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INFRASTRUCTURE AND GROWTH IN A SPATIAL FRAMEWORK: EVIDENCE FROM THE EU REGIONS

CHIARA DEL BO AND MASSIMO FLORIO

Infrastructure and growth in a spatial framework: evidence from the EU regions

Chiara Del Bo and Massimo Florio (Università degli Studi, Milano)

Abstract

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This paper examines the return to infrastructure in EU regions in a spatial framework. The paper innovates on earlier literature on infrastructure and growth by a combination of regional focus, disaggregation of infrastructure types and consideration of spatial dependence. Different types of infrastructure capital are considered as determinants of economic performance at NUTS2 level. To account for growth spillovers among regions, a spatial Durbin model is estimated. The results confirm the important role of infrastructure, and identify the highest rates of return as associated with TLC, quality and accessibility of transportation networks, with a positive impact of roads and railways.

JEL: H54, O11, R11
Keywords: infrastructure capital, regional growth, spatial economics.

1. Introduction

The European Union has committed over € 350 billion to regional policy for the 2007-2013 period, focusing specifically on infrastructure. In 2000-2006, transport in lagging behind regions accounted for around 26% of total expenditure, while the planned expenditure in the current 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 crucial sectors. This strategy can be justified by the theoretical models according to which public capital is complementary to private capital in promoting growth (see Barro and Sala i Martin (2004) for a review). The empirical evidence on the relationship between infrastructure and growth is however still debated. Different types of infrastructure capital have a different impact on economic activity, and regional spillovers and contiguity effects may play an important role in shaping the final growth effect of public investment. It is therefore important, from a policy-maker's perspective, to understand the returns to investment in different types of infrastructure capital, while accounting for the specific regional and spatially linked dimension of the European Union countries.

As mentioned, growth theory suggests that public capital in a broad sense is complementary to private capital in promoting growth (e.g. Barro (1990)) and in stimulating household consumption. When considering specifically infrastructure investment, a very lively research agenda stemmed from Aschauer's (1989) pioneering article, 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 implied elasticity (the estimated value 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.[1]

In this vein, but with new data and different methodology, this paper tests the relationship between a set of disaggregated infrastructure indicators and economic performance at the regional NUTS2 level with an empirical model derived from the production-function approach. The empirical analysis is based on a comprehensive database at the European regional level. The paper's contribution focuses on spatial dimensions in the data. In fact, it is shown that the validity of standard econometric techniques is questioned if potential spillover effects are neglected. The main empirical results provide a fresh and better understanding of the contribution to economic activity, at the regional level, of different components of infrastructure, such as roads, TLC and other infrastructure types in the presence of spatial autocorrelation and spillovers, while controlling for structural regional characteristics.

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 gauge the returns on GDP levels and growth for this factor, focusing especially on the European Union. The empirical analysis is presented in Sections 3 and 4. The regional output elasticity to an aggregate infrastructure index and several disaggregations of infrastructure capital are analyzed in Section 3, starting from a baseline production function, augmented with relevant controls. Spatial patterns of the analyzed dataset are taken explicitly into account in the empirical investigation with spatial econometric techniques in Section 4. Section 5 summarizes and concludes.

2. Motivation

After controlling for regional characteristics and spatial patterns, what is the impact of different types of infrastructure on regional performance in the EU? This paper contributes to earlier literature in three combined ways: first, the focus is on infrastructure at the regional level for the 27 Member States of the EU; second, infrastructure is disaggregated by types, to avoid potential aggregation misspecifications; third, spatial econometric techniques are used to account for spillovers and possible proximity effects.

The core of the literature on infrastructure and growth is often based on information at the country level and on aggregate definitions of infrastructure, such as the stock of public capital. The present analysis is motivated by the fact that the focus and aim of EU capital grants through the Structural Funds are not countries, but regions,[2] and that the problem is not the overall infrastructure endowment, but the provision of specific investment types. The underlying intuition is that one Euro spent in tracks for high-speed trains, roads, or broad-band connectivity plays different roles and may have different returns.

Moreover, regional economic activities, including the services of infrastructure, spill over to other regions. Therefore, it is argued that the literature that focuses on the growth potential of EU Structural Funds at the aggregate level is often at risk of misspecification, because spatial and sectoral aggregation do not properly account for spatial autocorrelation and sectoral heterogeneity. Given the regional focus of the analysis, one cannot ignore spillover and contiguity effects and must take these into account with spatial econometric techniques. The empirical analysis will verify (Sections 3 and 4) the effect of investing in specific components of infrastructure (namely direct transport infrastructure, telecommunications and indirect accessibility indicators) on regional GDP in a context where interactions between regions are adequately described and accounted for.

To interpret empirical results, it is important to consider the channels through which infrastructure may affect growth, and how to measure the actual return to 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 in a federation or union, while social cost-benefit analysis will be more appropriate for policy evaluation (Florio and Vignetti (2005), Florio (2006)).

When considering the rate of return to 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, infrastructure is beneficial to output growth if is complementary to firms' investment by positively affecting the private rate of return, or by enhancing households' consumption.

For this reason, recent contributions in the field try to find a comprehensive measurement for the return to infrastructure, moving away from the simple output elasticity of infrastructure proposed by Aschauer (1989); several authors have proposed broader sector analysis, specifically considering the contribution of disaggregated infrastructure capital on growth (for example Shantayanan et al. (1997); Albala-Bertrand and Mamatzakis, (2007)) and identified the social rate of return on road infrastructure and energy capacity (Canning and Bennathan (2000)).

Focusing on the European Union, an increasing number of studies specifically consider infrastructure and analyze growth performance at the regional level. One of the most important targets of this stream of research is to assess the effectiveness of EU Structural Funds on growth and convergence across countries and regions. For example, 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 to infrastructure and direct public investments on output for EU regions. Rothengatter and Schaffer (2004) consider a large set of EU regions and build indices of infrastructure quantity weighted for their quality. Transport infrastructure networks are considered together with immobile factors of production. They find different results for high-density and low-density regions: the quality of the 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. Other 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 the economic performance differently, according to the features of the region where these investments are undertaken. The possibly negative role of transport infrastructure is also analyzed from a new economic geography perspective. Puga (2002), for example, shows that decreasing transport costs for goods and services may further depress peripheral regions, thus possibly going against the guiding principles of EU regional policy.

In this context, some definition, measurement and estimation issues are worth of consideration. 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.

In addition to the problem of the definition of public capital and identification of its main components, there is also a problem of measurement. Detailed data on government spending are not always available. Most studies have therefore used physical measures of infrastructure by introducing a variable for its physical stock in econometric models: transport, energy and communications are the most used typologies in the empirical analysis (Canning (1998), Cieslik and Kaniewska, (2004)). Some authors have proposed to measure infrastructure not only considering the stock component, but also taking into account its quality, measured by scaling the stock of existing infrastructure with the number of people that potentially can benefit and utilize it (Hulten (1996)); Calderon and Serven (2005)), or by dividing it by the square area (Canning (1998)).

Different techniques have been 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 estimation is based on a production or cost function. Sturm (1998), 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. Estimates of the marginal product of public capital in the empirical papers considered range from 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, and remark the possibility of reverse causation between public capital and productivity when the production function approach is used.

Most studies consider one single infrastructure sector (Roller and Waverman (2001); Fernald (1999); Loyaza et al. (2003)). Sometimes 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 (2005), Calderon et al. (2011)).

Bom and Lighard (2008) propose an interesting meta-analysis on the empirical results for public capital productivity. By surveying 76 studies that analyze the effect of public capital on growth, with returns calculated with a production function approach, the authors 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 fixed capital), and the authors explicitly control for publication bias. The main result 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.

The literature mentioned so far does not explicitly address the regional and spatial dimension of the relationship between aggregate and disaggregated infrastructure and output growth. The stress on the regional and spatial dimension characterizes some studies which generally focus on transport infrastructure, such as Seitz (1995) for German cities, Holtz-Eakin and Schwartz (1994) and Chandra and Thompson (2000) for the US and Moreno and Lopez Bazo (2007) for Spanish provinces. A recent contribution by Crespo-Cuaresma et al. (2009) examines the impact of infrastructure on the convergence process of EU regions.

Bronzini and Piselli (2009) provide evidence, from Italian regional data, of the positive spillover effect on regional productivity of neighbors' investment in public infrastructure while Ezcurra et al. (2005) obtain similar results for regions in Spain. Cohen and Monaco (2009) find that the impact of port infrastructures on neighboring counties in the US is positive and highly significant. On the contrary, Holl (2003) provides evidence of negative spillover effects of motorways on the location of new manufacturing establishments in Spanish municipalities, while Moreno and Lopez-Bazo (2007) provide evidence in favor of negative spillovers at the regional level in Spain. Similar results are found for TLC infrastructure at the state level in the US, suggesting that the effects of investment in infrastructure by neighboring areas should be addressed carefully.

In order to assess the role of different forms of infrastructure in regional economic performance, the empirical strategy pursued in this paper starts with a baseline model, where the relationship between infrastructure and economic performance is modeled with a Cobb-Douglas production function.

The focus is on three main components of infrastructure, namely telecommunication (TLC) indicators (Roller and Waverman (2001)), indirect indicators in the form of accessibility indices (Vickerman (2000)) and direct transport infrastructure indicators (Moreno and Lopez-Bazo (2007)).

In the paper, the baseline specification relies on a production function augmented with several dimensions of infrastructure endowment, considered both separately and together in aggregate indices obtained through principal component analysis (PCA). This production function is estimated with OLS, TSLS and spatial models. Spatial spillover effects are then explicitly modeled and interpreted.

3. Empirical analysis

The data used for the empirical analysis refers to information for 262 European NUTS2 (Nomenclature des Unités Territoriales Statistiques) regions in 2007 and is taken from Eurostat and ESPON (European Observation Network, Territorial Development and Cohesion). The list of regions in the sample and a detailed description of the main variables used are presented in Appendix 1.

While a note of caution should be put forward with respect to the choice of the level of spatial disaggregation (see for example Basile (2008) and references herein for a discussion of this issue and the original contribution of Unwin (1996) on the MAUP (modifiable areal unit problem)), and functional areas would be the ideal level of spatial disaggregation, the NUTS2 system has several advantages, since it is comparable across EU countries and allows the use of official EUROSTAT data on the main variables of interest for this paper. Also, structural funds' allocation and spending, along with decisions on infrastructure investment, are often taken at the NUTS2 administrative level.

To verify the role of a region's infrastructure stock on economic performance, the starting point of the present paper's empirical analysis is an augmented Cobb-Douglas production function, with fixed capital, labor, human capital and infrastructure as the main production factors. Our empirical strategy is to consider the a-spatial production function (and the related OLS estimates) as a benchmark and then proceed with a specific-to-general approach by extending the empirical model with spatial interaction effects (Elhorst, 2011). The baseline empirical model is therefore of the type:

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

where *K*, *L*, *I* and *H* represent respectively the stock of physical capital, labor force, infrastructure endowment and human capital. *Y* represents GDP in purchasing power standard (henceforth PPS), *K* is physical capital estimated according to the perpetual inventory method,[3] *L* represents regional labor force, and finally H stands for Human Capital (proxied in the empirical regressions by the percentage of the labor force with higher education).

The exponents in eq. (1.) represent the income shares for the production factors, and measure the relative income elasticities. As such, their estimates provide evidence for the presence of economies of scale in the economy. As usual, in the log-linearized reduced version, the estimated parameters can be thought of GDP elasticities to each regressor.

Eq. (1.) is log-linearized and estimated with robust OLS, with the inclusion of country fixed effects in every model. Turning to the analysis of the contribution of the disaggregated components of infrastructure stock, Table 1 summarizes the results of estimates obtained by adding single infrastructure variables one by one in the model of equation 1.

The main results are based on the distinction between direct and indirect indicators of infrastructure and TLC and information society components, as indicated in the previous Section, which are summarized as follows:

- TLC infrastructure and information society: number of households with broadband, firms with website and e commerce[1];
- Indirect indicators: accessibility indicators such as multimodal potential accessibility and time to market;
- Direct indicators: transport infrastructure, measured in km over square area, such as length of roads (motorways, regular roads) and railways.

For each of the three domains, we include one indicator at a time, and compute an aggregate index through Principal Component Analysis.

Our choice of disaggregated infrastructure indicators aims at combining information on the stock of traditional, road and rail, infrastructure with new networks, crucial for the current economic environment. We also include measures aimed at capturing, to a certain extent, the quality of the infrastructure stock (accessibility indicators).

In detail, the TLC domain, the regional percentage of households with a broadband connection is a direct indicator of the stock of TLC network infrastructure, while firms with website and individuals that use the internet to purchase goods and services represent an indirect measure of the extent of availability and usage of TLC infrastructure. Traditional direct infrastructure is instead measured by the density (over regional area) of motorways (including highways), other roads and electrified rail lines and represent the traditional infrastructure measure. Finally, as indirect quality measures, we consider two additional measures. Multimodal accessibility, an index calculated by ESPON, originally refers to the NUTS3 centroid and is then aggregated 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 (which in turn lays its foundations in gravitational models of trade). Time to market measures the time to reach the region's main market.

[TABLE1 ABOUT HERE]

When considering TLC infrastructure measures, columns 1-4 of Table 1 show that all the infrastructure dimensions enter the production function with a positive and statistically significant sign, while the other traditional factor inputs (fixed capital, labor and human capital) have reasonable parameter values. It appears that the percentage of firms with a website and

[1] Measured as individuals who ordered goods or services over the Internet for private use (Eurostat)

households with a broadband connection exhibit the highest estimated coefficients (0.31 and 0.30, respectively in columns 3 and 1), indicating that what can be generally defined as information society communications, especially from the production side, are good predictors of a region's economic performance. A highly significant coefficient is also associated with e-commerce (column 2). The aggregate TLC infrastructure measure (column 4), obtained through a PCA on the single components, is statistically significant and has an associated coefficient of 0.15.

When considering what has been defined as indirect indicators of infrastructure, in columns 5 and 6 of Table 1, both multimodal potential accessibility and time to market have the expected and statistically relevant effect on regional GDP. The elasticity of output with respect to this indicator is approximately 0.21, while, as expected, time to market negatively affects economic performance, with an estimated elasticity of -0.42.

The third set of disaggregated infrastructure measures considered is related to traditional transport indicators: roads (motorways and other roads) and railways. Columns 7 to 11 of Table 1 show that motorways and railways are significantly and positively correlated with regional activity, while other roads seem to be statistically insignificant. The estimated coefficient for the aggregate PCA index (column 11) is 0.05, indicating that the overall availability of a road and rail network is positively associated with regional economic activity. However, the estimated returns are significantly lower (ranging between 0.07 for motorways and 0.15 for railways) than those found for TLC and indirect infrastructure, possibly indicating that transport infrastructure is near to a steady state level, especially in more mature European countries. This finding could also be linked to issues related to sub-optimal routing. Allowing for the possibility that the services of road infrastructure may be affected by congestion (Montolio, Solé-Ollé, 2009), in column 10 of Table 1, a congestion indicator is added (number of intraregional commercial trips) and results show that the return on motorways is positive and significant (0.07) while congestion has the expected negative effect (-0.06).

In column 12 several indicators have been added together, overall providing evidence in line with the previous reduced models, highlighting the important and positive role for TLC infrastructure and high quality direct transport infrastructure, such as highways and rail lines. Finally, in the last column, the aggregate infrastructure index, based on a Principal Components Analysis on the TLC and direct infrastructure indicators, is positively associated with regional GDP, with an estimated coefficient of 0.10.

3.1 Identification: Two-Stages Least Squares

In order to overcome the possible endogeneity issue due to the fact that the level of infrastructure in each region may be positively correlated with the level of GDP, the estimation of the augmented production function with the aggregate indices for direct, TLC and total infrastructure measures is performed with two-stages least squares (TSLS). The chosen instruments are two geographical variables which are correlated with regional infrastructure stock, as recently highlighted by Ramcharan (2009), but are not directly linked to the dependent variable. Both instruments are statistically valid (i.e., they are correlated with the explanatory variable, as physical impedance makes it harder to build transport infrastructure, but not with the dependent variable, as for example in the Austrian region of Slesia).

The first instrument is a dummy which takes on value one if the region participates to the Interreg Alpine Space Programme. Alps represent the major chain on the European soil, and 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 ranges from 1 to 5 (1 meaning minimum accessibility). Both are taken from the ESPON database. Results from the TSLS estimation (Table 2) confirm the main results, bo for single infrastructure components (columns 1 and 2) and for the aggregate indicator (*PCA Total* in column 3). An interesting result, which confirms our previous findings, is that the highest return seems to be associated with the TLC indicator, highlighting the importance of investing in new infrastructure and network components in the EU.

[TABLE2 ABOUT HERE]

4. Spatial autocorrelation and regional GDP

The previous Section has 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. Moreover, it has been highlighted how adding specific infrastructure in the model does offer better insights as compared with some of the earlier empirical literature. However, results may be misleading if the possibility that GDP[4] and infrastructure capital may be spatially linked among regions is not accounted for, and OLS estimates could be missing important features of the regional data. Spatial diagnostic tests suggest that data is affected by spatial autocorrelation. In fact, Moran's I statistic calculated for the dependent variable (regional GDP) is equal to 0.40, significant at all conventional levels. Appendix 2 provides a visual representation of the spatial distribution of the aggregate infrastructure indicator. Hence, spatial models need to be considered and tested against simple OLS.

As a consequence of spatial autocorrelation issues, values of the estimated parameters previously obtained (Table 1) are biased. This issue has been taken into account by resorting to the appropriate spatial econometric model which formally considers the role of a change in own and neighboring explanatory and dependent variables (Anselin (2001)). Following Florax et al. (2003), the paper adopts a modified forward stepwise procedure to identify the most appropriate spatial empirical model. The starting point is the result of OLS estimation. Then, the presence of spatial dependence is verified with Lagrange multiplier (LM) tests. Results of tests (Table 3) suggest the estimation of the spatial error (SEM) model. The more general specification, the Spatial Durbin Model (SDM) is then considered and Likelihood Ratio (LR) tests are used to verify its validity. Formal test results (see below) suggest the use of the SDM.

The SDM, which is the basis for the empirical analysis, is of the form:

(2.) $y = \alpha\kappa + \rho Wy + X\beta + WX\theta + \varepsilon$

where W is a row-standardized contiguity matrix based on the inverse of geographical distance, ρ is the spatial lag coefficient, X is the matrix of control variables which include labor force, capital stock, human capital and infrastructure indicators and κ is a vector of ones. Our empirical model is thus:

(2a.) $y = \alpha\kappa + \rho Wy + K\beta_1 + L\beta_2 + H\beta_3 + I\beta_4 + WK\theta_1 + WL\theta_2 + WH\theta_3 + WI\theta_4 + \epsilon$

The SDM specification allows for spatial effects arising from the spatial lag of the dependent variable, the spatial lag of explanatory variables and a contagion effect:

(3.) $y = (I - \rho W)^{-1}(\alpha\kappa + X\beta + WX\theta + \varepsilon)$

Justification for the SDM specification is suggested by the spatial dependence in observed and unobserved values of our main regressors, such as human capital (see Fischer et al. (2009)) and infrastructure (Rietveld and Wintershoven (1997)) and that regional GDP and infrastructure may be influenced by common shocks to the underlying spatial data generating process.

The SDM is a general spatial model, which, in restricted form, can be interpreted as a spatial lag (SAR) or spatial error (SEM) model. The choice of this unconstrained specification was driven by LM tests and LR tests, as presented in Table 3. The LM tests (both robust and non robust) are based on residuals of simple OLS estimation for equation 1.

The LR tests are each based on a restriction: in eq. 2, first we test the restriction ($\theta = 0$), which corresponds to the case of the spatial lag model; then, we test a second restriction ($\rho\beta + \theta = 0$), which implies the spatial error model.[5]

The LR test comparing the SDM and spatial lag model is based on a comparison of the residuals of the unrestricted and restricted SDM model. The statistic is equal to 56.27 (the reference value is 6.63). To the right tail of the test distribution, the restriction of non significance of the spatial lag of the explicative variables is rejected, with a significance level of 99%. Hence, the SDM model is to be adopted against the spatial lag. Analogously, the SDM is also preferable to the spatial error model, since the LR statistic associated to the restriction is equal to 26.81 (reference value is 9.21), with a significance level of 99%.

[TABLE 3 ABOUT HERE]

Table 4 presents the results of estimation of the SDM model, focusing on the aggregated and disaggregated infrastructure components analyzed in Table 1 in an a-spatial setting. We start by considering TLC infrastructure measures (columns 1-4), indirect indicators (columns 5 and 6) and direct infrastructure measures (columns 7-10) are then added to the specification. In the final column the aggregate infrastructure indicator, obtained through a PCA on the direct transport and TLC measures, is considered.

[TABLE4 ABOUT HERE]

The spatial autocorrelation coefficient ρ is positive and significant across all specifications, indicating that EU regions are characterized by a positive and significant level of spatial correlation, with an estimated coefficient value ranging from 0.15 (column 2) to 0.30 (column 11). The coefficients on the relevant controls mimic the behavior highlighted in the previous analysis, with a relevant role for the aggregate indices (overall, TLC and road PCA) and single components.

The coefficients associated to the explanatory variables in a spatial setting are significant for labor force, human capital and most infrastructure vectors (with the exception of e-commerce, column 2, and motorways, column 7).The aggregate infrastructure component (column 11) has an associated coefficient of 0.07, while, looking at the single components, indirect indicators (columns 5 and 6) seem extremely relevant, with coefficients of 0.17 for multimodal accessibility and -0.53 for time to market. When focusing on TLC indicators, firms with websites (column 3) seems to be the most important component (estimated coefficient of 0.21), followed by households with broadband, while the effect of e-commerce appears statistically insignificant. When turning our attention to traditional transport infrastructure, railways (column 9) and motorways (column 7) have the highest associated estimated coefficients.

Considering the spatially lagged explanatory variables, regional output seems to be a negative function of the labor foce, human capital and infrastructure endowment in neighboring regions across all specifications (*W*Labor Force,* W**Human Capital* and *W*Infrastructure*). In particular, time to market (column 6) and firms with website (column 3) exhibit the highest coefficients.

While spatially lagged regressors provide an idea of interactions among regions, the sign and magnitude of the SDM (direct and indirect) impacts can be estimated more precisely, providing a more complete and accurate picture of the spillover effects, especially with respect to infrastructure.

Thus, in order to better assess the importance of spatial spillovers, following LeSage and Pace (2009), summary measures of direct, indirect and total impacts are computed. These measures are capturing the cumulative effect in the EU regions of changes in the independent variables, which induce a change in the long run steady state equilibrium. The aim is to verify whether the positive direct effect of an increase in a region's infrastructure endowment is accompanied by a negative spillover effect to and from other regions and if the total effect can be identified.

A change in an explanatory variable *l* in region *i* on GDP in the same region *i* (direct effect) is not simply the partial derivative $\frac{\partial y_i}{\partial x_{il}}$, but is influenced also by feedback effects from corresponding changes in the dependent variable in neighboring regions. The SDM specification gives rise to theses complex effect because spatially lagged values of both the dependent and explanatory variables are explicitly included. Similarly, a change in an explanatory variable *l* in region *j* might affect GDP in region *j*, indicating that the partial derivative $\frac{\partial y_i}{\partial x_{jl}}$ may be different from zero. LeSage and Pace (2009) have provided the theoretical framework to interpret these direct and indirect effects, by transforming the spatial weight matrix and by considering the role of off and on diagonal elements. Formally, the SDM can be re-written as:

(4.) $$y = \sum_{l=1}^{k} S_l(W)x_l + V(W)\kappa_n\alpha + V(W)\varepsilon$$

where $S_l(W) = V(W)(I_n\beta_l + W\theta_l)$ and $V(W) = (I_n - \rho W)^{-1}$.

In this setting: $\frac{\partial y_i}{\partial x_{il}} = S_l(W)_{ii}$ and $\frac{\partial y_i}{\partial x_{jl}} = S_l(W)_{ij}$.

The average total impacts are calculated by averaging over all regions of the sum of the rows (or columns) of matrix $S_l(W)$; average direct impacts are obtained as the average of the diagonal elements of matrix $S_l(W)$ and average indirect impacts are obtained as a difference between the previous measures.

Scalar summary measures of these direct and indirect effects can be calculated by an approximation of the matrix $S_l(W)$ and by using the traces of powers of the weight matrix;

inference on these measures is drawn by using Bayesian Markov Chain Montecarlo estimation methods which provides a posterior distribution for the scalar summary measures of impact. Inference is based on 2000 simulated draws.[6] Formally:

$$Direct = n^{-1} tr(S_l(W))$$

$$Total = n^{-1} \kappa_n^{'} tr(S_l(W)) \kappa_n$$

$$Indirect = Total - Direct$$

The interpretation of the direct and indirect effects (Table 5) will highlight the overall impact of aggregate infrastructure endowment, summarized by the three PCA indicators and then identify the disaggregated components that appear to yield higher returns and overall positive impact on economic output, taking into account the spatial diffusion and spillover processes at play.

[TABLE5 ABOUT HERE]

Focusing mainly on the infrastructure indicators, we can verify that direct effects are statistically significant (with the exception of e-commerce, column 2) and overall have the expected sign. Comparing the coefficients with those obtained by estimating the SDM (Table 4), the magnitude and significance are comparable, with some evidence in favor of small feedback effects for TLC components of regional infrastructure, especially households with broadband and firms with website (columns 1 and 3 feedback effect of 0.0007 and 0.05,), railways (column 9, feedback effect of 0.009) and indirect indicators, with a slightly higher effect for time to market (column 7, feedback effect in absolute terms of -0.024), indicating once again the importance of an optimally routed direct infrastructure network. The feedback effect, following Lesage and Pace (2009) is the difference between the SDM coefficients and the estimated direct impact, and represents the effect of the impacts spilling over to neighboring regions and back to the region itself. If the difference is positive, the implied feedback effect is positive.

The share of firms with website (Column 4) seems to influence regional GDP both directly and through a small but positive feedback loop, which works through neighboring regions and back to the origin. In general, positive, albeit small, significant feedback effects are reported for most infrastructure indicators.

In order to examine the spillover effects of infrastructure cumulated over the whole sample of EU regions considered, the indirect effects are analyzed. Considering only statistically significant coefficients, we can see that an increase of railways in region *i* will negatively affect neighboring regions (with an estimated effect of -0.09, column 10), suggesting the existence of negative spatial spillover effects (for a similar result in US states, using a different econometric framework, see Yilmaz et al., 2002). Similar conclusions can be drawn from the aggregate indicator (column 11), with an indirect effect of -0.05, statistically significant at the 5% level. Households with broadband (column 1) and the aggregate TLC indicator (column 4) also seem to be characterized by negative spillover effects. Time to market presents the highest negative[7] spillover effect (0.244, column 6) indicating once again the importance of a well designed transport network that affect commuting times and access to the main markets. Overall, it appears that negative spatial spillover effects impact both the traditional road and rail infrastructure endowmentand the TLC infrastructure, with a significant role played by indirect indicators that may proxy for the quality of the traditional transport network.Finally, total effects summarize the overall impact of regional infrastructure endowment in a spatial framework and represent the long run results of a new steady state situation. With this interpretation in mind, it can be concluded that time to market (column 6) has an estimated coefficient of -0.27, while the coefficient associated with multimodal accessibility (column 5) is approximately 0.10, indicating the importance of the quality of the road infrastructure, in terms of creating a network that will enhance a region’s accessibility and attractiveness. Considering telecommunication infrastructure, firms with website (column 3) has an estimated total effect of0.12. finally, considering the aggregate indicator (column 11), the total impact is of around 0.02. This coefficient can be interpreted as an elasticitiy, indicating that a 10% increase in the overall infrastructure network will correspond to a significant increase in regional performance of around 0.2%, accounting for both direct, own-region effects, and potentially negative spillovers to neighboring regions. Focusing on time to market, the coefficient of -0.26 indicates that decreasing the time to reach the region’s main market by 10% (through improvements of the existing transport network or by expanding it) might lead to an improvement of regional GDP of approximately 3%.

To conclude, it appears that spatial issues are relevant when examining the overall impact of infrastructure endowment, both in aggregate and disaggregated components, and that complex feedback and spillover effects are at play. What emerges clearly is the importance of TLC and quality of the road and rail infrastructure network, providing a framework for evaluation of public investment in regional infrastructure**.**

5. Concluding remarks

This paper has offered a new assessment of the economic contribution of disaggregated infrastructure capital to European regions’ GDP, in a spatial framework. The main results point to a significant and positive role of investment in information and communication technology, 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 by firms 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), with a positive but slightly lower coefficient associated to endowment of traditional road and railway infrastructure. The paper also controls for possible endogeneity issues by using TSLS for road transportation network. Preliminary exploratory spatial analysis has shown that infrastructure and GDP are spatially autocorrelated and this has been taken into account in subsequent analyses. Using spatial econometric techniques, it is verified that the core results are robust and consistent even when spatial correlation issues are taken into account. The paper's findings suggest a positive correlation between regional infrastructure endowments, both in aggregate and disaggregated terms, with economic activity. The role of direct and spatial spillover effects is also highlighted, confirming the possibility of negative spatial spillovers infrastructure endowment. Spatial clustering of transportation networks may cause traffic concentration–enhancing policies (e.g. the EU's corridors) to incorrectly assign funds, were these spillover effects ignored.

These results, however, highlight the importance of directing public investment to specific disaggregated category of infrastructure with high return. An important policy implication of our analysis is that when in a federal or quasi-federal union there are matching grants for infrastructure investment, selectivity across sectors is needed, and this is more important than regional targeting. The different returns to one Euro spent by the EU through its Structural Funds imply that misallocation is possible if the grants are lump sum transfers to member states or regions, without constraints on investment priorities, and if funds are allocated with political considerations in mind by the recipient governments. When the overall objective of a federation is to promote convergence across regions, incentives to investment must go where the social returns are highest. Moreover, our empirical results show, in contrast to some earlier literature, that policy concerns about interregional spillovers are misguided. Targeting the investment grants to sectors with the highest growth potential is indeed beneficial to the receiving region, and even when there are spillovers to other regions, the overall impact on economic performance is confirmed. This is in accordance with intuition: if two regions are neighbors, they share the economic benefits of possibly interrelated networks, and this is a mutually reinforcing mechanism. In other words, the present analysis suggests investment complementarity across regions. This ensures that capital grants act as a growth multiplier, while leakages do not completely offset the possible positive effects of policies aiming at stimulating convergence.

Dep Var: GDP	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Capital Stock	0.294***	0.295***	0.296***	0.252***	0.278***	0.286***	0.315***	0.316***	0.336***	0.366***	0.307***	0.286***	0.267***
	3.70	*3.75*	*3.86*	*3.50*	*3.37*	*3.39*	*4.76*	*3.87*	*4.29*	*7.17*	*3.82*	*4.06*	*3.54*
Labor Force	0.741**	0.754***	0.733***	0.767***	0.742***	0.737***	0.713***	0.738***	0.690***	0.720***	0.727***	0729***	0.746***
	9.13	*9.30*	*9.25*	*10.53*	*8.75*	*8.26*	*10.36*	*8.82*	*8.50*	*11.94*	*8.84*	*10.15*	*9.85*
Human Capital	0.287***	0.278***	0.331***	0.287***	0.359***	0.345***	0.294***	0.371***	0.271***	0.169***	0.304***	0.188***	0.253***
	4.54	*4.04*	*4.97*	*5.12*	*5.10*	*4.81*	*4.68*	*5.20*	*3.94*	*2.31*	*4.25*	*3.11*	*3.77*
TLC Infrastructure													
Households with broadband	0.296***											0.142**	
	5.70											*2.53*	
E-commerce		0.266***										0.097**	
		7.02										*2.06*	
Firms with website			0.314**									0.159***	
			4.77									*2.79*	
PCA TLC				0.149***									
				6.98									
Indirect Infrastructure													
Multimodal Accessibility					0.215***							0.001	
					3.95							*0.01*	
Time to Market						-0.423**						-0.082	
						-3.06						*-0.55*	
Direct Infrastrutture													
Motorways							0.069***			0.069***		0.032**	
							5.39			*4.35*		*2.33*	
Other Roads								-0.1018				-0.038	
								-0.51				*-1.55*	
Railways									0.150***			0.063**	
									4.32			*2.13*	
PCA Road											0.054***		
											3.88		
Congestion										-0.061**			
										-1.95			
PCA Total													0.099***
													6.91
Constant	2.753***	1.323***	2.776***	2.649***	1.773***	5.059***	2.6701***	2.372***	2.603***	2.469***	2.418***	2.9329***	2.604***
	5.89	*2.95*	*6.30*	*6.42*	*3.44*	*5.82*	*6.70*	*5.01*	*5.61*	*8.80*	*5.21*	*6.54*	*5.97*
R^2	0.978	0.976	0.978	0.981	0.975	0.974	0.977	0.973	0.976	0.982	0.976	0.9648	0.981
n° obs.	209	209	209	209	209	209	209	209	209	161	209	209	209

Note: t-statistics associated with robust standard errors are in italics. *: Significant at the 90% level. **: Significant at the 95% level. ***: Significant at the 99% level. Country fixed effects included in all columns, omitted country: UK.

Table 1: The role of TLC, indirect and direct indicators of infrastructure

Dep Var: GDP	(1)	(2)	(3)
Capital Stock	0. 243***	0.302***	0.273***
	3.63	*3.27*	*3.72*
Labor Force	0. 774***	0.724***	0.745***
	11.49	*8.68*	*10.03*
Human Capital	0. 263***	0.275***	0.260***
	3.98	*3.56*	*3.71*
Infrastructure			
PCA TLC	0.185***		
	4.38		
PCA Road		0.0804**	
		2.56	
PCA Total			0.092***
			3.27
Constant	2.643***	2.434***	2.434***
	6.94	*5.09*	*6.06*
R^2	0.980	0.976	0.981
N° Obs	209	209	209
Instruments: alpine region, geographical accessibility			

Note: t-statistics associated with robust standard errors are in italics.
*: Significant at the 90% level. **: Significant at the 95% level. ***: Significant at the 99% level. Country fixed effects included in all columns, omitted country: UK.

Table 2: Transport infrastructure (TSLS)

Moran's and LM tests	Statistic	p-value
Spatial error:		
Moran's	3.559	0.000
Lagrange multiplier	7.663	0.006
Robust Lagrange multiplier	7.416	0.006
Spatial lag:		
Lagrange multiplier	0.276	0.599
Robust Lagrange multiplier	0.030	0.863

Table 3: Diagnostics

Dep Var: GDP	**(1) Households with broadband**	**(2) E-commerce**	**(3) Firms with website**	**(4) PCA TLC**	**(5) Multimodal Accessibility**	**(6) Time to Market**	**(7) Motorways**	**(8) Other Roads**	**(9) Railways**	**(10) PCA Road**	**(11) PCA**
Labor Force	0.844***	0.825***	0.857***	0.875***	0.828***	0.809***	0.823***	0.828***	0.784***	0.827***	0.873***
	24.54	*8.37*	*26.31*	*25.40*	*25.07*	*25.08*	*25.31*	*25.36*	*23.56*	*25.69*	*28.47*
Capital Stock	0.185***	0.207***	0.168***	0.150***	0.183***	0.188***	0.195***	0.212***	0.237***	0.194***	0.142***
	5.47	*6.04*	*5.27*	*4.40*	*5.63*	*5.96*	*6.11*	*6.63*	*7.41*	*6.15*	*4.57*
Human Capital	0.289***	0.324***	0.277***	0.272***	0.315***	0.295***	0.273***	0.313***	0.243***	0.281***	0.241***
	6.74	*7.52*	*7.15*	*6.75*	*8.11*	*7.67*	*6.79*	*8.00*	*5.85*	*7.14*	*6.27*
Infrastructure	0.087**	-0.001	0.206***	0.062***	0.174***	-0.531***	0.046***	-0.065***	0.089***	0.042***	0.070***
	2.38	*-0.03*	*5.35*	*4.41*	*3.98*	*-4.93*	*4.30*	*-3.35*	*4.38*	*4.67*	*6.89*
Constant	1.807***	1.863***	2.165***	1.885***	1.637***	3.079***	2.123***	1.771***	1.703***	*1.783****	1.801***
	8.14	*8.37*	*7.93*	*8.29*	*6.95*	*4.73*	*8.60*	*8.26*	*7.81*	*8.43*	*8.57*
*W*Labor Force*	-0.281***	-0.252***	-0.234***	-0.306***	-0.245***	-0.263***	-0.236***	-0.266***	-0.234***	-0.270***	-0.338***
	-5.23	*-4.67*	*-4.18*	*-5.60*	*-4.64*	*-5.18*	*-4.42*	*-5.16*	*-4.63*	*-5.26*	*-6.47*
*W*Capital Stock*	0.102***	0.096***	0.058	0.121**	0.086**	0.085**	0.059*	0.071**	0.041	0.084**	0.107***
	2.74	*2.54*	*1.56*	*3.23*	*2.38*	*2.42*	*1.65*	*1.96*	*1.12*	*2.35*	*3.10*
*W*Human Capital*	-0.136***	-0.147***	-0.135 ***	-0.128***	-0.169***	-0.148***	-0.131***	-0.172***	-0.093**	-0.144***	-0.112***
	-3.33	*-3.45*	*-3.66*	*-3.27*	*-4.46*	*-3.97*	*-3.38*	*-4.48*	*-2.34*	*-3.82*	*-3.02*
*W*Infrastructure*	-0.088**	-0.018	-0.105**	-0.052**	-0.094**	0.320***	-0.018	0.071***	- 0.091***	-0.025**	-0.056***
	-2.42	*-0.59*	*-2.01*	*-3-61*	*-2.11*	*3.07*	*-1.45*	*4.07*	*-4.45*	*-2.93*	*-5.43*
ρ	0.172***	0.149***	0.175***	0.177***	0.162***	0.189***	0.172***	0.178***	0.198***	0.186***	0.229***
	3.23	*2.78*	*3.26*	*3.35*	*3.03*	*3.61*	*3.20*	*3.93*	*3.81*	*3.52*	*4.52*
R^2	0.966	0.9651	0.9686	0.9677	0.9671	0.9678	0.9674	0.9668	0.9674	0.967	0.970
n° obs	209	209	209	209	209	209	209	209	209	209	209
Log Likelihood	178.186	175.713	188.599	184.466	182.941	186.498	184.383	183.209	186.017	185.895	196.042

Note: t-statistics are in italics. *: Significant at the 90% level. **: Significant at the 95% level. ***: Significant at the 99% level.

Table 4: The role of TLC, Indirect and Direct indicators of Infrastructure: Spatial Durbin Model

	(1) Households with broadband	(2) E-commerce	(3) Firms with website	(4) PCA TLC	(5) Multimodal Accessibility	(6) Time to Market	(7) Motorways	(8) Other Roads	(9) Railways	(10) PCA Road	(11) PCA
Direct Effects											
Labor Force	0.832***	0.816***	0.850***	0.861***	0.817***	0.798***	0.816***	0.817***	0.777***	0.7989***	0.856***
	24.99	*25.04*	*27.32*	*26.25*	*25.54*	*25.78*	*27.09*	*25.61*	*24.92*	*28.10*	*28.47*
Capital Stock	0.196***	0.2172***	0.175***	0.165***	0.192***	0.201***	0.204***	0.221***	0.246***	0.2274***	0.160***
	6.10	*6.98*	*5.75*	*5.18*	*6.18*	*6.87*	*7.01*	*7.37*	*8.38*	*8.43*	*4.56*
Human Capital	0.284***	0.317***	0.270***	0.263***	0.306***	0.285***	0.164***	0.304***	0.238***	0.3204***	0.235***
	6.72	*7.60*	*7.07*	*6.46*	*8.12*	*7.75*	*6.70*	*7.68*	*6.05*	*8.53*	*6.26*
Infrastructure	0.080**	-0.003	0.201***	0.057***	0.170***	-0.507***	0.045***	-0.058***	0.080***	0.0437***	0.070***
	2.39	*-0.11*	*5.32*	*4.44*	*3.87*	*-4.94*	*4.25*	*-3.49*	*4.20*	*4.74*	*6.89*
Indirect Effects											
Labor Force	-0.154***	-0.140***	-0.095**	-0.169***	-0.122***	-0.125***	-0.107***	-0.134***	-0.091***	-0.2905*	-0.159***
	-4.38	*-3.82*	*-2.53*	*-4.79*	*-3.43*	*-3.71*	*-3.11*	*-3.82*	*-2.72*	*-2.57*	*-4.78*
Capital Stock	0.150***	0.139***	0.098***	0.164***	0.127***	0.136***	0.104***	0.122***	0.102***	0.1944***	0.162***
	4.57	*4.02*	*2.65*	*4.78*	*3.73*	*4.41*	*3.22*	*3.77*	*3.53*	*3.34*	*4.92*
Human Capital	-0.097**	-0.107***	-0.096***	-0.088**	-0.129***	-0.105***	-0.093**	-0.132***	-0.052	-0.4425***	-0.066*
	-2.47	*-2.61*	*-2.72*	*-2.26*	*-3.62*	*-2.92*	*-2.55*	*-3.54*	*-1.39*	*-4.31*	*-1.72*
Infrastructure	-0.080**	-0.021	-0.078	-0.050***	-0074*	0.244**	-0.011	0.066***	-0.084***	-0.0274	-0.046***
	-2.36	*-0.68*	*-1.40*	*-3.22*	*-1.67*	*2.30*	*-0.90*	*3.95*	*-4.34*	*-1.22*	*-4.46*
Total Effects											
Labor Force	0.678***	0. 676***	0.755***	0.691***	0.695***	0.673***	0.709***	0.684***	0.686***	0.5787***	0.696***
	20.88	*19.54*	*19.25*	*20.19*	*20.61*	*20.86*	*22.59*	*20.27*	*21.40*	*7.11*	*20.16*
Capital Stock	0.346***	0.356***	0.273***	0.329***	0.320***	0.338***	0.308***	0.344***	0.348***	0.4219***	0.322***
	13.66	*12.55*	*7.79*	*11.17*	*12.03*	*13.51*	*11.64*	*13.64*	*14.43*	*8.34*	*11.14*
Human Capital	0.187***	0.211***	0.174***	0.175***	0.177***	0.180***	0.171***	0.171***	0.186***	-0.1221	0.169***
	3.70	*4.40*	*4.12*	*3.82*	*4.24*	*4.18*	*3.99*	*3.77*	*4.37*	*-1.19*	*3.59*
Infrastructure	0.000	-0.024	0.123**	*0.012*	0.096**	-0.262**	0.034***	0.007	-0.002	0.0164	0.018*
	0.02	*-1.08*	*2.12*	*1.03*	*2.15*	*-2.24*	*2.62*	*0.58*	*-0.14*	*0.71*	*1.80*

Note: t-statistics based on 2000 simulated draws are in italics. *: Significant at the 90% level. **: Significant at the 95% level. ***: Significant at the 99% level.

Table 5: Scalar summary decomposition of spatial effects of infrastructure

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APPENDIX1: Regional coverage and data sources

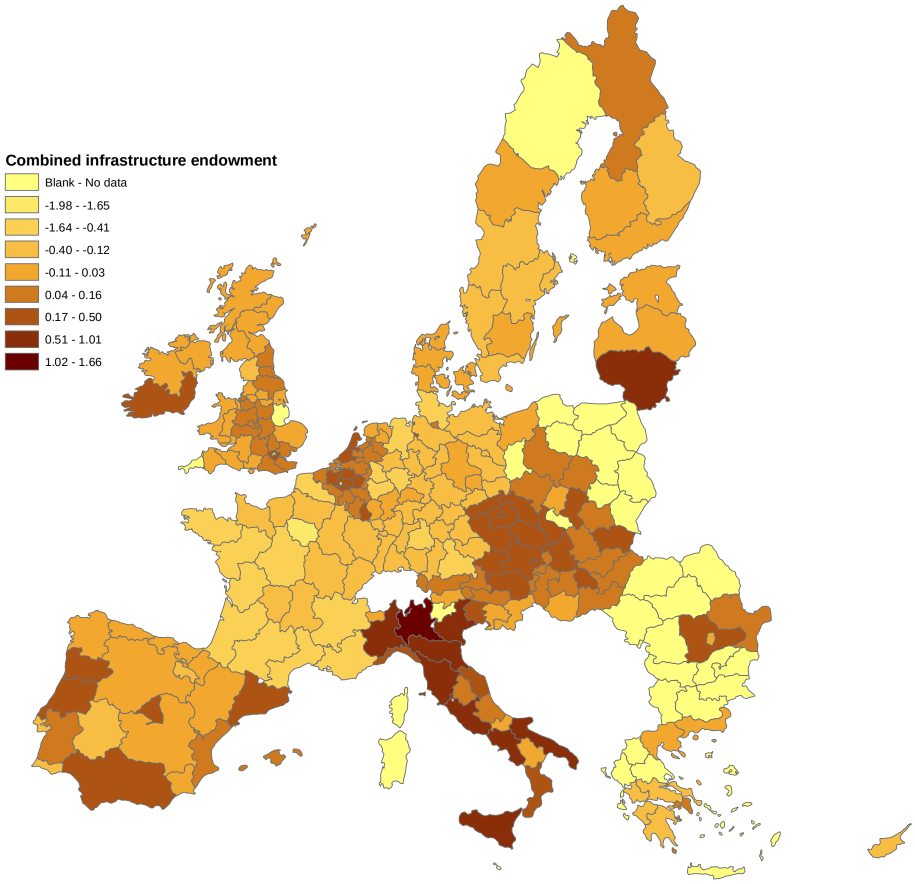
Austria: AT11, AT12, AT13, AT21, AT22, AT31, AT32, AT33, AT34; Belgium: BE10, BE21, BE22, BE23, BE24, BE25, BE31, BE32, BE33, BE34, BE35; Bulgaria: BG31, BG32, BG33, BG34, BG41, BG42; Cyprus: CY00; Czech Republic: CZ01, CZ02, CZ03, CZ04, CZ05, CZ06, CZ07, CZ08; Germany: DE11, DE12, DE13, DE14, DE21, DE22, DE23, DE24, DE25, DE26, DE27, DE30, DE41, DE42, DE50, DE60, DE71, DE72, DE73, DE80, DE91, DE92, DE93, DE94, DEA1, DEA2, DEA3, DEA4, DEA5, DEB1, DEB2, DEB3, DEC0, DED1, DED2, DED3, DEE, DEF0, DEG0; Denmark: DK; Estonia: EE00; Spain: ES11, ES12, ES13, ES21, ES22, ES23, ES24, ES30, ES41, ES42, ES43, ES51, ES52, ES53, ES61, ES62, ES63, ES64, ES70; Finland: FI13, FI18, FI19, FI1A, FI20; France: FR10, FR21, FR22, FR23, FR24, FR25, FR26, FR30, FR41, FR42, FR43, FR51, FR52, FR53, FR61, FR62, FR63, FR71, FR72, FR81, FR82, FR83; Greece: GR11, GR12, GR13, GR14, GR21, GR22, GR23, GR24, GR25, GR30, GR41, GR42, GR43; Hungary: HU10, HU21, HU22, HU23, HU31, HU32, HU33; Ireland: IE01, IE02; Italy: ITC1, ITC2, ITC3, ITC4, ITD1, ITD2, ITD3, ITD4, ITD5, ITE1, ITE2, ITE3, ITE4, ITF1, ITF2, ITF3, ITF4, ITF5, ITF6, ITG1, ITG2; Lithuania: LT00; Luxembourg: LU00; Latvia: LV00; Malta: MT00; Netherlands: NL11, NL12, NL13, NL21, NL22, NL23, NL31, NL32, NL33, NL34, NL41, NL42; Poland: PL11, PL12, PL21, PL22, PL31, PL32, PL33, PL34, PL41, PL42, PL43, PL51, PL52, PL61, PL62, PL63; Portugal: PT11, PT15, PT16, PT17, PT18, PT20, PT30; Romania: RO11, RO12, RO21, RO22, RO31, RO32, RO41, RO42; Sweden: SE11, SE12, SE21, SE22, SE23, SE31, SE32, SE33; Slovenia: SI0; Slovakia: SK01, SK02, SK03, SK04; United Kingdom: UKC1, UKC2, UKD1, UKD2, UKD3, UKD4, UKD5, UKE1, UKE2, UKE3, UKE4, UKF1, UKF2, UKF3, UKG1, UKG2, UKG3, UKH1, UKH2, UKH3, UKI1, UKI2, UKJ1, UKJ2, UKJ3, UKJ4, UKK1, UKK2, UKK3, UKK4, UKL1, UKL2, UKM1, UKM2, UKM3, UKM4, UKN0.

Variable	*Measure*	*Source of raw data*
Capital Stock	Perpetual inventory method on gross fixed capital formation; (depreciation rate=0.025; baseline year 1998).	EUROSTAT 1998-2006
Labor Force	Total regional labor force	EUROSTAT 2006
GDP	Regional GDP in PPS	EUROSTAT 2006
Human capital	Percentage of labor force with higher education	EUROSTAT 2006
Direct Infrastructure	Length of motworways (km/area)	EUROSTAT 2006
	Length of other roads (km/area)	EUROSTAT 2006
	Length of electrified rail lines (km/area)	EUROSTAT 2006; authors' elaboration
PCA Road	Result of Principal Component Analysis on length of motorways per area, length of other roads per area, length of electrified rail lines per area and net installed MgW capacity per area.	EUROSTAT 2006; authors' elaboration
TLC Infrastructure	Fixed phone lines (national data regionalized with population shares)	EUROSTAT 2006; authors' elaboration
	Mobile phone subscriptions(national data regionalized with population shares)	EUROSTAT 2006
	% of firms with website	EUROSTAT 2006
PCA TLC	Result of Principal Component Analysis on fixed phone lines and mobile phones subscriptions	EUROSTAT 2006; authors' elaboration
Indirect Infrastructure	Multimodal accessibility	ESPON 2002
	Time to market	ESPON 2002
Congestion	Number of intraregional trips by trucks	ESPON 2002
PCA	Result of Principal Component Analysis on length of motorways per area, net installed MgW capacity per area fixed phone lines, mobile phones subscriptions and multimodal accessibility	EUROSTAT 2006, ESPON 2002; authors' elaboration

APPENDIX 2: Spatial distribution of the combined infrastructure indicator

Infrastructure provision is characterized by spatial autocorrelation patterns. Rietveld and Wintershoven (1997) test for the presence of both border and spillover effects in the provision of public infrastructure, showing that the presence of the first can be rejected, while the latter characterizes a sample of European regions which closely resembles ours.

Map 1 represents combined infrastructure endowment (obtained through a PCA on the main direct, indirect and TLC indicators of regional infrastructure) in the EU27 regions. Spatial autocorrelation characterizes our infrastructure index. In particular, along with a core-periphery pattern that mimics the well-known spatial distribution of wealth, we can discern a cluster of average infrastructure endowment in Poland and Baltic countries that offsets the low values recorded in Romania and Bulgaria. Capital regions (as expected) are better endowed with infrastructure than peripheral ones. This is true, for instance, for the metropolitan areas of Madrid, London, and Wien, Ile de France (Paris) and Lazio (Rome).



Map 1: Combined infrastructure endowment in the EU27 regions (ESPON and EUROSTAT data; authors' elaboration)

[1] For a review of early contributions, including Munnell (1990, 1991) and Morrison and Schwartz (1994), see the Gramlich (1994), and Sturm (1998). For recent surveys, Agenor and Moreno-Dodson (2006), Romp and de Haan (2007) and Straub (2008).
[2] EU Funds are transferred form the EU to Member States, and tied to assistance to regional or national programs.
[3] Base year: 1998.Linear depreciation rate of 2.5%.
[4] On this issue, see Le Gallo and Ertur (2003) and Ertur and Koch (2006).
[5] See Roberts (2006).

[6] This method provides sample draws from posterior distribution of model parameters and allows for inference on the estimates of direct, indirect and total effects. Implementation of this method was done by using LeSage'e econometric toolbox for Matlab and is based on LeSage and Pace (2009).

[7] The estimated indirect effect is positive, but recallling that the effect of time to market on GDP is negative implies that the actual spillover exerts a negative effect.