returns calculated with a production function approach, the author can provide an estimate of the meta-output elasticity of public capital. The empirical contributions considered are both single country and cross country analysis and different measures of public capital are considered (core capital, transportation capital, public investment to GDP ratio and regional capital), and the author explicitly controls for publication bias. The main result presented is that, taking into account the different econometric specifications, various proxies for public capital and the level of aggregation, the average output elasticity is in the order of 0.08.

3. Infrastructure and growth in EU27 regions: empirical analysis

The following Sections will test the relationship between determinants of regional economic performance, as indicated in the previous Sections, by performing an initial analysis of GDP in purchasing power parity both in levels and growth rates. We will try to identify a baseline model and subsequently extend it to include possibly missing variables, thus progressively reducing the variance of the dependent variable left unexplained. We will then consider explicitly the relationship between infrastructure capital and growth, discussing at depth the issue of convergence. The focus of the analysis is thus threefold:

- Contributing to the vast debate on regional convergence, by exploiting our disaggregated dataset on European NUTS2 regions;
- Assessing the role of regional infrastructure in explaining economic performance and the process of convergence itself;
- The role of NMS in potentially shifting the relationship amongst variables.

Data on the relevant variables for the 261 European regions between 1995 and 2005 is taken from Eurostat and ESPON: a detailed description of data sources is provided in the Appendix 1.

3.1 A model in levels

We start by considering a simple Cobb-Douglas production function, with capital and labor as the only production factors. A detailed description of data and sources can be found in Appendix 1.
Our baseline model is therefore:
(1.) $Y=K^{\alpha}L^{\beta}$
which is then log-linearized prior to estimation: $lnY=\alpha lnK+\beta lnL$.
Y represents GDP in purchasing power parity for 261 European regions, K is physical capital estimated over the period 1999-2005 according to the method of perpetual inventory method and L represents labor.
The exponents in eq. (1.) represent the income shares for the main production factors, and measure the relative income elasticities. As such, their estimate provides evidence for the presence of economies of scale in the economy. Not being constrained, if $\alpha+\beta>1$, data provide evidence of economies of scale. In the log-linearized version, the estimated parameters can be thought of elasticities, and can be interpreted as the effect of a variation of the variables on GDP.

Dep Variable: GDP	(1)	(2)	(3)	(4)
Private Capital	0.1926***	0.1521***	0.1786***	0.1995***
	(9.93/0.01)	(8.29/0.018)	(8.97/0.019)	(9.56/0.02)
Labor Force	0.8748***	0.4719***	0.7590***	
	(30.73/0.028)	(8.02/0.05)	(14.53/0.05)	
Labor Force (primary)				-0.11237***
				(-5.17/0.02)
Labor Force (secondary)				0.6791*** (16.34/0.04)
Labor Force (tertiary)				0.1462*** (3.99/0.03)
Human capital		0.4039***	0.1267**	0.2772***
		(7.62/0.05)	(2.63/0.048)	(4.15/0.06)
Constant	2.5462***	3.5814***	2.7399***	4.502***
	(12.27/0.20)	(15.46/0.23)	(12.57/0.21)	(9.47/0.11)
Prob>F.	0.0000	0.0000	0.0000	0.0000
R^2	0.8665	0.8912	0.8700	0.8629
N° obs	260	260	260	255

Table 1: Baseline Cobb Douglas production function (2005)

From the first column of Table 1,[5] we can see that the data display signs of Constant Returns to Scale (henceforth CRTS), since the sum of labor and capital shares is close to one, without imposing restrictions.

The coefficient on labor in this model, that does not include human capital and technological progress, is however not consistent with factor shares in country statistics. Therefore we move on to more complex models, that should account for other important factors of production, such as, for example, adding human capital in the production function, much in the spirit of Lucas (1988) and subsequently considering infrastructure indicators.

When adding human capital, our baseline model can be modified in the following way.

(2.) $Y=K^{\alpha}L^{\beta}H^{\gamma}$

where H stands for Human Capital (proxied in our empirical regressions either by the percentage of the labor force with high education, or by the percentage of the labor force employed in science and technology).

Column 2 of Table shows estimation of the log-linearized version of eq. (2.) for the year 2005:

Adding Human Capital to the model improves the overall performance: relative factor shares are brought to more reasonable values and the percentage of regional variance left unexplained diminishes. Human capital (Column 3), measured by the share of labor force with higher education, accounts for approximately 40% of regional GDP variation, much in line with previous empirical findings.

[5] In all tables, t-values (or z-values) and standard errors are provided in brackets.

Before turning our attention to the role of infrastructure, we consider if there can be a different role for different categories of workers in the model economy in contributing to the production of the final good. Industry level analyses have challenged the assumption of homogenous labor inputs underlying the production functions used in regional models. McQuaid (1986) considers industries in the manufacturing sector in the US and rejects the assumption of homogeneity of labor input factors. Therefore we apply this reasoning to our data and try to assess the contribution of workers in different sectors (primary, secondary and tertiary). Results for the following log-linearized model are shown in column 4 of Table 1:
(3.) $lnY=\alpha lnK+\beta_1\, lnL_{primary}+\beta_2\, lnL_{industry}+\beta_3\, lnL_{services}+\beta_4 lnH$

Evidence provided in column4 suggests that a high share of labor force in the primary sector negatively affects aggregate regional production; while employment in manufacturing and services exert a positive effect, with higher magnitude for the secondary sector.

3.2 Contribution of infrastructure to regional economic performance in levels

We shall now specifically consider the role of infrastructure stock in explaining cross regional variation in GDP.
We focus on infrastructural endowment, not spending, and consider three broad categories:

- TLC infrastructure: number of fixed phone lines and mobile subscriptions, households with internet and firms with website.
- Indirect infrastructure: accessibility indicators such as multi-modal potential access and time to market.
- Direct infrastructure: transport infrastructure, measured in km over square area, such as length of roads (motorways, regular roads) and railways.

Assuming for simplicity that output is produced according to the following Cobb-Douglas production function:

$$Y_t = K_t^{\alpha} L_t^{\beta} I_t^{\gamma} H_t^{\tau} \qquad (4.)$$

where K, L, I and H represent the stock of physical capital, labor force,infrastructure endowment and human capital.
Eq. (4.) can be estimated with OLS. Capital stock is obtained with the method of perpetual inventory. Infrastructure is measured through PCA on four infrastructure components[6] (first vector explaining 75% of the variance). Log-linearizing eq. (4.) and testing it 2005 data we get the following estimates (Table 2):

[6] These have been chosen according to complementarity of the underlying infrastructure and data availability. We chose the number of fix phone lines per regional population, the number of mobile phone lines per regional population, the stock vehicles (which is highly correlated with km of road measures and has more data points) and multimodal accessibility as calculated by the ESPON 1.2.1 project.

Dep Variable: GDP	
Private Capital	0.0919***
	(5.04/0.018)
Labor Force	0.19133**
	(3.11/0.06)
Human Capital	0. 4474***
	(9.19/0.04)
Infrastructure	0.1500***
	(8.18/0.01)
Constant	5.8276***
	(16.41/0.35)
Prob>F.	0.0000
R^2	0.9074
N° obs	212

Table 2: results from OLS estimation the infrastructure-augmented production function, 2005

The infrastructure component helps in explaining a significant percentage of total output variance. Under this specification, labor elasticity is around 20%, capital elasticity approximately 10%, human capital 45%, and our indicator of infrastructure availability along the three dimensions specified (TLC, soft and hard infrastructure) is around 15%. This aggregate measure indicates the overall availability of infrastructure in a very broad sense across regions.

We now turn to the estimation of the contribution of the single components of infrastructure stock, and see their impact on production, and ultimately the growth potential of territorial units associated with factor endowment.

Table 3 summarizes the results of estimates obtained by adding single infrastructure variables one by one in the production function of the form:

$$Y_t = K_t^{\alpha} L_t^{\beta} I_t^{\gamma} H_t^{\tau} \quad (5.)$$

where *K*, *L*, *I* and *H* represent the stock of physical capital, labor force, infrastructure endowment and human capital.

Dep Var.: GDP	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Private Capital	0.1357*** (7.47/0.01)	0.1206*** (6.53/0.01)	0.0856*** (4.86/0.01)	0.06933*** (4.13/0.01)	0.0953*** (5.79/0.01))	0.1141*** (6.68/0.01)	0.0644** (3.00/0.02)	0.1334*** (6.20/0.02)	0.0651** (3.08/0.02)	
Labor Force	0.2641*** (3.53/0.07)	0.4807*** (6.05/0.07)	0.6894*** (12.12/0.05)	0.7482*** (13.73/0.05)	0.5049*** (9.93/0.05)	0.4702*** (8.84/0.05)	0.6067*** (9.86/0.061)	0.5203*** (8.03/0.06)	0.6124*** (10.07/0.01)	0.7274*** (11.72/0.06)
Human Capital	0.3812*** (7.36/0.05)	0.4555*** (8.85/0.051)	0.2468*** (4.91/0.050)	0.2066*** (4.33/0.47)	0.3829*** (8.21/0.04)	0.4032*** (8.16/0.04)	0.3355*** (6.15/0.05)	0.3995*** (6.98/0.057)	0.3260*** (6.03/0.05)	0.28551*** (5.03/0.05)
Infrastructure										
TLC										
Fixed Phones	0.2409*** (4.28/0.05)									
Mobile Phones		0.4373*** (5.23/0.08)								
HH with internet access			0.2468*** (8.75/0.02)							
Firms with web site				0.4344*** (10.86/0.03)						
Indirect										
Potential accessibility					0.3020*** (6.09/0.04)					
Time to Market						-0.4829** (-3.07/0.15)				
Direct										
Motorways							0.0353** (2.55/0.01)			0.0712** (23.29/0.02)
Other Roads								-0.0366** (-2.36/0.01)		
Railways									0.0446** (3.28/0.05)	
Congestion										-0.0635** (-3.39/0.018)
constant	1.9917*** (4.59/0.43)	0.4054 (0.63/0.64)	3.11406*** (14.42/0.21)	2.052*** (8.60/0.23)	2.7855*** (10.20/0.27)	6.806*** (7.04/0.96)	4.1902*** (15.45/0.27)	3.5059*** (13.45/0.26)	4.2303*** (13.56/0.27)	4.5177*** (21.9/0.21)
Prob>F.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R^2	0.8985	0.9017	0.9161	0.9258	0.9207	0.9101	0.8928	0.8822	0.8953	0.9222
N° obs	260	260	251	251	236	236	181	198	181	140

Table 3: The role of TLC, Indirect and Direct infrastructure

When considering TLC infrastructure measures, columns 1-4 of Table 3 show that all the dimensions enter the production function with a positive and statistically significant sign, while the other factor inputs retain reasonable parameter values. It appears that the number of mobile phone subscriptions and the percentage of firms with a website exhibit the highest returns on output (0.44 and 0.43 respectively), indicating that what can be generally defined as information society communications are good predictors of a region's economic performance.

When considering what we define soft infrastructure, in columns 5 and 6 of Table 3, both multimodal potential accessibility and time to market have the expected and statistically relevant effect on regional GDP. Accessibility, an index calculated by ESPON, originally refers to the NUTS3 centroid and is then calculated for the corresponding NUTS2 regions. It is based on the assumption that the attraction of a destination increases with its size (in terms of population and GDP) and declines with distance, travel time and costs. The elasticity of output with respect to this indicator is approximately 0.3, while time to market negatively affects economic performance, with an estimated elasticity of -0.48.

We now analyze the traditional infrastructure measures, relating to roads (motorways and other roads) and railways. Columns 7-9 of Table 3 show that motorways and railways significantly and positively affect regional activity, while other roads seem to have a negative effect. However, the estimated returns are significantly lower (between 0.035 for motorways and 0.044 for railways) than those found for TLC and soft infrastructure, possibly indicating that transport infrastructure is at a steady state level, especially in more mature European countries. In column 10 of Table 3 we add a congestion indicator (number of intraregional commercial trips) and the return on motorways is higher (0.071) while congestion has the expected negative effect (-0.06).[7]

4. Spatial autocorrelation issues in the level model

The previous Sections have shown the potential growth-enhancing role of different aspects of a region's infrastructure endowment, disentangling the effect of transport infrastructure, telecommunications, information society and accessibility. However, results may be misleading if we don't account for the possibility that infrastructure capital may be spatially linked among regions, and that our OLS estimates could be missing important features of the data. As a consistency check on the robustness of our conceptual framework, we investigate whether our main variables of interest display spatial dependence (or correlation) and spatial heterogeneity (Anselin, (2001)). The former refers to data that display similar values when the units of observation are spatially linked or neighboring, while the latter describes a situation in which heteroskedasticity is determined by geographical proximity and location.

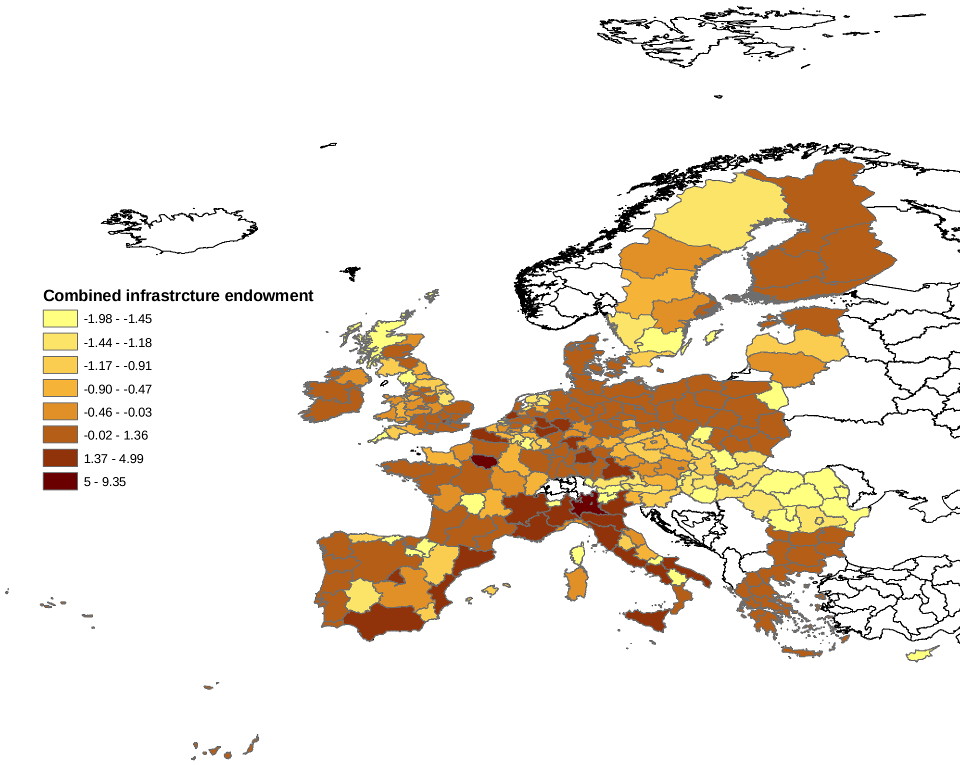
We will present spatial diagnostic tests and regressions both in the cross section and in the panel data setting. For details on spatial diagnostic and estimation techniques, refer to Appendix 2.

4.1 Single year analysis

Map 1 represents combined infrastructure endowment in the EU27 regions. Spatial autocorrelation issues seem to characterize our infrastructure measure, which was obtained by a PCA on TLC,

[7] Private capital was dropped due to multicollinearity issues.

direct and indirect infrastructure capital.[8] In particular, along with a core-periphery pattern that mimics the well-known spatial distribution of wealth, we can see a cluster of average infrastructure endowment in Poland and Baltic countries that offsets the low values recorded in Romania and Bulgaria; also, capital regions (for obvious reasons) seem to be better endowed with infrastructure than peripheral ones. This is true for the metropolitan areas of Madrid, London, and Wien, Ile de France and Lazio, for example.



Map 1: combined infrastructure endowment in the EU27 regions (Espon and Eurostat data; authors' elaboration)

We can also verify if a breakdown into the infrastructure component confirms patterns that show up in our indicator. Table 4 shows the results for the calculation of Moran's I statistic, which measures the degree of dependency among observations across space, on different infrastructure indicators as well as on three measures of GDP growth.

Variable	Moran's I statistic	Pseudo p-value
GDP growth rate 1999-2005	0.6746	0.001
Per capita GDP growth rate 1999-2005	0.7166	0.001
PPP GDP growth rate 1999-2005	0.3885	0.001
Infrastructure (PCA vector)	0.1228	0.001
Multimodal accessibility	0.4592	0.001
Mobile phones penetration	0.1707	0.001
Motorways (total regional kms)	0.3058	0.001
Railways (total regional kms)	0.3057	0.001

Table 4: Moran's I statistics for selected GDP growth and infrastructure endowment measures

[8] See note 3.

Spatial autocorrelation patterns affect both infrastructure data (although with different values on different infrastructures) as well as GDP growth measures. As a consequence, values of the estimated parameters we previously obtained (Table 1) may be biased. We can correct this bias with the spatial lag model and the spatial error model. The first assumes spatial autocorrelation to be in the dependent variable, the latter instead to be in the residuals of the OLS equation. In other words, if we indicate as Y our dependent variable (level of GDP), W a matrix of weights defining neighboring regions, and as X the matrix of our data (here the capital stock, the labor force and the infrastructure indicator) the spatial lag and spatial error models assume respectively:

$$Y = \rho WY + X\beta + \varepsilon \quad (6.)$$

$$Y = X\beta + \varepsilon \quad (7.)$$

where $\varepsilon = \lambda W\varepsilon + u$.

In Table 5 we present the results of the estimation of the spatial lag model:[9]

Variable	Coefficient	Standard error	z statistic	p-value
ρ	0.08333562	0.01781704	4.677299	0.0000029
Constant	3.261798	0.4247211	7.679858	0
Private Capital	0.2715687	0.02748179	9.881769	0
Labor	0.4662466	0.06078334	7.670632	0
Infrastructure	0.2238069	0.03171826	7.056088	0

Table 5: results from the spatial lag model estimation on the infrastructure-augmented production function (1999)

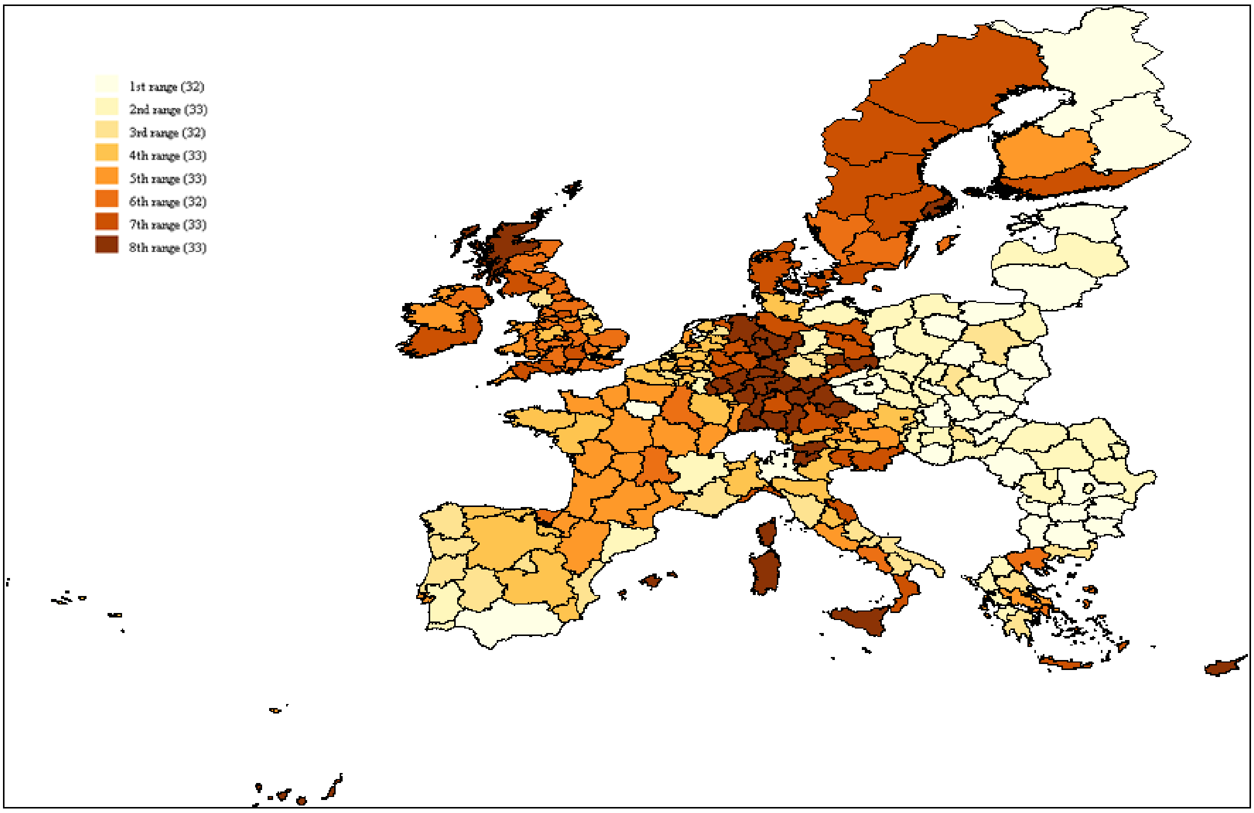
Table 5 shows that estimated coefficients, while retaining sign and magnitude from the OLS estimation, also suggest two interesting observations:

- Coefficients on all explanatory variables, capital, labor and the infrastructure measure, all yield higher estimated values, possibly meaning that the spatial lag model partially corrects underlying biases from spatial autocorrelation in both the dependent and the independent variables (if both capital stock, labor, infrastructures and GDP growth are autocorrelated over space, this might be the case);

- The estimated ρ coefficient, i.e. the degree to which GDP growth is autocorrelated over space, is small but significant (its value being around .08).

The model, however, does not wipe out the whole spatial autocorrelation in the data. Map 2 shows that residuals of this estimation are still correlated over space. This might be intrinsic to the autocorrelation patterns in the explanatory variables (all by nature tend to co-vary over space), or might reflect some omitted variables bias. This last issue, however, might be better assessed in a growth framework.

[9] The spatial error model turned out to be outperformed by the spatial lag model.



Map 2: residuals after estimating the spatial lag model on the infrastructure-augmented production function (Espon and Eurostat data; authors' elaboration)

4.2 Panel data analysis: Pooled OLS

In the next section we extend the previous considerations on spatial autocorrelation for a single year to data for the period 1999-2005. We want to check whether our results are consistent and if they are general enough to hold for longer periods of time. As a first step, we run a pooled OLS estimation of data for the 263 regions for the time period between 1999-2005. We compute Moran's I statistic to check for autocorrelation in the dependant variable (GDP) and, given the positive answer, estimate the spatial error and spatial lag models. We also plot the resulting Moran's I statistic and evaluate the implied physical measure of spatial autocorrelation effects. In Appendix 3, we construct 7 year averages by region of the main variables of interest (in order to smooth short run/business cycle variations) and run estimates on the averaged dataset to gain further insight on the underlying spatial mechanisms.

Table 6 shows the results for the calculation of Moran's I statistic on regional GDP and infrastructure data for five distance bands. The distance bands associated with the ancillary regional shape file to the estimation are related to the actual distances between each region's centroid, and are in the number of 70. Figures 1 and 2 plot the resulting Moran I statistic against the distance bands. From inspection of pseudo p-values, it is clear that there is a positive and statistically significant (albeit small, of the order of 6% for the first level distance and 4% for the second)[10] spatial autocorrelation in regional GDP up to 2 levels of distance. To translate this into a physical distance measure, a proxy was constructed in the following way. Considering the maximum distance between European regions to be approximately 5000 km, the associated range of spatial

[10] The estimated values for the statistic are significantly lower in the panel data set 1999-2005 compared to the single year analysis (Table 10). This might reflect that we are dealing with pooled data, which might smooth and reduce variance in the time series dimension of the data.

effects corresponds to approximately 140 km. Infrastructure is spatially autocorrelated up to three distance bands, with a corresponding physical range of 214 km. The fact that infrastructure seems to have a significant spatial component with a longer physical range with respect to GDP is not surprising, given the network notion of the concept and the fact that this is an aggregate infrastructure measure, which includes TLC components along with traditional road and railway measures.

Distance Bands	Moran's I statistic	Pseudo p-value	z statistic	E(I)	Sd(I)
GDP					
(0-1]	0.062	0	5.09	-0.001	0.012
(1-2]	0.035	0	5.074	-0.001	0.007
(2-3]	0	0.451	0.123	-0.001	0.006
(3-4]	-0.005	0.182	0.908	-0.001	-0.005
(4-5]	-0.008	0.079	1.411	-0.001	-0.005
Infrastructure					
(0-1]	0.069	0	5.642	-0.001	0.012
(1-2]	0.024	0	3.585	-0.001	0.007
(2-3]	0.012	0.017	2.109	-0.001	0.006
(3-4]	0.006	0.11	1.225	-0.001	0.005
(4-5]	0.001	0.415	0.215	-0.001	0.005

Table 6: Moran's I statistics for regional GDP and Infrastructure for selected distance bands (1999-2005)

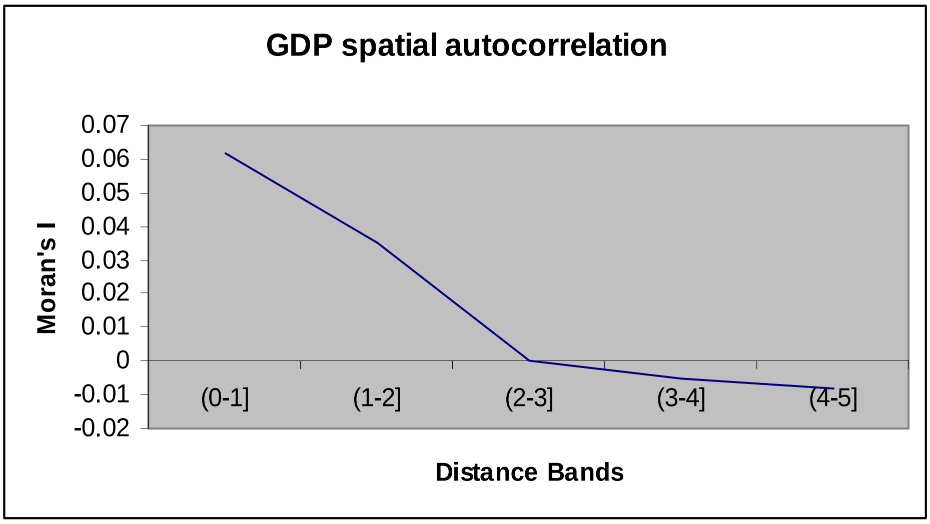


Fig. 1: Spatial autocorrelation for regional GDP (1999-2005)

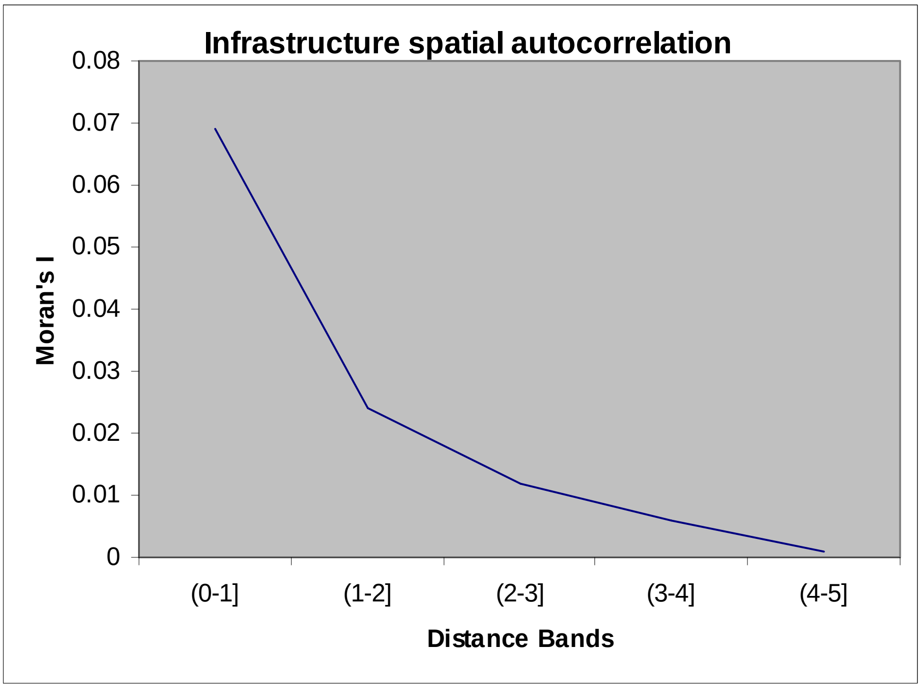


Fig. 2: Spatial autocorrelation for regional Infrastructure (1999-2005)

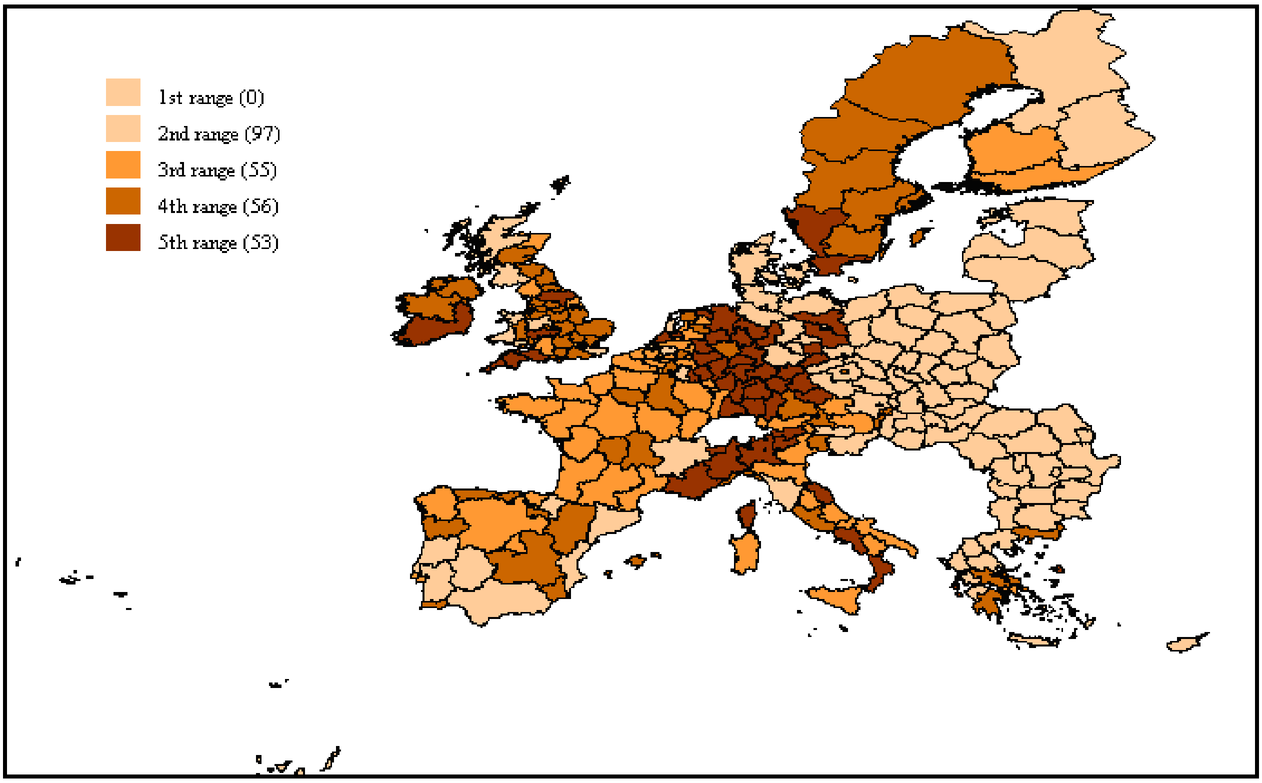
Results from the estimation of the spatial lag and error model are presented in Table 7.

Dep Variable: GDP	(1)		(2)
	Spatial lag model		Spatial error model
ρ	0.6013***	λ	0.9689***
	(28.51/0.0210)		(88.45/0.3355)
Private Capital	0.2554***	Private Capital	0.3393***
	(29.27/0.0087)		(34.49/0.0098)
Labor	0.5920***	Labor	0.5738***
	(35.62/0.1662)		(32.34/0.0177)
Infrastructure	0.1120***	Infrastructure	0.1165***
	(12.53/0.00893)		(12.45/0.0093)
Constant	-2.5253***	Constant	2.6436***
	(-11.37/0.2221)		(7.89/0.3355)
Variance ratio	0.824	Variance ratio	0.673
Squared Correlation	0.827	Squared Correlation	0.746
Sigma	0.45	Sigma	0.41
Log likelihood ratio test	663.711	Log likelihood ratio test	999.074
Wald test	812.773	Wald test	7823.824
Lagrange multiplier test	1541.346	Lagrange multiplier test	1.1e+04
N° Obs	1827	N° Obs	1827

Table 7: Spatial lag and Spatial Error Models (pooled 1999-2005 data)

Table 7 shows some interesting results. While the spatial lag model (column 1) results hold in the averaged model, the spatial error model (column 2) becomes significant and this may yield some further insight into the underlying mechanisms in the model. In particular, the value of the spatial error autocorrelation term (λ in our table) is very close to one and highly significant. Including an

error spatial autocorrelation term causes the capital stock coefficient to decrease and the labor force one to increase. Can we infer from this that the spatial autocorrelation in the data is driven by long run mechanisms, which do not show up here due to omitted variables?
This issue is linked to the spatial lag model results. In this case the averaged dataset results are consistent with the single year estimates (Table 5). However, the averaged estimation of the ρ coefficient (autocorrelation term in the spatial lag model) turns out to be significantly lower than the single year one, although the magnitude of the two estimates is comparable. If this value is close to zero, while the spatial error term approaches one, can we infer that it is not GDP that covaries over space, but it's instead something else captured by the residual? Also, as the average (over seven years) value is lower, can we infer that GDP covaries over time mostly in the short run? In other words, can we say that GDP is spatially auto correlated mainly for short run (business cycles, labor market swings etc.) mechanisms? In this case we might add a correction for the business cycle component in our model; the best solution, however, would be to resort on longer time span for the data set, which is beyond the scope of this paper. Finally, the linear estimation which includes our infrastructure measure causes the estimated spatial lag term to decrease with respect to the estimation of the simple Cobb Douglas production function. Does this allow us to infer that infrastructure endowment is part of the explanation of GDP's autocorrelation over space?



Map 3: Residuals after the 7 year averaged estimation of the spatial error model (Espon and Eurostat data; authors' elaboration)

We can have a guess on some of the above questions with some graphical analysis. Map 3 shows that some autocorrelation affects residuals even after estimating the spatial error model.[11] This may provide some weak evidence of a complex underlying mechanism: spatial autocorrelation in the data might be due both to GDP's autocorrelation over space, as well as to omitted variables bias.

[11] This map is based on the estimation presented in the Appendix, Table 16, over regional data averaged over the 7 year period considered. This restriction is due to software issues.

This last guess might be tested in a spatial panel structure, which might represent a possible evolution of this research.

If this last guess is true, simple (a-spatial) panel estimation with fixed effects should provide meaningful results. In particular, we would expect lower estimated values for estimated parameters on our factors of production (labor, capital and infrastructure); also, we would expect that the greatest variance stems from between (inter-regional) rather than within (inter-temporal) variation. Table 8 meets our expectations.

Dep Variable: GDP	(1)	(2)
	Fixed Effects	Random Effects
Private Capital	0.2310***	0.2386***
	(20.91/0.0110)	(23.26/0.0102)
Labor	0.7209***	0.5921***
	(11.75/0.0613)	(15.21/0.0389)
Infrastructure	0.1555***	0.1731***
	(5.63/0.0276)	(9.99/0.01734)
Constant	3.0073***	3.7607***
	(7.46/0.4030)	(13.57/0.2771)
Prob>F.	0.0000	0.0000
R^2: within	0.3508	0.3475
Between	0.7448	0.760
Overall	0.7395	0.7553
N° obs	1483	1483
N° Groups	212	212

Table 8: Fixed and Random effect regression (1999-2005)

5. Infrastructure and Growth

When moving on to an analysis of growth rates in the European region, a first issue regards convergence: do we find evidence of convergence at the NUTS2 level, and can we say something about NMS? Therefore, in Section 5.1, we consider regional growth rate of GDP in Purchasing Power Parity (add reference) between 1999 and 2005[12] and regress it against the initial level of per capita GDP, therefore testing the so called hypothesis of "unconditional beta convergence".

5.1 Unconditional convergence

Table 9 and 10 provide some evidence in favor of convergence amongst European region, both between per capita and absolute GDP in purchasing power parity, for the 8 and 11 year time span considered. The estimated parameter on the initial level of income is negative and statistically significant, with and without the inclusion of country dummies. The implied value of the

[12] We also perform the same analysis over the 10-year period 1995-2005, obtaining similar results. We focus our attention to the 1999-2005 period because relevant controls, considered in Section 4.2, are available only for this time span.

convergence parameter ranges from -1.6 %(GDP in absolute terms form 1999-2005) to -7% (GDP in per capita terms).[13]

Dep Variable:	(1)	(2)	(3)	(4)
	Growth 99-05		*Per capita growth 99-05*	
Initial GDP	-0.0172** (-2.45/0.007)	-0.0277*** (-6.24/0.0044)	-0.1166*** (-10.76/0.0108)	-0.1064*** (-20.12/0.0052)
Constant	0.4334*** (6.15/0.7052)		0.5666*** (18.78/0.0303)	
R^2:	0.0227	0.9637	0.3098	0.6107
Country Dummies	No	Yes	No	yes
N° obs	260		260	

Table 9: Convergence 1999-2005

Dep Variable:	*(1)*	*(2)*
	Growth 95-05	*Per capita growth 95-05*
Initial GDP	-0.02088** (-2.14/0.009)	-0.1304*** (-4.36/0.0298)
Constant	0.6628*** (6.90/0.0969)	0.7719*** (9.94/0.0776)
R^2:	0.0137	0.0690
Country Dummies	No	No
N° obs	260	260

Table 10: Convergence 1995-2005

We now perform the same empirical exercise, considering only GDP in per capita terms from 1999-2005, grouping our regions according to whether they belong to NMS (EU10), whether they were classified, according to the EU Structural Funds classification, as Objective 1 regions, and finally by performing a cluster analysis based on the 2005 income level. From Table 11 we can infer that NMS are actually converging faster with respect to regions in more mature economies (the estimated parameter on initial income is -0.1605 versus -0.0573) and the explanatory power of initial conditions is higher for NMS (R-squared of 67% in EU10 regions against 39% in the remaining countries).

When considering Objective One regions, it is clear that these are the laggards (-0.0960 versus -0.1278) and that they were correctly identified: similar results were obtained dividing the population according to our cluster analysis (low income regions have an estimated parameter on initial income of -0.0704 while the other regions have -0.1694).

[13] Considering a standard Cobb- Douglas production function, the implied rate of annual convergence is derived by: $\gamma = -\frac{1-e^{\beta T}}{T}$;see Mankiw, Romer and Weil.

Our conclusions therefore point in the direction of the existence of a process of convergence among European regions, especially those belonging to structurally less endowed, but highly dynamic, NMS.
In the following section we want to extend this intuition by considering conditional convergence and highlighting the role of infrastructure endowment in explaining growth of regions and the convergence process.

Dep Variable:	(1) Per capita growth 99-05	(2) Per capita growth 99-05
	EU-10	***EU-17***
	-0.1605***	-0.0573***
Initial GDP	(-8.36/0.0191)	(-11.87/0.0140)
Constant	0.5433***	0.2446***
	(13.63/0.0398)	(17.46/0.0140)
R^2:	0.6666	0.3894
N° obs	37	223
	Obj 1	***Non Obj 1***
	-0.0960***	-0.1278***
Initial GDP	(-7.94/0.0120)	(-20.28/0.0063)
Constant	0.34998***	0.4640***
	(11.81/0.0296)	(24.83/0.0186)
R^2:	0.4144	0.7113
N° obs	91	169
	Low GDP	***Others***
	-0.0704**	-0.1694***
Initial GDP	(-2.29/0.0307)	(-11.11/0.0152)
Constant	0.4388***	0.6841***
	(4.25/0.0971)	(17.91/0.0381)
R^2:	0.0467	0.4532
N° obs	109	151

Table 11: convergence for EU10, objective 1 regions, low income regions (1999-2005)

5.2 Some implications of infrastructure endowment on growth

When considering the impact of regional infrastructure stock on GDP growth, a useful tool is examining simple descriptive statistics. Table 12 displays the regional averages of the level of GDP per capita in PPP, length of motorways and railways, fixed phone lines and mobile phone subscriptions in 1999 and 2005 for the whole sample and splitting it according to timing of accession in the EU. We are therefore looking at the hard and TLC components of the overall infrastructure capital: we can’t consider the soft components due to lack of data availability.

Descriptive statistics	Countries	1999	2005	Variation
GDP	*EU27*	17166.3	21593.64	0.25
	EU6	20413.13	24468.1	0.19
	EU10	8492.754	12605.39	0.48
Motorways	*EU27*	229.8035	255.0104	0.10
	EU6	297.0963	313.9449	0.05
	EU10	68.4875	79.9875	0.16
Rail ways	*EU27*	950.0312	994.246	0.04
	EU6	887.6919	887.4817	-0.00
	EU10	1162.779	1173.559	0.00
Fixed phones (pc)	*EU27*	482.9252	468.2651	-0.03
	EU6	547.2639	541.8482	-0.00
	EU10	321.0339	295.7864	-0.07
Mobile phones (pc)	*EU27*	339.6845	968.5756	1.85
	EU6	364.5785	967.118	1.65
	EU10	116.0221	884.9879	6.62

Table 12: GDP and Infrastructure growth (Espon and Eurostat data; authors' elaboration)

In general, GDP has increased, especially in the EU10 regions (those belonging to NMS), while hard infrastructure is basically invariant, especially in the more mature economies. Fixed phones have decreased, but very slightly, while mobile phone subscriptions have soared. It is interesting to note that mobile phone growth displays a very high correlation with GDP growth and is a significant regressor in a basic growth regression. Also, as shown in Table 13, instead of using the initial level of GDP in 1999 to check for beta-convergence, when using the initial number of mobile phone subscriptions, we get a negative parameter, indicating that mobile phone subscriptions in 1999 are highly correlated with the initial level of GDP. The intuition behind these results parallels similar findings in the IO literature which consider vertically differentiated goods as the ones that have a positive elasticity with respect to income. Mobile phones can be easily thought of as vertically differentiated goods, where new generations differ in terms of quality.

Dep Variable: Per capita growth 99-05	(1)	(2)	(3)
Initial GDP	-0.1166***		
	(-10.76/0.0108)		
Initial mobile phones		-0.0366***	
		(-5.36/0.0068)	
Change in mobile phones			0.08977***
			(8.08/0.0111)
constant	0.5666***	0.7191***	0.1539***
	(18.7/0.0303)	(8.12/0.0885)	(10.5/0.0145)
R^2	0.3098	0.1001	0.2019
N° obs	260	260	260

Table 13: Mobile phones and growth

5.3 Preliminary issues

The relationship between infrastructure and growth is expected to be positive and significant. Policymakers believe better infrastructure to contribute positively to wealth formation. However, not all schools of economic thought would agree.

New economic geographers would actually claim that building more transport infrastructure would reduce commuting costs, hence making it increasingly convenient to buy goods manufactured in more productive regions, and ultimately fostering migrations from laggard to rich regions.

Applied economists would point out that there is a rift between theoretical models and the capability of the economist to actually estimate them, especially when considering short time spans. As is our case, hard infrastructure has not varied much over the period considered (1999-2005), and this causes serious problems in estimating a growth equation. In order to overcome this problem, we resort to Instrumental variable techniques, carried out in the following section.

6.4 Instrumental variable estimation

We now turn to our analysis of the impact of infrastructure endowment and growth both in the cross section and in a panel setting.

A possible solution to the above described problem is to resort on instrumental variables.

Often instruments are not easy to detect. In this case our problem is to assess the role of the *stock* of infrastructures on GDP *growth* over the analyzed period (1999-2005). Our guess is that the elevation structure of regional soil is a good instrument. In fact, it seems reasonable to assume that how large is the share of mountains in regional soil will influence the ease with which transport infrastructure is built. Ex ante, we expect that the higher the average elevation, the lower the available kilometers of roads and railways in the region. However, there is no ex ante expectation on any relationship between the average elevation of a region and its wealth (actually, some of the richest regions in our dataset can be defined as mountainous: Oberbayern is one such example).

Let our model be

$$\dot{Y} = \frac{(Y_T - Y_t)}{Y_t} = \beta_0 + \beta_1 * Y_t + \beta_2 * H_t + \beta_3 * INFR_t \qquad (6.)$$

where $\dot{Y}$ represents our growth measure, β_1 is the convergence parameter, *H* stands for Human Capital and *INFR* for infrastructure. It is reasonable to assume that all coefficients in eq. (6.) would be positive and significant. Our dataset is built as follows. Human capital is proxied by the share of labor force in Science and Technology. Infrastructure is proxied by the number of kms. of roads over labor force (all variables in eq. (6.) are in per capita terms). We provide estimates both for simple OLS in cross section and for pooled OLS (Table 14) performed on data from 1999 to 2005.

However, if we test it with OLS, we obtain the following, puzzling result, as shown in columns 1 and 2.

It is easy to notice that road infrastructure is strangely *negatively* associated to medium run economic performance, both in the cross section and in the panel setting. This can be easily explained: as argued before, the *level* of infrastructure in each region is positively correlated with the *level* of GDP and has not varied much over the time span we consider – hence, our measure is correlated with the convergence term, explaining the negative estimated coefficient[14]. To overcome this problem we resort on TSLS.

Ideally, we would need the average regional elevation. However, this data set seems not to be available. However, we have two useful proxies. The first instrument is a dummy which takes on value one if the region participates to the Interreg Alpine Space Programme. Alps represent the

[14] In our data set, linear correlation between the log of GDP per capita and the log of roads in kms per labor force equals .36.

major chain on the European soil. It seems reasonable to assume that we do not lose much consistent mountainous territory by using this simple dummy variable. The second is a categorical variable, which measures the region's purely geographical accessibility: it goes from 1 to 5 (1 meaning minimum accessibility). Both are taken from the ESPON database.

Now we can re-estimate eq. (6.). We thus obtain results in columns 3 and 4 for the cross section and pooled data:

Dep Variable: GDP growth	(1) Cross section (2005) OLS	(2) Panel data (1999-2005) OLS	(3) Cross section (2005) TSLS	(4) Panel data (1999-2005) TSLS
Initial GDP/labor	-0.2312***	-0.2192***	-0.2864***	-0.2968***
	(-20.17/0.0114)	(-39.32/0.0055)	(-9.48/0.0302)	(-16.47/0.0180)
Human Capital/labor	0.1882***	0.1191***	.2234***	0.1756***
	(5.40 /0.0349)	(8.17/0.0145)	(4.33/0.0516)	(7.29/0.0241)
Motorways/labor	-0.0118*	-0.0220***	.0877*	0.0958***
	(-1.69/0.0069)	(-7.47/0.0029)	(1.86/0.0471)	(3.85/0.0248)
Constant	1.8149***	1.9708***	2.3542***	2.6959***
	(16.19/0.1121)	(38.93/0.0506)	(7.97/0.2953)	(16.09/0.1675)
Prob>F.	0.0000	0.0000	0.0000	0.0000
R^2	0.7308	0.6259	0.469	0.225
N° obs	214	1479	214	1479

Table 14: OLS and TSLS results, growth as a function of infrastructure level (cross section 2005 and pooled OLS 1999-2005)

Now the coefficient associated to the level of infrastructure is meaningful. Its magnitude closely resembles the number we obtain in the level estimates, and the coefficient is also significant at all conventional levels.

The rate of convergence is equal to 0.06, probably a bit high with respect to similar studies. However, this may reflect the short time span observed as well as be partially due to a period of exceptional economic growth within laggard regions in NMS.

5.5 Growth in infrastructure capital

We now turn our attention to the impact of direct and TLC infrastructure growth between 1999 and 2005 on GDP growth for the same period. Data availability constrains our choice of variables, and we concentrate on the length of motorways over area and the number of mobile phone subscriptions. In the following tables we present results for OLS regressions, and we correct our estimation for possible spatial dependency issues.[15] Table 15 estimates a regression of the form:

$$growth = \alpha ln\Delta K + \beta\ ln\Delta L + \gamma lnH + \eta\ ln\Delta INFR$$

where the dependent variable is growth of GDP in purchasing power parity between 1999 and 2005, ΔK is the variation of private capital over the same period, ΔL the variation of labor force, H the

[15] The same regressions were performed by adding country dummies, using per capita GDP and motorways over labor force and we obtained similar results. Details available upon request.

stock of human capital (percentage of labor force with higher education) in 2005 and *ΔINFR* the variation of motorways over area and mobile phones (columns 1 and 2). We still find evidence of a convergence process and human capital endowment has a significant and positive elasticity. The effect of a change of infrastructure is of around 4% for kilometers of motorways over area and 6% for mobile phones.

We now consider the combined effect of the variation of the two types of infrastructure considered, and correct for the presence of spatial dependence and heteroskedasticity. Looking at columns 3-5 of Table15, we can see that wiping out spatial issues reduces the convergence parameter; ρ, the spatial autocorrelation parameter is positive and statistically significant, indicating that GDP growth is autocorrelated across space, and this might explain the lower convergence parameter with respect to simple OLS estimates. The spatial error autocorrelation parameter (λ) is statistically significant and approximately equal to 1. Infrastructure growth elasticities change: the effect of direct infrastructure capital change goes from 3% to 7% in the spatial error model, while TLC infrastructure increases in the spatial lag model (7%) and decreases in the spatial error model (4%), compared to the OLS estimate (4%). However, despite differences in magnitude, the effect remains positive and significant for both indicators.

Dep Variable: GDP growth	(1) OLS	(2) OLS	(3) OLS	(4) Spatial Lag	(5) Spatial Error
Initial GDP	-0.1212***	-0.0991***	-0.1026***	-0.0158**	-0.0111
	(-10.12/0.0119)	(-7.59/0.013)	(-8.61/0.0119)	(-2.08/0.0076)	(-1.24/0.2121)
Δ(Private Capital)	0.2030***	0.1654***	0.1751***	0.1563***	0.1324***
	(8.66/0.0234)	(6.78/0.0244)	(7.53/0.0232)	(6.91/0.0226)	(4.66/0.0283)
Δ(Labor Force)	0.1403**	0.2588***	0.2643***	0.3023***	0.2842***
	(2.74/0.0511)	(4.35/0.0595)	(4.84/0.0546)	(5.40/0.0559)	(4.14/0.068)
Human Capital	0.1167***	0.0991***	0.0989***	0.0252***	0.0305***
	(10.24/0.0114)	(8.12/0.0122)	(8.69/0.0113)	(2.61/0.0096)	(2.81/0.0108)
Infrastructure Growth					
Δ(Motorways/area)	0.0404**		0.0312*	0.0413**	0.0750***
	(2.12/0.0190)		(1.72/0.0181)	(2.16/0.0191)	(4.11/0.0182)
Δ(Mobile Phones)		0.0564***			
		(4.40/0.0128)	0.0607***	0.0723***	0.0470***
			(4.92/0.0123)	(7.37/0.0098)	(2.93/0.0160)
ρ				0.2907***	
				(5.08/0.0572)	
λ					1.0064***
					(462.056/0.002)
Constant	0.8100***	0.6227***	0.6470***	0.0597	0.1026**
	(10.44/0.7757)	(7.16/0.0869)	(8.02/0.0806)	(1.32/0.0451)	(2.04/0.0503)
Prob>F.	0.00	0.00	0.00	0.00	0.00
R^2	0.6551	0.5729	0.6936	0.5735	0.6528
N° obs	203	253	202	202	202
			Sigma-square	0.0048	0.0039
			S.E of regression	0.0693	0.0062
			Log likelihood	326.079	350.3867
			Akaike info criterion	-636.159	-686.773
			Schwarz criterion	-607.643	-661.821

Table 15: Growth of infrastructure: OLS, spatial lag and spatial error models (1999-2005)

6. Concluding remarks

This paper has empirically explored the economic contribution of disaggregated infrastructure capital to European regions' income level, growth and convergence process. We considered TLC, direct and indirect types of infrastructure and our main results point in the direction of a significant and positive role of investment in information, overall accessibility, quality and quantity of transport infrastructure on the levels of GDP. The highest rates of return are associated mainly with

TLC (internet access for both firms and households and communication networks in general), quality and accessibility of the region's transportation network (measured by overall accessibility and time to reach the region's main market), while endowment of traditional road and railway infrastructure has a positive but slightly lower impact. We also show that infrastructure is spatially autocorrelated and we check whether this may bias our findings. Using spatial econometric techniques, we find that our results are robust and consistent even when spatial correlation and heteroskedasticity issues are taken into account. We also find clear evidence of a convergence process occurring across European regions, and the speed of β-convergence is higher for the NMS. This result holds also when we move on to consider conditional convergence, and take explicitly into account the role of infrastructure capital. We find evidence of a positive effect of the stock and growth of TLC and transportation infrastructure on growth, with estimated coefficients in line with previous economic findings, and robust to several econometric specifications and methods. Our results suggest a relatively higher coefficient on TLC infrastructure, and further analyses and investigations are needed to assess the role of indirect infrastructure on growth.

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Appendix 1: Data Sources

Variable	*Measure*	*Source of raw data*
Private capital	Perpetual inventory method on gross fixed capital formation; (depreciation rate=0.025).	Eurostat 1999-2005
Labor Force	Total regional labor force	Eurostat 1999-2005
GDP	Regional GDP in PPP (both aggregate and per capita)	Eurostat 1995-2005
Human capital	Percentage of labor force with higher education Percentage of labor force working in S&T	Eurostat 1999-2005
Infrastructure	Length of motworways (km/area) Length of other roads (km/area) Length of electrified rail lines (km/area) Fixed phone lines Mobile phone subscriptions	Eurostat 1999-2005
	Multimodal accessibility Time to market Households with internet	ESPON 2002
Congestion	Number of intraregional trips by trucks	ESPON 2002

Appendix 2: A Review of Spatial Econometrics Techniques

Spatial econometrics is a set of statistical tools and techniques that deal with the treatment of spatial autocorrelation and spatial heterogeneity in cross section and panel data. The seminal reference is Ansellin 1988 and represents the basis of the material for this Appendix.

Spatial autocorrelation (sometimes referred to as spatial interaction) models explicitly the correlation of a variable with itself through geographical space, and spatial autocorrelation statistics (Moran’s I and Geary’s C) measure the degree of dependency among observations in space. If there is positive spatial autocorrelation, values of the analyzed variable in neighboring areas are similar, while the presence of negative spatial autocorrelation implies differences in neighboring areas. No spatial autocorrelation implies that the values of the variable of interest are not related to the geographical dimension.

Spatial heterogeneity describes heteroskedasticity in the error terms which is explicitly related to geographical space, in the sense that the location of observations is the driving force behind heteroskedasticity.

Spatial econometric techniques mirror time series analysis, with spatial autoregressive and spatial moving average processes. In this setting, however, the time lag is substituted by the notion of a spatial lag operator, which is a weighted average of variables in neighboring locations. This information is summarized by a spatial weight matrix *W*. The spatial lag for variable *y* at Iocation *i* is:

$$[Wy]_i = \sum_{j=1....N} w_{ij} y_j ,$$

and can be thought of as a weighted average of spatial neighbors. The row elements in matrix W for each observation sum to 1, with zero on the diagonal and some non-zero off-diagonal elements. The formula for each weight is:

$$w_{ij} = \frac{c_{ij}}{\sum_{j=1...N} c_{ij}}$$

, with $c_{ij}=1$ if location *i* is linked to location *j*, and $c_{ij}=0$ otherwise.

Several assumptions can be made with respect to the definition of neighbors based on different notions of contiguity, and this is reflected in the form of the weight matrix *W*. The two most common forms of contiguity are rook contiguity (Figure 3, left) and queen contiguity(Figure 3, right), with names borrowed from the game of chess.

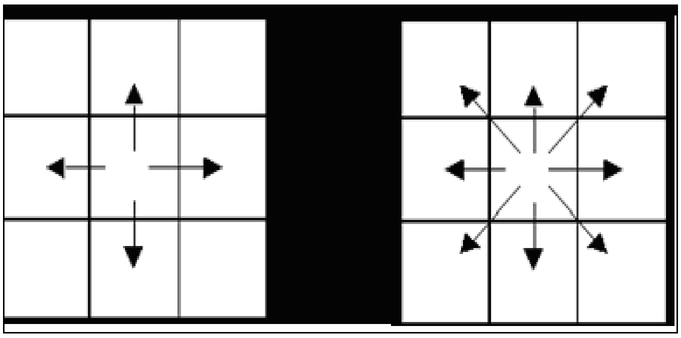

Fig. 3: Rook and Queen contiguity

Weight matrices can also be constructed not only with reference to geographical distance, but also on economic and trade distance, the structure of the social network or distance decay.

Spatial regression models can be divided in two types: spatial lag and spatial error models. In a standard regression model, spatial issues can be incorporated in the form of an additional regressor, the spatially lagged dependent variable, and this is the spatial lag model of the form (in matrix notation):

$$y = \rho Wy + X\beta + \varepsilon$$

$$y = (I - \rho W)^{-1} X\beta + (I - \rho W)^{-1} \varepsilon$$

Spatial issues can also be incorporated in the error structure, by considering spatial dependence in the error disturbance, and this is the spatial error model:

$$y = X\beta + \varepsilon$$

$$E[\varepsilon\varepsilon'] = \Omega(\theta)$$

Model 1 is relevant when the research interest lies in the analysis of the spatial interaction, and is estimated with ML methods. OLS would be biased and inconsistent since one of the independent variables, the spatially lagged dependant variable, is correlated with the disturbances. The spatial autoregressive coefficient, ρ, measures the degree to which the dependent variable is autocorrelated over space.

Model 2 is instead preferred when the researcher wants to correct for spatial dependence in the error term. The value of the spatial error autocorrelation term is represented by λ. OLS techniques are unbiased but inefficient, since the error structure is non-spherical.
Moran's I statistic is the most commonly used specification test for spatial autocorrelation and mirrors the time series correlation test. The test statistic is of the form:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{e'We}{e'e}$$

Appendix 3: Pseudo-panel analysis: Results from time averaged data

Column 1 of Table 16 shows results for the spatial lag model, while column 2 results for the spatial error model considering 7 year averages by region of the main variables of interest (in order to smooth short run/business cycle variations) .

Dep Variable: GDP	(1)		(2)
	Spatial lag model		Spatial error model
ρ	0.0434*** (2.5632/0.0169)	λ	0.9923*** (373.3597/0.0026)
Private Capital	0.2330*** (12.6841/0.02715)	Private Capital	0.2330*** (8.0471/0.0289)
Labor	0.6726*** (13.2205/0.05087)	Labor	0.8794*** (17.1989/0.0511)
Infrastructure	0.1482*** (5.1200/0.0289)	Infrastructure	0.0491* (1.8842/0.0260)
Constant	1.6190*** (5.0822/0.3185)	Constant	1.9542*** (7.1579/0.2730)
R^2	0.8154	R2	0.8767
Sigma-square	0.3674	Sigma-square	0.2454
S.E of regression	0.60618	S.E of regression	0.4954
Log likelihood	-239.697	Log likelihood	-188.782
Akaike info criterion	489.394	Akaike info criterion	385.566
Schwarz criterion	507.216	Schwarz criterion	399.823
N° Obs	261	N° Obs	261

Table 16: Spatial lag and Spatial Error Models (averaged 1999-2005 data)