Riccardo Crescenzi and Andrés Rodríguez-Pose

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ABSTRACT

This paper analyses the role of infrastructure endowment and investment in the genesis of regional growth in the European Union. *It assesses the economic effects of the existence and improvement of transport networks in light of their interactions with innovation and local socio-economic conditions. The analysis accounts for spatial interactions between different regions in the form of spillovers and network externalities. The regression results highlight the impact of infrastructural endowment on regional economic performance, but also the weak contribution of additional investment. Regions having good transport infrastructure endowment and being well connected to regions with similar good endowments tend to grow faster. However, investment in infrastructure within a region or in neighbouring regions seems to leave especially peripheral regions more vulnerable to competition. Furthermore, the positive impact of infrastructure endowment on growth tends to wane quickly and is weaker than that of, for example, the level of human capital.*

Riccardo Crescenzi (rcrescen@uniroma3.it) is professor of economics at the Robert Schuman Centre of the European University Institute, Florence, and at the Università degli Studi Roma Tre. **Andrés Rodríguez-Pose** (A.Rodriguez-Pose@lse.ac.uk) is Head of the Department of Geography and Environment, London School of Economics.

Infrastructure endowment and investment as determinants of regional growth in the European Union

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1. Introduction

Infrastructure development – in particular transport infrastructure – is generally considered desirable in terms of achieving both economic efficiency and territorial equity for a series of reasons. First, a modern and efficient infrastructure endowment is supposed to be a necessary competitive asset for the maximization of the local economic potential and for allowing an efficient exploitation of resources. Second, it is often perceived that improvements in infrastructure endowments not only provide accessibility, but also contribute to a better market integration of peripheral and lagging regions, allowing them to catch up with the more advanced territories. In the EU, in particular, infrastructure development has been regarded as a necessary condition for the economic success of the regions, as well as a tool for an equitable distribution of the benefits of the process of European integration. Infrastructure would thus not only contribute to enhance the benefits of integration, but will also be the main means for spreading its benefits.

Given this predominant view, it comes as no surprise that infrastructure, in general, and transport infrastructure, in particular, have acquired an important role in European Union policy. The Treaty on the European Union explicitly puts forward (Article 154) "the establishment and development of trans-European networks in the area of transport, telecommunications and energy infrastructure" as a policy tool to help achieve the objectives of an integrated internal market (Article 14), on the one hand, and of "an overall harmonious development" in terms of economic and social cohesion, on the other. The European Commission's (2005) "Integrated Guidelines for growth and jobs (2005-2008)" have re-asserted the role of infrastructure development in the micro-economic field for raising Europe's growth potential and cohesion. As a consequence, the development of infrastructure in the Member States has been supported, integrated and coordinated by means of the trans-European networks (TENs) in the fields of energy, telecommunications and transport. In particular, the construction of the Trans-European Transport Network (TEN-T) has been driven by the Community Guidelines agreed by the Essen European council which led, in 1996, to the identification of 14 priority projects. This list of projects was extended in 2004 following the progressive enlargement of the EU to 25 and then 27 members, to comprise 30 priority projects to be completed by 2020 and a variety of smaller projects. The establishment of the TEN-T has provided an overall planning framework for the development of a European-wide transport infrastructure, superseding a previous system fundamentally based on the needs of individual regions, which lacked a supra-regional perspective (Vickerman 1995).

Infrastructure development absorbs a significant percentage of the financial resources of the European Union. For the programming period 2000-2006, EUR 195 billion (at 1999 prices) were allocated to the Structural Funds (Puga 2002, p.374), of which around two-thirds were allocated to Objective 1 regions. Roughly half of this Objective 1 allocation was earmarked for the development of new infrastructure (Rodríguez-Pose and Fratesi 2004). In addition, about half of the EUR 18 billion of the Cohesion Fund for the same period went into infrastructure and European Investment Bank (EIB) loans totalled EUR 37.9 billion (European Commission 2007). The TEN-T alone have mobilized a substantial amount of financial resources for transport infrastructure both under the specific heading of the Common Transport Policy and by drawing upon Structural and Cohesion funds. In the 2000-2006 Structural Funds programming period, TEN-T not only received a budget of EUR 4.2 billion, but also benefited from the allocation of EUR 16 billion under the Cohesion Fund and from part of the EUR 34 billion of the European Regional Development Fund (ERDF) invested in transport infrastructure. In the 2007-2013 financial framework, about EUR 8 billion have been earmarked for TEN-T "but the ERDF and the Cohesion Fund will continue to be the main sources of community assistance for co-funding of the TEN-T" (European Commission 2007, p.5). About EUR 35 billion under the cohesion fund will be chiefly earmarked to the priority projects.

We analyze whether huge EU expenditure on transport infrastructure is paying off.

The aim of this paper is to analyse whether this huge investment in transport infrastructure is paying off, by examining how infrastructure development and especially investment in transport infrastructure has affected regional development in the EU – proxied by GDP per capita growth. The impact of transport infrastructure is assessed in a broad theoretical perspective in which other relevant features with a bearing on regional economic performance are also considered, allowing for a more accurate assessment of the effect of infrastructure capital. These include the concentration of innovative activities, the presence of (un-)favourable social conditions, agglomeration economies, and inward mobility of individuals. We also assess the spatial interactions between each region and its neighbouring areas in the form of spillovers, by explicitly analysing the impact of both internal and external conditions on regional economic performance. The inclusion in the analysis of the infrastructure endowment (and other conditions) in neighbouring regions makes it possible to isolate the impact of a favourable geographical location of any given region not only in terms of its capacity to reap network externalities, but also to benefit from other growth-enhancing conditions of interconnected regions. Finally, the paper also aims at providing some policy lessons, including an assessment of the magnitude and policy implications of the spillover of infrastructure investment across regions.

The paper is organised into four further sections. First, we introduce the theoretical framework for the analysis. Second, we present the empirical model and provide its theoretical justification. Third, the empirical results are discussed. The final section concludes with some economic policy implications.

2. Infrastructure and regional economic development

2.1 The rationale for public infrastructure development

The justification – in terms of growth and cohesion – for the significant financial resources devoted by the EU to the development of infrastructure relies crucially on the underlying model of the functioning of the regional economy and on the factors assumed as drivers of economic growth. Infrastructure has traditionally been regarded from three different perspectives. First, as an 'unpaid factor of production', directly generating improvements in output; second, as an 'augmenting factor', enhancing the productivity of labour and capital; and, third, as an incentive for the relocation of economic activity (Lewis 1998). Aschauer (1989) introduces the idea – previously somewhat overlooked in the economic literature – that differences in the stocks of public infrastructure and private capital could provide an important explanation for differences in levels of national output. In Aschauer's framework, other things being equal, the higher the stock of public infrastructure, the higher the capital productivity in the private sector: An increase in infrastructure endowment produces an increase in productivity and, albeit at a lower rate, in labour costs (Biehl 1991). The resulting labour cost/productivity ratio is a proxy for the region's competitive position: The regions where productivity exceeds labour costs will benefit from higher income and more jobs, which will stimulate inward migration and capital inflows. Hence, improvements in infrastructure endowment will benefit the regional economy in excess of its potential GDP, as productivity will outstrip labour costs. This approach produced a stream of empirical literature based on regressions *à la Aschauer* that provided significant evidence in support of the positive impact of infrastructure investment: The yearly rate of return to public investment was estimated to be higher than 100 percent (Holtz-

Eakin 1993; Glomm and Ravi-Kumar 1994). From a different perspective, the classical location theory, by emphasising the advantages of locations benefiting from better accessibility and lower transport costs, also supported the view of infrastructure investment as a means for better economic performance. Seitz and Licht (1995) suggest – on the basis of the duality theory – a third separate approach to the problem of the relationship between transport costs and regional growth: "investing in public infrastructures can be considered an instrument to improve the competitiveness of cities, regions and nations by reducing production and transport costs" (p. 239). The economic policy implications of these approaches seemed sufficiently straightforward to justify the emphasis placed by EU policy makers on their programme of infrastructure development.

These clear-cut conclusions have been challenged by a variety of theoretical and empirical studies. First, Gramlich (1994) has not only questioned the direction of causality of Aschauer's regressions and highlighted how the lack of an agreed definition about the concept of infrastructure may have led to significant measurement inconsistencies. He also suggests that the way in which infrastructure is managed and priced is relevant when assessing their impact. Furthermore, the implausibly high rate of return to public investment of the Aschauer-style analyses contrast markedly with the evidence produced by micro-level impact analyses (*e.g.* Munnell 1990; Evans and Karras 1994; Button 1998; Vanhoudt *et al.* 2000). Growth models that determine the stock of capital endogenously have partially overcome such methodological limitations. When applied to analyse the impact of infrastructure, they deliver completely different results. In this vein, Vanhoudt *et al.* (2000, p. 102) not only find that "causality does not run from public investment to growth, but rather the opposite way", but also suggest that public investment "can hardly be considered as an engine for long-run structural growth".

The direct relationship between improved accessibility and regional economic development has proven weak.

Second, the direct relationship between improvement in the general level of accessibility and economic development (and, by implication, greater cohesion) has proven weak when replacing the simplified spatial model of the classical location theory by a more realistic view of the European territory and its economic geography. On the one hand, the actual importance of transport costs and accessibility *per se* is changing: If it is true that new forms of transport (such as high speed trains) have created new locational advantages and disadvantages and that the volume of freight movements and travel has generally increased, it is also true that overall transport costs and the significant element of fixed costs they contain (packaging, shipping *etc.*) are a small (and decreasing) fraction of total industrial cost (Glaeser and Kohlhase 2004; Vickerman *et al.* 1997). Furthermore telecommunications have had an important and not yet fully understood impact on the mobility of goods and people and new location factors (*e.g.* quality of life), rather than mere accessibility, have emerged as significant sources of competitive advantage. On the other hand, the change in accessibility induced by the development of TEN-T has, in fact, widened (rather than reduced) regional disparities for a series of reasons that include:

a) Providing central and peripheral regions with a similar degree of accessibility may damage firms in lagging regions by opening their local market, unless other advantages are developed (Puga 2002); and
b) The problem of peripheral regions seems to lay more in the absence of adequate intraregional networks for the dispersion of traffic around major centres and the enlargement of the local market rather than in the interregional connectivity supported by TEN-T projects (Martin and Rogers 1995; Vickerman 1995).

In light of all these considerations, it seems realistic to conclude with Button (1998) that "the exact importance of infrastructure as an element in economic development has long been disputed (…) but the body of evidence available is far from conclusive" (pp. 154 and 156) thus making the economic justification for the EU infrastructure investment much weaker than in Aschauer's framework.

The potential ambiguity of the impact of transport infrastructure on economic development has been explicitly addressed – in an analytical framework with imperfect competition and increasing returns to scale – by the New Economic Geography (NEG). This approach enables us to address the specific nature of transport infrastructure more effectively when compared to other forms of capital given "its role in facilitating trade and in allowing individuals, companies, regions and nation states to exploit their various competitive advantages" (Button 2001, p. 278). The development of transport infrastructure, by increasing the accessibility of economically weaker regions, "not only gives firms in less developed regions better access to inputs and markets of more developed regions (…) but it also makes it easier for firms in richer regions to supply poorer regions at a distance, and can thus harm the industrialisation prospects of less developed areas" (Puga 2002, p. 396). By allowing even *a priori* identical regions to endogenously differentiate between an industrialised core and a backward periphery in response to changes in their degree of accessibility,[1] NEG models have formally accounted for the potentially ambiguous effect of changes in the degree of accessibility ('two-way' roads effect) (Puga 2002). In addition, they have highlighted the differential effect of inter- and intraregional connections and the hub-and-spoke effect generated by uneven access conditions to major infrastructures.

New economic geography models lack univocal conclusions on the determinants of economic success, reducing their usefulness for policy makers.

This strand of literature has shown that the development of transport infrastructure needs to be treated in a geographical perspective in order to reveal the specificities of this form of public capital and its impact on economic development. However, from an operational point of view, this approach presents important limitations as it poses significant obstacles to any attempt to empirically test its analytical models. Furthermore, contributions in NEG lack an univocal conclusion on the actual determinants of the economic success of a region (apart from history and/or path dependence) in response to changes in its accessibility (Martin 1999; Neary 2001). As a consequence the direct regional policy implications of this approach have so far been limited.

2.2 A broader theoretical framework for the assessment of the impact of transport infrastructure development

Any model trying to assess the full impact of the endowment and of new investment in infrastructure in any given region has to take into consideration the overall set of conditions that shape the relationship between accessibility and regional growth dynamics, which the NEG has fundamentally left unexplored (Cheshire and Magrini 2002). A variety of forces in any given economy exert an influence on how economic performance can react to changes in accessibility. These include a raft of education, innovation and institutional factors that determine the potential of any space to benefit or not from relative changes in accessibility (Rodríguez-Pose 1998; Rodríguez-Pose and Crescenzi 2008). Local actors, factors, and institutions need to be taken into account as the implementation of successful infrastructure policies will depend on the dynamic interaction between accessibility and local conditions.

Growth is a multivariate process, where not only infrastructure endowment and investment, but also innovative efforts in the form of R&D activities, human capital accumulation, the sectoral

1 These changes in accessibility, in turn, alter the balance between the set of dispersion and agglomeration forces constantly at work in the economy. Indeed, in these models the equilibrium depends on the interactions between agglomeration forces (economies of scale, home market effect, backward and forward linkages, labour pool) and dispersion forces (prices for intermediates, wages, competition).

specialisation of the labour force, migration and geographical location, among other factors, exert a direct influence and interact with one another in order to determine the economic dynamism of any given space (Fagerberg *et al.* 1997; Cheshire and Magrini 2002). These factors, associated in unique ways in any given territory, respond and adjust to external changes in different ways (Rodríguez-Pose 1998). While some economic factors (such as capital and technology) are more able to adjust in response to external challenges – such as EU integration – by virtue of their relatively higher mobility, social structures tend to be much less flexible. Consequently specific sets of structural conditions will be associated with diverse levels of economic performance. Different local features of the labour force, the level of employment of local resources, the demographic structure and change or the accumulation and quality of human capital are among the factors that need to be taken into consideration when analysing the impact of infrastructure endowment and investment, as a similar investment on infrastructure in two different regions may lead to different outcomes as a consequence of the interaction with local economic conditions.

Infrastructure investment interacts with local economic conditions.

Furthermore, as transport infrastructure is about connectivity, any analysis of its economic impact needs to be placed in a spatial perspective by considering both the impact of endogenous conditions as well as those of neighbouring regions. Transport infrastructure endowment (and investment) may exert an influence on economic activity which is not limited by regional boundaries. The effect of transport infrastructure in one region may spill over into another, significantly affecting/benefiting its economic performance: As highlighted by Puga (2002, p. 400) "sometimes the project in a single region can have a strong welfare effect rippling through numerous regions". However, this spillover effect is affected by distance decay and thus tends to be bounded in space, essentially benefiting/affecting neighbouring areas (Seitz 1995; Chandra and Thompson 2000). Since transport infrastructure's "impact may be prone to leak outside (of) small economic areas" (Chandra and Thompson 2000, p. 458), the assessment of this spillover effect needs to be included in the empirical analysis as appraisals based on too tightly drawn study areas may lead to biased estimations (Holl 2006). In this perspective, it is necessary not only to capture the shorter-run Keynesian effect of infrastructure expenditure or the effect of relocation of economic activities in response to the change in transport costs, but also to provide a full appraisal of the impact of the network benefits arising when transport infrastructure allows for closer interactions with economic agents from neighbouring regions, thus increasing their interactions and possibly spreading agglomeration benefits (Rosenthal and Strange 2003). For this reason we extend the standard 'new growth theory' perspective on externalities (see Vanhoudt *et al.* 2000) to account for the impact of transport infrastructure upon the possibility/probability/frequency of keeping in touch with different ideas/organizations/products from those locally available thus either directly affecting growth by providing an additional source of knowledge or producing an indirect effect (Crescenzi 2005). We address the issue of spatial externalities arising from transport infrastructure from this standpoint by explicitly considering the intensity of innovative efforts pursued in neighbouring regions. The spatial boundness of knowledge spillovers (Audretsch and Feldman 2004; Cantwell and Iammarino 2003; Sonn and Storper 2008) may – even in the presence of equally good interregional connectivity – allow highly-accessible core regions to benefit from innovative activities pursued in their proximity, while preventing spillovers from reaching peripheral remote regions.

3. The model

In accordance with the framework developed in the previous section, the empirical investigation aims at integrating the role of infrastructure in shaping economic growth in Europe into a model that takes into consideration other endogenous and external factors.

The choice of empirical variables to be included in the model is determined according to the following matrix:

	Endogenous Factors	External Factors (Spillovers)
Infrastructure endowment and investment	Kilometres (km) of motorways (level and annual change)	Infrastructure in neighbouring areas
R&D	Investment in R&D in the region	Investment in R&D in neighbouring regions
Relative wealth	GDP per capita	GDP per capita in neighbouring regions
Agglomeration economies	Total regional GDP	Total GDP in neighbouring regions
Social filter	Structural characteristics that would make a region more 'innovation prone', including: • Education • Sectoral composition • Use of resources (unemployment) • Demographics	Same characteristics in neighbouring regions
Human capital mobility	Migration rate	Migration in neighbouring areas
National effects	National growth rate	

We estimate the effect on per-capita-GDP growth of the level and change of transport infrastructure in a region and its neighbours.

By developing the framework above, we obtain the following empirical model:

(1) $$y_{i,t} = \alpha_i + \beta \ln GDP0_{i,t} + \gamma Inf_{i,t} + \delta x_{i,t} + \zeta SpillInf_{i,t} + \varphi Spillx_{i,t} + \kappa \ln Nay_{i,t} + \varepsilon_{i,t}$$

where:

y represents the growth rate of regional GDP per capita;

ln*GDP0* is the initial level of GDP per capita;

Inf denotes infrastructure endowment and investment;

x is a set of structural features/determinants of growth of region *i*;

Spill indicates the presence of these factors in neighbouring regions;

Nay represents the national growth rate of per capita GDP of the member state region *i* belongs to;

ε is an idiosyncratic error;

and where *i* represents the region and *t* time.

In the following we describe the variables included in the model in detail.

Growth rate of regional GDP per capita: The annual growth rate of regional GDP is the dependent variable and is used as a proxy for the economic performance of the region.

Level of GDP per capita: As customary in the literature on the determinants of regional growth performance, the initial level of GDP per capita is introduced in the model in order to account for the region's initial wealth. The significance and magnitude of the coefficient associated to this variable will allow us to test the existence of a process of convergence in regional per capita incomes and to measure its speed.

Existing stock and annual variation of transport infrastructure endowment: Transport infrastructure may affect economic performance through a variety of mechanisms not only related to its contribution to the regional stock of public capital, but also associated to its influence on the spatial organisation of economic activities. In order to capture the direct impact of transport infrastructure on regional growth, the model includes a specific proxy for both the stock of transport infrastructure and the annual additional investment in this area. The former is proxied by the kilometres (km) of motorways (Canning and Pedroni 2004; see Table A1 in Annex 1 for further detail on the definition of the variable) in the region, standardised by regional population[2], while the latter is proxied by its annual change.

The length of regional motorways serves as a proxy for regional infrastructure.

Although other indicators may be as useful in capturing the role of transport infrastructure, the length of regional motorways (and change thereof) is adopted as a proxy for regional infrastructure because of, first, the constraints in terms of regional data availability[3] (which *a priori* prevented us from considering alternative accurate proxies) and, second, its capacity to capture in a direct way the impact of better accessibility irrespective of the differentiated and hard-to-quantify cost of accessibility in different regions and countries. Motorways have been preferred to other modes of transport (*e.g.* rail) for their greater use in the shipment of goods, which results in their stronger impact on the spatial allocation of economic activity (Button 2001; Puga 2002). Furthermore, the initial emphasis of the main EU support plan for transport infrastructure development (the TEN-T) was on motorways before shifting to high-speed trains. As a consequence this mode of transport has benefited from policy support for a long enough time span as to allow a meaningful policy assessment.

In addition to infrastructure, our variable of interest, we include some additional drivers of regional economic performance as independent variables. These include:

R&D expenditure: The percentage of regional GDP devoted to R&D is the main measure of economic input used to generate innovation in each region. From an endogenous growth perspective this variable is regarded – as one of the key factors behind long-run interregional differences in productivity and income. Local R&D expenditure is also frequently used as a proxy for the local capability to adapt to innovation produced elsewhere (Cohen and Levinthal 1990; Maurseth and Verspagen 1999). There are, however measurement problems associated with this variable that must be borne in mind as they may partially hide the contribution of R&D towards economic performance. First, the relevant time-lag structure for the effect of R&D activities on productivity and growth is unknown and may vary significantly across sectors (Griliches 1979). Second, as pointed out by Bilbao-Osorio and Rodríguez-Pose (2004) for the case of European regions, the returns from public and private R&D investment may vary significantly. Furthermore, the fact that not all innovative activities pursued at the company level are classified as formal 'Research and Development' may be a source of further bias in the estimations. Having acknowledged these points, we assume R&D expenditure to be a proxy for "the allocation of resources to research and other information-generating activities in response to perceived profit opportunities" (Grossman and Helpman 1991, p. 6) in order to capture the existence of a system of incentives (in the public and the private sector) towards intentional innovative activities.

2 Dividing by population is to account for the different size of regions. The proxy for infrastructure endowment has also been standardised by the total area of the region and by its total GDP. As shown in the appendix, the results of the analysis do not change significantly when these alternative proxies are used.

3 See Table A1 in Annex 1 for a discussion of the source of the data and Section 4.1 for a discussion of data availability and limitations.

Socio-Economic Conditions: Structural socio-economic conditions are introduced into the analysis by means of a composite index, which combines a set of variables describing the socio-economic dynamism of the region. In the framework discussed in the previous section the structural dynamism of the region is a crucial pre-condition for its capability to benefit from changes in accessibility due to investment in new transport infrastructure. The socio-economic features that seem to be more relevant for shaping the reaction capabilities of a region are those related to two main domains: Educational achievement (Lundvall 1992; Malecki 1997) and the productive employment of human resources (Fagerberg *et al.* 1997; Rodríguez-Pose 1999). The first domain is measured by educational attainment, expressed by the shares of persons with completed higher education, both relative to the labour force and to the overall population (human capital accumulation in the labour force and in the population respectively). The second domain, *i.e.*, the structure of productive resources, is measured by the percentage of the labour force employed in agriculture and the percentage of long-term unemployment. These two variables are used because of the traditionally low productivity of agricultural employment compared to other sectors, and because agricultural employment, in particular in some peripheral regions of the EU, is in reality synonymous with 'hidden unemployment'[4]. The long-term component of unemployment is an indicator of labour-market rigidity and, indirectly, an additional indication of the presence of individuals with inadequate skills (*i.e.*, a proxy for the quality of human capital, as opposed to its quantity measured by the human capital accumulation variables) (Gordon 2001).

We deal with problems of multicollinearity, which prevent the simultaneous inclusion of all these variables in our model, by means of principal component analysis (PCA). PCA allows us to merge the variables discussed above into a single indicator (called 'social filter index') that preserves as much as possible of the variability of the source data. The output of the PCA is shown in Table A2 in the Annex 2 for both the EU-15 countries (covering the 1990-2004 period) and for the EU-25 (for the 1995-2004 period). The eigenanalysis of the correlation matrix shows that the first principal component alone is able to account for 57 and 58 percent of the total variance for the EU-15 and EU-25, respectively.

Educational attainment is found to be a major component of the socio-economic tissue of regions.

The first principal component scores are computed from the standardised value of the original variables by using the coefficients listed under PC1 in Table A3 in Annex 2. These coefficients assign a large weight to educational attainment, which thus is found to be a major component of the socio-economic tissue of the regions. By contrast, a negative weight is assigned to the long-term component of unemployment and to the percentage of agricultural labour. This first Principal Component (PC1) explains 58 percent of the total variance of the original indicators and constitutes what we call the 'Social Filter Index' that is introduced into the regression analysis as an aggregate proxy for the socio-economic conditions of each region. Given its theoretical and empirical relevance (large weight in the PCA), a separate proxy for productive human capital accumulation will be introduced into the regression analysis, defined as the share of persons with completed higher education in total employment.

In addition to the endogenous variables, the model also includes variables representing the potential spillovers from neighbouring regions that may affect economic performance in the region of interest. These spillover variables are:

Extra-Regional Infrastructure (endowment and investment): In order to assess the impact of infrastructure on regional economic growth in the most comprehensive way possible, the model

4 Unemployment is 'hidden' in the fabric of very small farm holdings in many EU peripheral areas (Caselli and Coleman 2001). Agricultural workers also show low levels of formal education, scarce mobility, and tend to be aged.

needs to account for development both within each individual region and across the whole of Europe, as what matters is not only the relative density of infrastructure within the borders of the region, but also the endowment of infrastructure in neighbouring regions. Hence, and as discussed in the previous section, in our framework transport infrastructure is not reduced to mere components of the 'aggregate' neo-classical concept of physical capital but includes the potential for networking and connectivity among individuals and firms. We thus introduce the endowment of transport infrastructure in neighbouring regions as a proxy for the degree of interregional connectivity. Where the internal infrastructure endowment is reinforced by a good endowment in neighbouring regions the most favourable infrastructural conditions are supposed to be in place. Where, instead, internal infrastructures are not complemented by adequate neighbourhood conditions, bottlenecks and criticalities may arise, negatively affecting the accessibility of the region. Following the same line of reasoning, changes in infrastructure endowment (through new investment) may exert an influence on the economic performance of neighbouring regions.

Extra-regional infrastructure endowment is proxied by the average of infrastructure intensity in neighbouring regions. The extra-regional infrastructure endowment $SpillInf_i$ is calculated as:

$$(2) \quad SpillInf_i = \sum_{j=1}^{n} Inf_j w_{ij}$$

where Inf_j is a proxy for the infrastructure endowment of the j-th region and w_{ij} is a generic 'spatial' weight. In order to minimize both the endogeneity induced by travel-time distance weight and the potential bias due to the different number of neighbours of central and peripheral regions, we consider the *k nearest neighbours* (with k=4)[5]:

$$(3) \quad w_{ij} = \begin{cases} 1/k & \text{if j is one of the k nearest neighbours to i} \\ 0 & \text{otherwise} \end{cases} \qquad \text{with } i \neq j$$

R&D activity in neighbouring regions may have a positive impact on economic performance through knowledge spillovers.

Extra-Regional Innovation: The economic success of an area depends both on its internal conditions and on those of neighbouring interconnected regions. In particular, where innovative activities pursued in neighbouring regions are shown to exert a positive impact on local economic performance, there is evidence in favour of interregional spillover effects: Knowledge produced in one region spills over into another (through the mechanisms discussed in the previous section), thereby influencing its economic performance. The spillover variable captures the 'aggregate' impact of innovative activities pursued in the neighbourhood. The significance of this indicator suggests that access to extra-regional innovation facilitates the interregional transfer of knowledge. Proximity enables the transmission of knowledge which, in turn, has an impact on regional growth.

The measure of 'accessibility' of extra-regional innovative activities is calculated in the same way as that of the accessibility of extra-regional infrastructure presented in equation (2). For each region i:

$$(4) \quad SpillR\&D_i = \sum_{j=1}^{n} R\&D_j w_{ij}$$

where *R&D* is our proxy for regional innovative efforts and *w* is as above.

5 Alternative definitions for the spatial weights matrix are possible: Distance-weights matrices (defining the elements as the inverse of the distances) and other binary matrices (rook and queen contiguity matrices). However, the *k*-nearest-neighbours weighting scheme seems the most appropriate to capture the neighbourhood effect while minimising the endogeneity due to higher infrastructure density in central regions. The use of different values for the parameter *k* generated similar results to those presented in the paper.

Agglomeration and absolute size of the local economy: Different territorial configurations of the local economy may give rise to different degrees of agglomeration economies. The geographical concentration of economic activity has an impact on productivity (Duranton and Puga 2003), which needs to be controlled for in order to single out the differential impact of infrastructure endowment. From this perspective, the relative concentration of wealth (the 'scale' side of agglomeration economies) and the absolute size of clusters need to be considered. A useful proxy for these factors is the total GDP of each region.

Migration: The degree of internal[6] labour mobility is reflected by the regional rate of migration (*i.e.*, the increase or decrease of the population due to migration flows as a percentage of the initial population). A positive rate of migration (*i.e.*, net inflow of people from other regions) is a proxy for the capacity of the region to benefit from better accessibility and transport infrastructure by attracting new workers, increasing the size of its labour pool and its 'diversity' in terms of skills and cultural background.

4. Results of the analysis

4.1 Estimation issues, data availability and units of analysis

Explanatory variables are lagged to address endogeneity, and national GDP growth controls for spatial autocorrelation.

We estimate the model by means of Fixed-Effect Panel Data regressions.[7] The effect of spatial autocorrelation (*i.e.*, the lack of independence among the error terms of neighbouring observations) is minimized by explicitly controlling for national growth rates. Furthermore, by introducing the 'spatially lagged' variables *SpillInf* and *Spillx* in our analysis, we take into consideration the interactions between neighbouring regions, thereby minimizing their effect on the residuals. Another concern is endogeneity, which we address by introducing all explanatory variables with a one-year lag. In addition, in order to resolve the problem of different accounting units, explanatory variables are expressed, for each region, as a percentage of the respective GDP or population.

The model is run for 1990-2003 for the EU-15 and for 1995-2003 for the new member states in line with data availability. As a consequence, longer term effects can only be analysed for the EU-15. Instead, when the sample is extended to the EU-25, the analysis is necessarily more prone to the potential distortions ascribable to the economic cycle. This sort of analysis should ideally be focused on FURs (Functional Urban Regions)[8] rather than on NUTS (*Nomenclature des unités territoriales statistiques*) administrative regions, as it would allow a more accurate separation of the impact of infrastructure provision within the borders of a functionally integrated area from that attributable to an increase in connectivity between different functional regions. Unfortunately, the lack of available data for many of the relevant explanatory variables has prevented contemplating functional regions. As a consequence we have been forced to rely on a mix of NUTS1 and NUTS2 regions, selected in order to maximise their homogeneity in terms of the relevant governance structure and also considering data availability. The unit of analysis with the greatest relevance in terms of the institutions that may be relevant for the decision of developing new transport infrastructure – or which may be taken as

6 Migration data are provided by Eurostat in the 'Migration Statistics' collection. However there are no data for Spain and Greece. Consequently, in order to obtain a consistent measure across the various countries included in the analysis, we calculate this variable from demographic statistics. "Data on net migration can be retrieved as the population change plus deaths minus births. The net migration data retrieved in this way also include external migration" (Puhani 2001, p. 9). Net migration was standardised by the average population, obtaining the net migration rate. Consequently, it is impossible to distinguish between national, intra-EU, and extra-EU migration flows.

7 According to the Breutsch and Pagan Test fixed effects estimation has to be preferred given the high significance of the individual effects.

8 The concept of FURs has been defined as a means to minimize the bias introduced by commuting patterns. A FUR includes a core city, where employment is concentrated, and its hinterland, from which people commute to the centre. For a detailed analysis of this concept see Cheshire and Hay (1989).

a target area for such investment by the national government and/or the European Commission – was selected for each country. Consequently, the analysis uses NUTS1 regions for Belgium, Germany[9] and the United Kingdom and NUTS2 for all other countries (Austria, Finland, France, Italy, the Netherlands, Portugal, Spain, Sweden in the EU-15, as well as in the Czech Republic, Hungary, Poland, and Slovakia, when the EU-25 is considered). Countries without equivalent sub-national regions (Denmark[10], Ireland, Luxembourg for the EU-15 and Cyprus, Estonia, Latvia, Lithuania, and Malta for the EU-25) are, as a consequence of the need to control for national growth rates, excluded *a priori* from the analysis.[11] Lack of regional data on infrastructure from either Eurostat or national authorities means that Greece cannot be taken into consideration either.

The entire dataset is based on Eurostat Regio data with the exception of the statistics on educational achievement which are based on Labour Force Survey Data provided by Eurostat. Where fully comparable data are available, missing data in Eurostat Regio have been complemented by data from National Statistical Offices. Table A1 in Annex 1 provides detailed definitions of the variables included in the analysis and further detail on the sources used to complement Eurostat data. In a few cases where information for a specific year and region was missing in all sources, the corresponding value has been calculated by linear interpolation or extrapolation.

4.2 Transport infrastructure and regional growth in the EU regions

Capital cities and regions with high concentration of innovative activities have recorded strong economic growth.

Figures 1a, 2a and 3a (for the EU-15) as well as 1b, 2b and 3b (for the EU-25) provide a visual representation of the phenomena under analysis. Figures 1a and 1b plot the initial GDP per capita of each region against the corresponding growth rate over the 1990-2004 and 1995-2004 periods, respectively. Both figures show some (weak) degree of regional convergence. The figures also confirm the positive economic performance of capital city regions (such as Brussels, Paris, and Stockholm) and of the regions where highly innovative activities are concentrated (such as Bayern, Bremen, Utrecht, and South East England). Fast growth is recorded in some initially disadvantaged regions of the EU-15 in Spain and Portugal and in some regions of the new member states of the Union (in particular in the capital city regions of Bratislava, Budapest, and Warsaw, and, to a lesser extent, Prague). Conversely, a number of regions in the lower area of each figure are either unable to catch up with the rest of the EU (on the left hand side) or show a less dynamic economic performance. The regression analysis will provide some explanations for the observed regional growth pattern and shed some new light on the potential role of transport infrastructure (and its development) on these dynamics.

Figures 2a and 2b represent a first picture of infrastructure endowment and its change over time in the regions of the EU-15 and EU-25, respectively. Figure 2a highlights the development of major transport connections in the Objective 1 regions, fundamentally in Spain and Portugal but also in Austria (Burgenland), Sweden (Norra Mellansverige) and in the Objective 2 region of Basse Normandie (France). Figure 2b also reveals the effort of some regions in the new member states of developing

9 The NUTS2 level corresponds to *Provinces* in Belgium and to the German *Regierungsbezirke*. In both cases these statistical units of analysis have little administrative and institutional meaning. For these two countries the relevant institutional units are *Régions* and *Länder*, respectively, codified as NUTS1 regions. The lack of correspondence between NUTS2 level and actual administrative units accounts for the scarcity of statistical information on many variables (including R&D expenditure) below the NUTS1 level for both countries.

10 Even if Denmark introduced regions above the local authority level on January 1st 2007 in line with the NUTS2 classification, regional statistics are not available from Eurostat.

11 As far as specific regions are concerned, no data are available for the French Départments d'Outre-Mer (FR9). Trentino-Alto Adige (IT31) has no correspondent in the NUTS2003 classification. Due to the nature of the analysis, the islands (PT2 Açores, PT3 Madeira, FR9 Départements d'Outre-mer, ES7 Canarias) and Ceuta y Melilla (ES 63) were not considered due to the problems with the computation of the spatially lagged variables.

new transport infrastructure. This is particularly evident in the western regions of Poland, in Hungary (Nyugat-Dunantul and Eszak-Magyarorszag), and in Slovakia (Západné Slovensko and Východné Slovensko). Improvements in these regions contrast with the backwardness of a large number of EU-25 regions which still show a very low density of transport infrastructure (lower left-hand corner of the figure). In general, "so far as roads are concerned, there are continuing differences between the EU-15 countries and the new member states in the density of motorways: With the exception of Slovenia and Lithuania, they all score under 50 percent of the EU average" (European Commission 2007, p. 60).

The scatter plots suggest some regional convergence between 1990 and 2004.

Figure 1a. EU-15: Initial GDP conditions and regional growth rate, 1990-2004

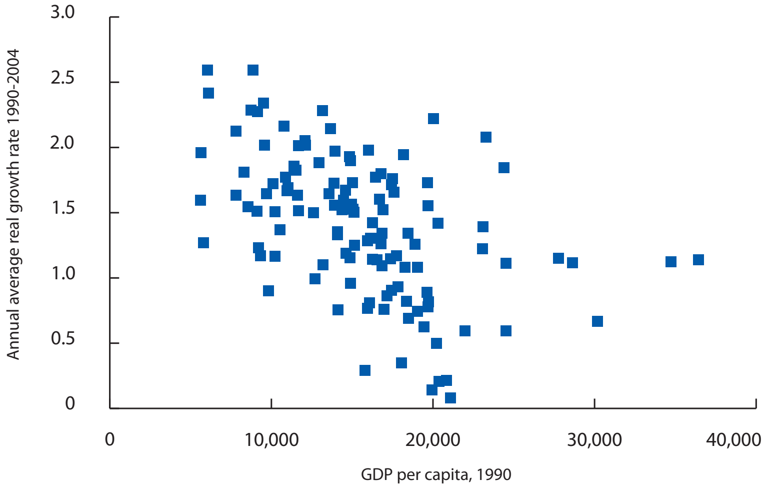
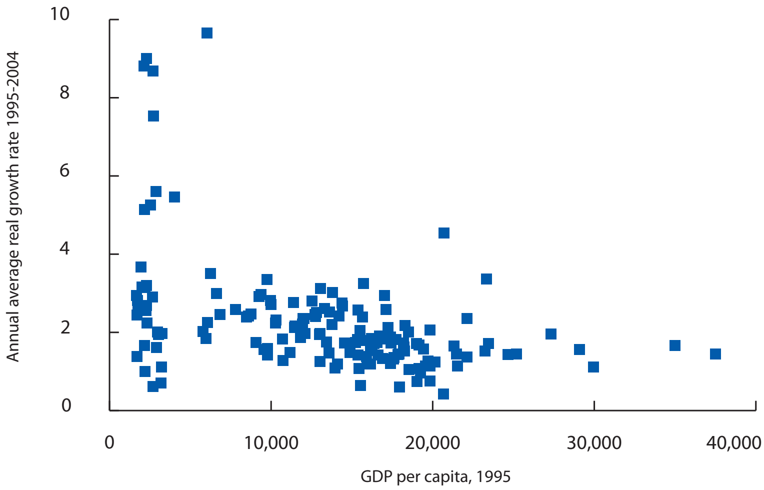


Figure 1b. EU-25: Initial GDP conditions and regional growth rate, 1995-2004



Source: Eurostat Regio database; own calculations

Figure 2a. EU-15: Endowment and change in motorways per thousand inhabitants, 1990-2004

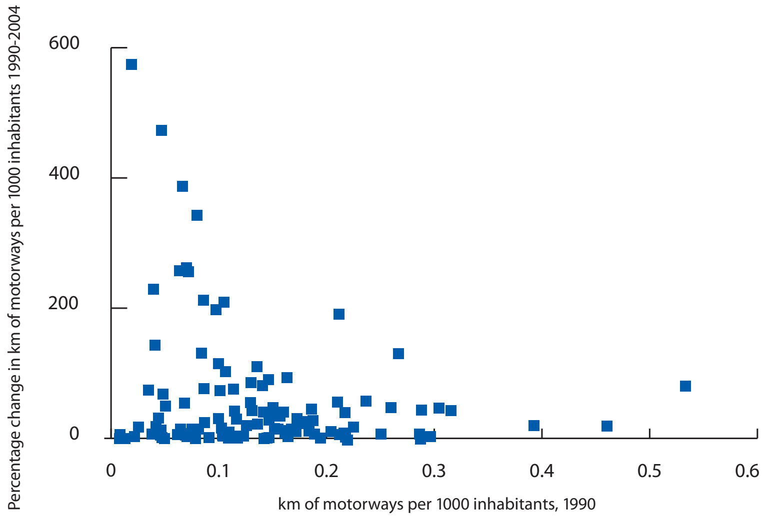
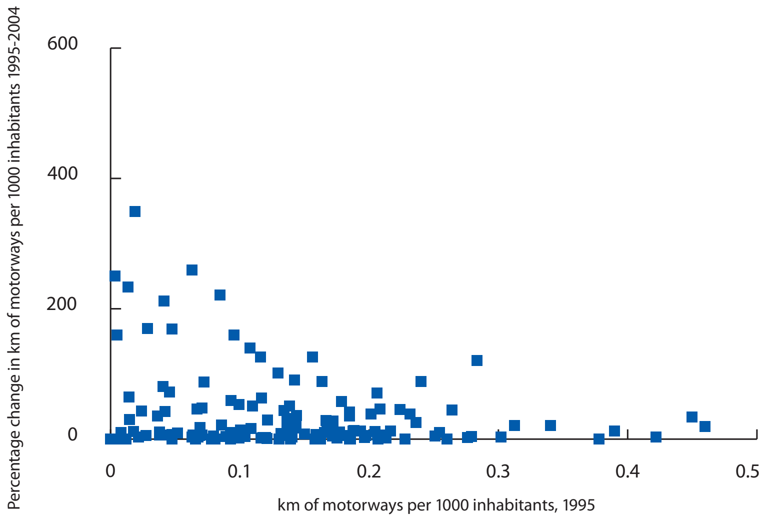


Figure 2b. EU-25: Endowment and change in motorways per thousand inhabitants, 1995-2004



Source: Eurostat Regio database; own calculations

Figures 3a and 3b combine regional growth dynamics and infrastructure development in the same picture. The figure plots information on initial regional GDP per capita (x-axis), the annual average real growth rate (y-axis), and the corresponding variation in transport infrastructure endowment, with the area of the circles being proportional to the percentage increase in motorway density (km per thousand inhabitants). In Figure 3a (and, to a lesser extent, in Figure 3b) transport infrastructure investment seems to be higher in the regions showing a marked 'convergence' trend over the observation period. In other words, the figures suggest some correlation between infrastructure investment and regional convergence. However, the correlation is far from perfect, implying the need for more careful investigation of the factors conditioning such a relationship, *i.e.*, the set of local conditions which allow infrastructure investment to foster regional economic performance.

Transport infrastructure investment has been higher in regions with a marked 'convergence trend'.

Figure 3a. EU-15: Initial GDP conditions, regional growth and infrastructure development, 1990-2004

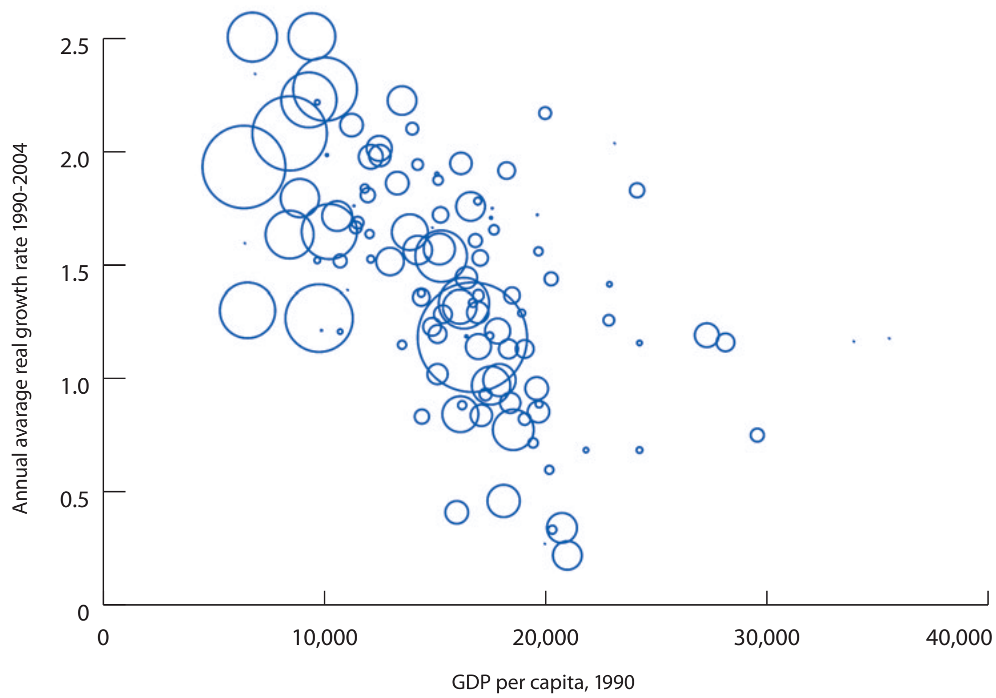
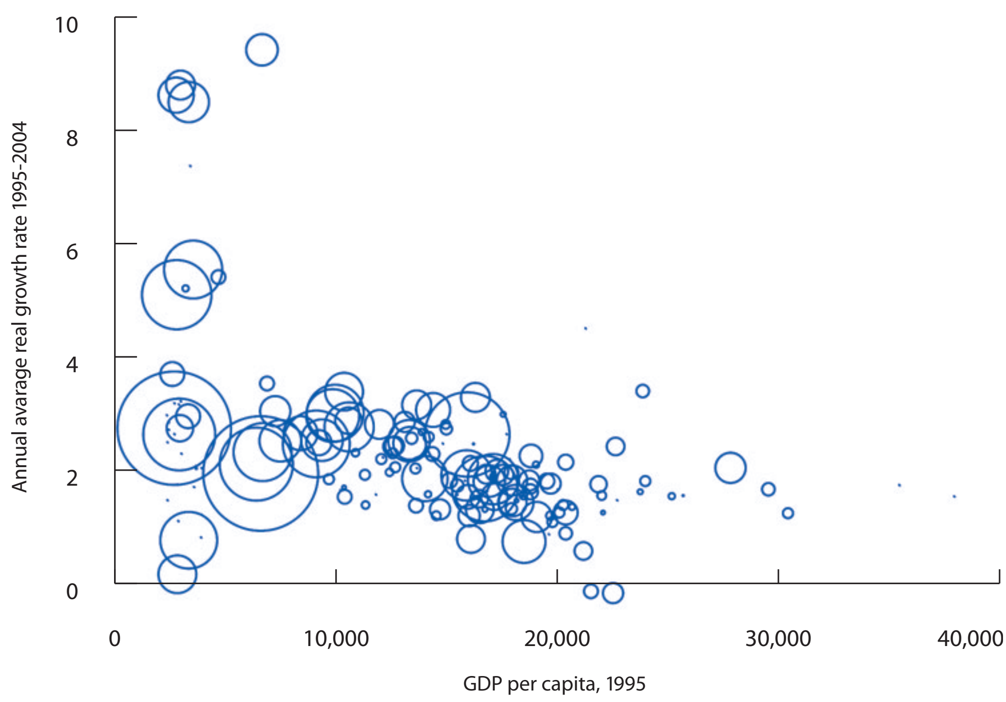


Figure3b. EU-25: Initial GDP conditions, regional growth and infrastructure development, 1995-2004



Source: Eurostat Regio database; own calculations

Note: Circular area proportional to percentage change in km of motorways per 1000 inhab., 1990-2004 (EU-15) and 1995-2004 (EU-25), respectively.

4.3 Results

The results for the estimation of the model of empirical analysis are presented in Tables 1a, 2a and 3a for the EU-15 covering the period from 1990 to 2004 and in Tables 1b, 2b and 3b for the EU-25 covering the 1995-2004 time span. Further results with different proxies for transport infrastructure (km of motorways per square-kilometre and per unit of regional GDP, respectively) are included in Annex 4.[12]

In Regressions 1-2 of Tables 1a and 1b the preferred proxies for infrastructural endowment and investment are introduced together with the controls for initial conditions and spatial autocorrelation (*i.e.*, the level of GDP per capita and the national growth rate, respectively). In Regressions 3-4 the impact of the same indicators in neighbouring regions is assessed. In Regression 5 our proxies for local innovative efforts and knowledge spillovers are introduced, broadening the analysis from a 'new growth theory' perspective. From Regression 6 onwards the variables relative to the socio-economic conditions ('Social Filter Index'), the accumulation of human capital and the territorial organisation of the local economy (migration and agglomeration) are introduced sequentially.

The level of infrastructure has a positive effect on regional growth, the change has not.

Controlling for the level of GDP per capita whose significantly negative (albeit small) coefficient suggests a weak trend towards regional convergence, Regression 1 in Tables 1a and 1b seems to offer a result in line with analyses *à la* Aschauer: The local endowment of transport infrastructure is an important and robust predictor of economic growth. Both for the EU-15 (longer term effect) and the EU-25 (shorter time-span) the density of local transport infrastructure shows a positive and highly significant coefficient and this coefficient is robust to the introduction of additional control variables in the equation in columns (2) to (8). However, this picture of the regional growth mechanics changes immediately when the impact of further investment in infrastructure is assessed. The annual change in infrastructure endowment is not significant for the EU-15 (Table 1a, Regression 2) and has a negative and significant coefficient for the EU-25 (Table 1b, Regression 2).

These results are partially in line with the existing literature. While there seems to be a clear correlation between the levels of GDP and infrastructure endowment, attempts to explain economic growth by transport investment have been much less successful (Vickerman *et al.* 1997). Our results find a correlation between the change in economic wealth and the level of infrastructure endowment but we fail to identify any evidence of a systematic relationship between further investment and economic growth. In interpreting this evidence it must be borne in mind that our proxy for infrastructure development – kilometres of motorways normalised by regional population – can only capture a limited amount of the Keynesian impact of the construction phase, as it is not based upon expenditure data. The proxy captures the 'quantity' of infrastructure actually built irrespective of different costs under different natural and institutional conditions. Furthermore,

12 For all specifications the constraints in terms of data availability have forced us to rely on a relatively short time span, producing a 'large *N* /small *T*' panel whereby the cross-sectional dimension of the dataset (N) is significantly larger than the time dimension (T). In this context, the low time-series variability of the dataset *a priori* prevents non-stationarity from affecting our estimates through spurious correlation. The hypothesis of stationarity is confirmed by three different unit root tests for panel data (the Im-Pesaran-Shin, the augmented Dickey-Fuller and the Phillips-Perron tests) which, as expected, reject the hypothesis of non-stationarity at conventional significance levels (see Tables A4a and A4b in Annex 3). The R-squared confirms the overall goodness-of-fit of all the regressions presented. Following Wooldridge (2002, pp. 275-276), the estimates are based on a "robust variance matrix estimator [which] is valid in the presence of any heteroskedasticity or serial correlation […], provided that *T* is small relative to *N*". The large sample size also allows us to rely on the asymptotic theory to consider the distribution of test statistics as standard also with non-normal residuals. Furthermore, in order to minimize spatial correlation the national growth rate has been included in all equations. Spatial autocorrelation in the residuals has been checked for using the Moran's *I* test (Cliff and Ord 1972) for each year. The test statistics are not significant for the majority of the years covered by the regression (not reported). In all other cases the magnitude of Moran's *I* was low.

Table 1a. EU-15: Regional growth and transport infrastructure, 1990-2004

Dependent variable: Regional GDP per capita (annual growth rate)	Simple model: Infrastructure endowment (1)	Infrastructure endowment and investment (2)	*plus*: Infrastructure network effects (3)	(4)	*plus*: Innovation activities and spillovers (5)	*plus*: Further socio-economic control variables (6)	(7)	(8)
Km of motorways per 1000 inhabitants	0.093***	0.117***	0.049***	0.046**	0.058***	0.043**	0.045***	0.042**
	(0.015)	*(0.017)*	*(0.018)*	*(0.018)*	*(0.018)*	*(0.017)*	*(0.017)*	*(0.017)*
Log of GDP per capita	-0.047***	-0.049***	-0.076***	-0.079***	-0.086***	-0.171***	-0.145***	-0.220***
	(0.008)	*(0.008)*	*(0.009)*	*(0.009)*	*(0.009)*	*(0.015)*	*(0.013)*	*(0.034)*
Annual national growth rate	0.005***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Change in km of motorways/1000 inhab.		-0.075	-0.054	-0.048	-0.046	-0.039	-0.032	-0.035
		(0.052)	*(0.048)*	*(0.046)*	*(0.045)*	*(0.043)*	*(0.042)*	*(0.042)*
Spatial weighted average of km of motorways/1000 inhab.			0.169***	0.186***	0.210***	0.185***	0.202***	0.213***
			(0.023)	*(0.024)*	*(0.026)*	*(0.025)*	*(0.026)*	*(0.027)*
Spatial weighted average of Change in km of motorways/1000 inhab.				-0.180***	-0.194***	-0.162***	-0.151**	-0.151**
				(0.067)	*(0.067)*	*(0.060)*	*(0.061)*	*(0.060)*
Total intraregional R&D expenditure (all sectors) in percent of GDP					0.001***	0.001***	0.001***	0.001***
					(0.000)	*(0.000)*	*(0.000)*	*(0.000)*
Spatial weighted average of total R&D expenditure					0.001*	0.000	0.000	0.000
					(0.001)	*(0.000)*	*(0.001)*	*(0.000)*
Ratio of employed people with higher education in percent							0.002***	0.002***
							(0.000)	*(0.000)*
Log of total Gross Value Added (level)								0.074***
								(0.028)
Migration rate								-0.001***
								(0.000)
Social Filter Index						0.013***		
						(0.002)		
Constant	0.447***	0.468***	0.708***	0.732***	0.794***	1.626***	1.327***	1.297***
	(0.075)	*(0.074)*	*(0.084)*	*(0.084)*	*(0.088)*	*(0.140)*	*(0.116)*	*(0.118)*
Observations	1680	1560	1560	1560	1560	1560	1560	1560
Number of groups (NUTS regions)	120	120	120	120	120	120	120	120
R-squared	0.14	0.16	0.18	0.19	0.20	0.25	0.24	0.25
R-squared within	0.14	0.16	0.18	0.19	0.20	0.25	0.24	0.25
R-squared overall	0.04	0.05	0.05	0.05	0.04	0.05	0.05	0.01
R-squared between	0.13	0.10	0.13	0.13	0.12	0.19	0.17	0.02

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table 1b. EU-25: Regional growth and transport infrastructure, 1995-2004

Dependent variable: Regional GDP per capita (annual growth rate)	Simple model: Infrastructure endowment (1)	Infrastructure endowment and investment (2)	*plus*: Infrastructure network effects (3)	(4)	*plus*: Innovation activities and spillovers (5)	*plus*: Further socio-economic control variables (6)	(7)	(8)
Km of motorways per 1000 inhabitants	0.066***	0.107***	0.107***	0.104***	0.110***	0.111***	0.109***	0.104***
	(0.020)	*(0.025)*	*(0.030)*	*(0.030)*	*(0.029)*	*(0.029)*	*(0.029)*	*(0.028)*
Log of GDP per capita	-0.070***	-0.101***	-0.101***	-0.102***	-0.106***	-0.103***	-0.113***	0.027
	(0.009)	*(0.012)*	*(0.013)*	*(0.013)*	*(0.013)*	*(0.015)*	*(0.016)*	*(0.037)*
Annual national growth rate	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.002***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Change in km of motorways/1000 inhab.		-0.107***	-0.107***	-0.103***	-0.100***	-0.100***	-0.101***	-0.098**
		(0.037)	*(0.038)*	*(0.038)*	*(0.038)*	*(0.038)*	*(0.038)*	*(0.039)*
Spatial weighted average of km of motorways/1000 inhab.			0.001	0.018	0.023	0.031	0.016	0.061
			(0.036)	*(0.038)*	*(0.039)*	*(0.038)*	*(0.038)*	*(0.038)*
Spatial weighted average of Change in km of motorways/1000 inhab.				-0.100	-0.079	-0.083	-0.069	-0.093
				(0.070)	*(0.068)*	*(0.068)*	*(0.067)*	*(0.067)*
Total intraregional R&D expenditure (all sectors) in percent of GDP					0.002	0.002	0.002	0.002**
					(0.001)	*(0.002)*	*(0.002)*	*(0.001)*
Spatial weighted average of total R&D expenditure					0.004**	0.005**	0.004**	0.004**
					(0.002)	*(0.002)*	*(0.002)*	*(0.002)*
Ratio of employed people with higher education in percent							0.000*	0.001**
							(0.000)	*(0.000)*
Log of total Gross Value Added (level)								-0.142***
								(0.033)
Migration rate								-0.000
								(0.000)
Social Filter Index						-0.001		
						(0.002)		
Constant	0.659***	0.941***	0.942***	0.955***	0.976***	0.950***	1.040***	1.126***
	(0.082)	*(0.108)*	*(0.118)*	*(0.120)*	*(0.122)*	*(0.139)*	*(0.141)*	*(0.142)*
Observations	1449	1288	1288	1288	1288	1288	1288	1288
Number of groups (NUTS regions)	161	161	161	161	161	161	161	161
R-squared	0.15	0.19	0.19	0.20	0.20	0.20	0.20	0.22
R-squared within	0.15	0.19	0.19	0.20	0.20	0.20	0.20	0.22
R-squared overall	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.02
R-squared between	0.17	0.12	0.12	0.12	0.12	0.12	0.13	0.05

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

since new infrastructure is recorded by official statistics only after final completion, our proxy is intrinsically better equipped to capture the *ex-post* impact of transport infrastructure on accessibility, the mobility pattern, and spatial re-organisation of economic activity.

Once a satisfactory level of infrastructure endowment is in place, economic growth is made easier thanks to the 'traditional' micro-economic impact on productivity. However, this level may well be the result – rather than the cause – of a dynamic local economy whose previous growth pattern may have supported and stimulated the enhancement of local infrastructural endowment (Vanhoudt *et al.* 2000), thus making infrastructure a factor that accompanies the process of regional development rather than being one of its engines. This idea is confirmed by the non significant or even negative impact of the development of further infrastructure. The impact of an additional kilometre of motorway depends on a variety of conditions related to both the nature of the connection developed and to the features of the areas actually involved in the project. As an example, Vickerman *et al.* (1997, p. 3) suggest that "transport improvements have strong and positive impacts on regional development only where they result in removing a *bottleneck*", while Chandra and Thompson (2000) find evidence of a positive direct impact of the construction of a new interstate highway only for the US counties "that the highway directly passes through" (p.487). The direct impact of further infrastructure development may be absent where the appropriate conditions are not met. It may be even negative where the additional infrastructure increases the exposure to external competition of a weak economic tissue as discussed in Section 2.

A region benefits when neighbours are also well endowed with infrastructure but additional highways might lure firms away.

The picture is not complete unless interregional spillovers are fully accounted for, as in Regressions 3 and 4 where we consider the impact of the level and the change of infrastructure endowment in neighbouring regions, respectively. The empirical analysis suggests that the infrastructure endowment of neighbouring regions exerts a positive influence on local economic performance (Regression 3), and that this impact is highly statistically significant for the EU-15 (Table 1a), though not significant for the EU-25 sample (Table 1b). Where a good internal endowment of infrastructure is complemented by an equally good endowment in neighbouring regions, connectivity and accessibility are enhanced and bottlenecks and inefficiencies in interregional connections are prevented. Hence better economic performance ensues. Conversely – and symmetrically with the evidence discussed before – further investment in transport infrastructure in neighbouring regions has a negative impact on local economic performance: The coefficient of the proxy for infrastructure spillovers is negative and highly significant for the EU-15 (Table 1a, Regression 4) and not significant for the EU-25 (Table 1b, Regression 4). Transport infrastructure investment in neighbouring regions may negatively affect the local economy in the same way as internal investment does. The further development of transport infrastructure in neighbouring regions may not only increase the exposure of the local economy to external competitive forces but may also encourage re-location of local economic activity towards better endowed neighbours as observed by Chandra and Thompson (2000) for the US case.

Let us now consider the determinants of regional growth more accurately by introducing a proxy for local innovative efforts and knowledge spillovers, in line with the 'endogenous growth' approach (Regression 5). The results suggest that local innovative activities are important predictors of economic growth in the case of the EU-15 (Table 1a) but much less so in the EU-25 (Table 1b) while exposure to knowledge spillovers tends to be a positive factor in both samples. This piece of evidence on the relevance of knowledge flows is in line with other analyses of the EU regional growth and innovation dynamics (Crescenzi *et al.* 2007; Rodríguez-Pose and Crescenzi 2008). The possibility of benefiting from knowledge flows is a differential source of competitive advantage for the EU regions, which allows them to compensate for the weaknesses of their internal innovative capacity. How can transport infrastructure contribute to these knowledge-based economic dynamics? The empirical results confirm the robustness of our previous conclusions: The internal and external infrastructural endowment plays a role but its changes do not. Other factors are probably more important for a knowledge-based economy.

An important clue in this direction is provided by Regressions 6 and 7 where the proxies for internal socio-economic conditions are introduced into the analysis, presenting the full specification of our empirical model. In the longer-run perspective provided by the EU-15 sample the socio-economic conditions of the regions – as proxied by the social filter index discussed in Section 3 – are an important determinant of economic performance (Table 1a, Regression 6) while this effect is less accentuated in the EU-25 case (Table 1b, Regression 6). However, where the most important component of regional socio-economic structure – *i.e.*, human capital accumulation – is autonomously assessed its impact is positive and significant in both cases (Tables 1a and 1b, Regression 7). The local socio-economic conditions, in general, and of human capital accumulation, in particular, by avoiding the important side-effects of infrastructural development – which often more than offset any short-term positive impact – are much better predictors of economic growth and thus more convincing tools for regional development strategies.

The full model underscores the importance of a skilled workforce and R&D but also the robustness of the infrastructure results.

In order to test for the robustness of these results further control variables are introduced into the model (Regression 8). In particular, we control for some relevant proxies for the territorial organisation of the local economy: The magnitude of agglomeration economies and the capacity to attract migration inflows. The absolute size of the local economy (our proxy for agglomeration) is synonymous with better economic performance in the EU-15 (Table 1a) while it turns out to be detrimental when the new members of the EU and a shorter time-span are considered (Table 1b). The net rate of migration is either negative (EU-15) or not significant (EU-25), suggesting that the inward mobility of people is not *per se* supportive of economic growth after controlling for the overall level of human capital accumulation. However, what matters more for the purpose of this paper is that both the magnitude and the significance of infrastructure endowment are not sensitive to the inclusion of controls.

Tables 2a, 2b, 3a and 3b present a dynamic picture of the link between economic performance and the variables included in the full specification of our model (Regression 8 of Tables 1a and 1b). Tables 2a and 2b present several annual lags in all variables, allowing for a maximum of five years between the base year of the variables and their impact on regional growth. This highlights the different time-span necessary for each factor to produce its impact on economic performance. In Tables 3a and 3b the model is estimated by sequentially introducing several annual lags of the proxies for infrastructure endowment and investment only in order to specifically capture their cumulative dynamics over time (holding all other variables fixed at time *t-1* as in Tables 1a and 1b). The tables for the EU-25 are discussed only for comparison purposes since the period from 1995 to 2003 is too limited to allow for the introduction of several time lags without severely affecting the overall significance of the analysis. In any case, the results of the dynamic analysis for the EU-15 and the EU-25 are similar.

Turning specifically to Tables 2a and 2b, the results underscore the interesting dynamics between the endowment with and additional investment in infrastructure on the one hand and economic growth on the other. The results point to a short-lived impact of infrastructure endowment and investment in a region when other variables are controlled for. The endowment of motorways relative to the population in any given region is initially significant, but its significant association with growth disappears after the second annual lag, suggesting that after three years the current infrastructure endowment is no longer a valid predictor of economic performance (Tables 2a and 2b, Regression 2). Similarly, the negative and significant association between investment in new

Table 2a. EU-15: Regional growth and transport infrastructure with annual lags, 1990-2004

Dependent variable: Regional GDP per capita (annual growth rate)	(1)	(2)	(3)	(4)	(5)
Number of annual lags in all variables	2	3	4	5	6
Km of motorways per thousand inhabitants	0.046**	0.019	0.028	0.053***	0.026
	(0.023)	*(0.020)*	*(0.023)*	*(0.015)*	*(0.020)*
Change in km of motorways/1000 inhab.	0.014	-0.043*	-0.048*	-0.012	0.049
	(0.031)	*(0.024)*	*(0.028)*	*(0.029)*	*(0.033)*
Spatial weighted average of km of motorways/1000 inhab.	0.233***	0.083***	0.048	0.038	-0.073**
	(0.033)	*(0.025)*	*(0.030)*	*(0.023)*	*(0.029)*
Spatial weighted average of Change in km of motorways/1000 inhabitants	-0.075	-0.108**	-0.114**	0.002	0.017
	(0.049)	*(0.046)*	*(0.047)*	*(0.044)*	*(0.054)*
Log of GDP per capita	-0.256***	-0.123***	-0.161***	-0.049	0.163***
	(0.043)	*(0.043)*	*(0.035)*	*(0.051)*	*(0.043)*
Total intraregional R&D expenditure (all sectors) in percent of GDP	0.000**	-0.000	-0.000	0.000**	0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Spatial weighted average of total R&D expenditure	-0.001	-0.002***	-0.001**	0.001***	0.001**
	(0.000)	*(0.000)*	*(0.001)*	*(0.000)*	*(0.000)*
Ratio of employed people with higher education in percent	0.002***	0.001***	0.001***	0.000	0.001**
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Log of total Gross Value Added (levels)	0.089**	0.011	0.042	-0.029	-0.184***
	(0.036)	*(0.038)*	*(0.029)*	*(0.046)*	*(0.039)*
Migration rate	-0.000***	-0.000**	-0.000	0.000	0.001***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Annual national growth rate	0.001***	0.000	-0.000	-0.001***	-0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Constant	1.498***	1.061***	1.122***	0.763***	0.332**
	(0.132)	(0.106)	(0.128)	(0.131)	(0.149)
Observations	1440	1320	1200	1080	960
Number of groups (NUTS regions)	120	120	120	120	120
R-squared	0.18	0.13	0.13	0.13	0.15
R-squared within	0.18	0.13	0.13	0.13	0.15
R-squared overall	0.00	0.02	0.01	0.03	0.00
R-squared between	0.01	0.07	0.03	0.08	0.01

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table 2b. EU-25: Regional growth and transport infrastructure with annual lags, 1995-2004

Dependent variable: Regional GDP per capita (annual growth rate)	(1)	(2)	(3)	(4)	(5)
Number of annual lags in all variables	2	3	4	5	6
Km of motorways per thousand inhabitants	0.073**	0.025	0.032	-0.010	0.111*
	(0.033)	*(0.028)*	*(0.032)*	*(0.039)*	*(0.062)*
Change in km of motorways/1000 inhab.	-0.015	0.003	-0.044	0.036	-0.118*
	(0.034)	*(0.041)*	*(0.051)*	*(0.038)*	*(0.068)*
Spatial weighted average of km of motorways/1000 inhab.	0.024	0.063	-0.129***	0.022	0.063
	(0.044)	*(0.048)*	*(0.045)*	*(0.051)*	*(0.083)*
Spatial weighted average of Change in km of motorways/1000 inhabitants	0.022	0.033	-0.128*	-0.018	-0.080
	(0.067)	*(0.061)*	*(0.066)*	*(0.054)*	*(0.093)*
Log of GDP per capita	0.048	-0.075*	-0.079*	0.178**	0.060
	(0.044)	*(0.043)*	*(0.045)*	*(0.080)*	*(0.110)*
Total intraregional R&D expenditure (all sectors) in percent of GDP	0.001	-0.000	-0.002	-0.002	0.003**
	(0.001)	*(0.001)*	*(0.002)*	*(0.002)*	*(0.002)*
Spatial weighted average of total R&D expenditure	0.006***	0.010***	-0.009***	0.001	0.002
	(0.001)	*(0.003)*	*(0.003)*	*(0.003)*	*(0.003)*
Ratio of employed people with higher education in percent	0.000	-0.000	0.000	0.000	0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Log of total Gross Value Added (levels)	-0.176***	-0.018	0.039	-0.121*	0.104
	(0.041)	*(0.039)*	*(0.038)*	*(0.072)*	*(0.101)*
Migration rate	0.000	-0.000***	0.000**	0.001***	-0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Annual national growth rate	-0.002***	-0.003***	-0.002***	-0.001**	-0.001***
	(0.000)	*(0.000)*	*(0.001)*	*(0.000)*	*(0.000)*
Constant	1.289***	0.890***	0.399***	-0.451**	-1.585***
	(0.180)	(0.136)	(0.128)	(0.186)	(0.185)
Observations	1127	966	805	644	483
Number of groups (NUTS regions)	161	161	161	161	161
R-squared	0.22	0.21	0.12	0.12	0.37
R-squared within	0.22	0.21	0.12	0.12	0.37
R-squared overall	0.02	0.08	0.05	0.01	0.19
R-squared between	0.04	0.13	0.07	0.01	0.29

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table 3a. EU-15: Regional growth and the impact of transport infrastructure over time, 1990-2004

Dependent variable: Regional GDP per capita (annual growth rate)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Km of motorways per thousand inhabitants	0.042**	0.044**	0.044**	0.078***	0.109***	0.114***	0.101***
	(0.017)	*(0.020)*	*(0.022)*	*(0.026)*	*(0.026)*	*(0.031)*	*(0.030)*
Change in km of motorways/1000 inhab.	-0.035	-0.028	-0.013	-0.077**	-0.096***	-0.083**	-0.063*
	(0.042)	*(0.043)*	*(0.036)*	*(0.038)*	*(0.037)*	*(0.037)*	*(0.037)*
Spatial weighted average of km of motorways/1000 inhab.	0.213***	0.203***	0.104***	0.112***	0.079**	0.105***	0.123***
	(0.027)	*(0.032)*	*(0.029)*	*(0.033)*	*(0.036)*	*(0.036)*	*(0.043)*
Spatial weighted average of Change in km of motorways/1000 inhab.	-0.151**	-0.166***	-0.024	-0.059	-0.075	-0.030	-0.039
	(0.060)	*(0.063)*	*(0.048)*	*(0.066)*	*(0.062)*	*(0.064)*	*(0.072)*
Log of GDP per capita	-0.220***	-0.205***	-0.124***	-0.154***	-0.071	-0.092**	-0.121**
	(0.034)	*(0.040)*	*(0.039)*	*(0.039)*	*(0.050)*	*(0.039)*	*(0.048)*
Total intraregional R&D expenditure (all sectors) in percent of GDP	0.001***	0.001***	0.001	0.001	0.004***	0.003*	0.002*
	(0.000)	*(0.000)*	*(0.000)*	*(0.001)*	*(0.001)*	*(0.002)*	*(0.001)*
Spatial weighted average of total R&D expenditure	0.000	-0.000	-0.003***	-0.003	0.002**	0.002*	0.002
	(0.000)	*(0.001)*	*(0.001)*	*(0.002)*	*(0.001)*	*(0.001)*	*(0.001)*
Ratio of employed people with higher education in percent	0.002***	0.002***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Log of total Gross Value Added (levels)	0.074***	0.057*	-0.011	0.013	-0.072	-0.110***	-0.144***
	(0.028)	*(0.033)*	*(0.034)*	*(0.033)*	*(0.044)*	*(0.033)*	*(0.045)*
Migration rate	-0.001***	-0.000***	0.000	-0.000	-0.000	0.000	0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Annual national growth rate	0.004***	0.004***	0.002***	0.002***	0.002***	0.001***	0.000
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Lag 2 Change in km of motorways/1000 inhab.		0.026	0.012	-0.010	-0.053	-0.075**	-0.042
		(0.027)	(0.027)	(0.039)	(0.036)	(0.035)	(0.034)
Lag 2 Spatial weighted average of Change in km of motorways/1000 inhab.		-0.048	-0.068	-0.124**	-0.078	-0.120**	-0.106
		(0.048)	*(0.043)*	*(0.052)*	*(0.059)*	*(0.059)*	*(0.068)*

Lag 3 Change in km of motorways/1000 inhab.			-0.037	-0.036	-0.030	-0.052	-0.039
			(0.024)	*(0.025)*	*(0.024)*	*(0.039)*	*(0.041)*
Lag 3 Spatial weighted average of Change in km of motorways/1000 inhab.			-0.099**	-0.125***	-0.051	0.069	0.013
			(0.046)	*(0.046)*	*(0.057)*	*(0.061)*	*(0.064)*
Lag 4 Change in km of motorways/1000 inhab.				-0.041*	-0.067***	-0.056**	-0.047
				(0.022)	*(0.020)*	*(0.022)*	*(0.036)*
Lag 4 Spatial weighted average of Change in km of motorways/1000 inhab.				-0.114**	-0.175***	-0.167***	-0.201***
				(0.048)	*(0.045)*	*(0.048)*	*(0.069)*
Lag 5 Change in km of motorways/1000 inhab.					-0.020	-0.036	-0.005
					(0.024)	*(0.023)*	*(0.033)*
Lag 5 Spatial weighted average of Change in km of motorways/1000 inhab.					-0.045	-0.052	-0.102**
					(0.044)	*(0.044)*	*(0.049)*
Lag 6 Change in km of motorways/1000 inhab.						0.016	-0.001
						(0.026)	*(0.021)*
Lag 6 Spatial weighted average of Change in km of motorways/1000 inhab.						-0.111**	-0.132***
						(0.047)	*(0.046)*
Lag 7 Change in km of motorways/1000 inhab.							0.011
							(0.029)
Lag 7 Spatial weighted average of Change in km of motorways/1000 inhab.							-0.023
							(0.045)
Constant	1.297***	1.331***	1.273***	1.325***	1.376***	1.976***	2.595***
	(0.118)	*(0.130)*	*(0.112)*	*(0.134)*	*(0.149)*	*(0.150)*	*(0.162)*
Observations	1560	1440	1320	1200	1080	960	840
Number of groups (NUTS regions)	120	120	120	120	120	120	120
R-squared	0.25	0.22	0.17	0.19	0.23	0.36	0.44
R-squared within	0.25	0.22	0.17	0.19	0.23	0.36	0.44
R-squared overall	0.01	0.01	0.03	0.03	0.02	0.02	0.02
R-squared between	0.02	0.02	0.11	0.08	0.06	0.05	0.04

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table 3b. EU-25: Regional growth and the impact of transport infrastructure over time, 1995-2004

Dependent variable: Regional GDP per capita (annual growth rate)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Km of motorways per thousand inhabitants	0.104***	0.107***	0.089***	0.078*	0.100	0.128	0.219***
	(0.028)	*(0.035)*	*(0.032)*	*(0.043)*	*(0.061)*	*(0.103)*	*(0.080)*
Change in km of motorways/1000 inhab.	-0.098**	-0.079*	-0.094**	-0.086*	-0.157**	-0.203*	-0.298***
	(0.039)	*(0.041)*	*(0.040)*	*(0.052)*	*(0.066)*	*(0.115)*	*(0.088)*
Spatial weighted average of km of motorways/1000 inhab.	0.061	0.012	0.008	-0.047	0.131	0.360**	0.587***
	(0.038)	*(0.046)*	*(0.049)*	*(0.063)*	*(0.082)*	*(0.145)*	*(0.110)*
Spatial weighted average of Change in km of motorways/1000 inhab.	-0.093	-0.017	0.032	0.072	-0.256**	-0.400**	-0.666***
	(0.067)	*(0.066)*	*(0.077)*	*(0.104)*	*(0.120)*	*(0.188)*	*(0.171)*
Log of GDP per capita	0.027	0.024	-0.025	-0.107**	-0.167**	-0.378***	-0.386***
	(0.037)	*(0.044)*	*(0.046)*	*(0.047)*	*(0.081)*	*(0.138)*	*(0.116)*
Total intraregional R&D expenditure (all sectors) in percent of GDP	0.002**	0.001	0.001	-0.000	-0.001	-0.000	0.000
	(0.001)	*(0.001)*	*(0.001)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Spatial weighted average of total R&D expenditure	0.004**	0.003**	0.002*	0.000	0.000	0.001	-0.001*
	(0.002)	*(0.002)*	*(0.001)*	*(0.001)*	*(0.001)*	*(0.001)*	*(0.001)*
Ratio of employed people with higher education in percent	0.001**	0.001***	0.001***	0.001**	0.002***	0.001	0.003***
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.001)*	*(0.001)*
Log of total Gross Value Added (levels)	-0.142***	-0.143***	-0.089**	-0.000	0.115	0.437***	0.166
	(0.033)	*(0.041)*	*(0.044)*	*(0.045)*	*(0.082)*	*(0.134)*	*(0.117)*
Migration rate	-0.000	-0.000	0.000	0.000	0.000	0.001***	0.000*
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
Annual national growth rate	0.002***	0.003***	0.002***	0.000	-0.001**	0.000	0.008***
	(0.000)	*(0.001)*	*(0.001)*	*(0.000)*	*(0.000)*	*(0.001)*	*(0.001)*
Lag 2 Change in km of motorways/1000 inhab.		-0.039	-0.020	-0.044	-0.092	-0.212*	-0.304***
		(0.036)	(0.033)	(0.036)	(0.058)	(0.113)	(0.085)
Lag 2 Spatial weighted average of Change in km of motorways/1000 inhab.		-0.010	0.074	0.104	-0.043	-0.378**	-0.607***
		(0.067)	*(0.061)*	*(0.068)*	*(0.101)*	*(0.181)*	*(0.151)*

Lag 3 Change in km of motorways/1000 inhab.			-0.020	-0.029	-0.002	-0.083	-0.292***
			(0.046)	*(0.051)*	*(0.052)*	*(0.105)*	*(0.083)*
Lag 3 Spatial weighted average of Change in km of motorways/1000 inhab.			0.057	0.114*	0.169**	-0.018	-0.536***
			(0.065)	*(0.063)*	*(0.081)*	*(0.157)*	*(0.133)*
Lag 4 Change in km of motorways/1000 inhab.				-0.052	-0.006	-0.059	-0.139*
				(0.049)	*(0.047)*	*(0.090)*	*(0.077)*
Lag 4 Spatial weighted average of Change in km of motorways/1000 inhab.				-0.153**	-0.091	0.063	-0.300*
				(0.076)	*(0.073)*	*(0.149)*	*(0.153)*
Lag 5 Change in km of motorways/1000 inhab.					0.046	-0.089	-0.170**
					(0.041)	*(0.093)*	*(0.077)*
Lag 5 Spatial weighted average of Change in km of motorways/1000 inhab.					0.027	0.106	-0.375**
					(0.066)	*(0.128)*	*(0.146)*
Lag 6 Change in km of motorways/1000 inhab.						-0.094	-0.165*
						(0.094)	*(0.088)*
Lag 6 Spatial weighted average of Change in km of motorways/1000 inhab.						0.044	-0.378**
						(0.127)	*(0.149)*
Lag 7 Change in km of motorways/1000 inhab.							-0.076
							(0.051)
Lag 7 Spatial weighted average of Change in km of motorways/1000 inhab.							-0.217***
							(0.082)
Constant	1.126***	1.168***	1.092***	0.996***	0.372	-0.881**	1.804***
	(0.142)	*(0.179)*	*(0.176)*	*(0.213)*	*(0.267)*	*(0.377)*	*(0.380)*
Observations	1288	1127	966	805	644	483	322
Number of groups (NUTS regions)	161	161	161	161	161	161	161
R-squared	0.22	0.22	0.18	0.13	0.14	0.35	0.80
R-squared within	0.22	0.22	0.18	0.13	0.14	0.35	0.80
R-squared overall	0.02	0.02	0.05	0.10	0.00	0.03	0.10
R-squared between	0.05	0.05	0.10	0.15	0.00	0.05	0.11

Note: Robust standard errors in parentheses; * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

transport infrastructure and growth detected in Tables 1a and 1b above disappears after the fourth annual lag in the EU-15 sample (Table 2a). This means that any negative impact of infrastructure investment recorded in some cases quickly vanishes after the local economy begins to react to new competitive conditions, making infrastructure a less relevant predictor of economic growth than other variables included in the analysis (Rodríguez-Pose and Fratesi 2004).

The effects of the spillovers from infrastructure in neighbouring areas on economic growth generally last slightly longer but also tends to wane with time: The positive and significant effect of transport infrastructure endowment in the rest of the EU on the economic growth of any given region disappears after three years, and the negative and robust association with investment in infrastructure in neighbouring regions after four (Table 2a). In contrast, other variables included in the model remain significant in time. This is, for example, the case of the spillovers from the total R&D investment in neighbouring regions, which not only remains significant throughout the period of analysis, but whose association with regional growth switches from negative in the relative short term to positive (Table 2a). Migration effects on growth undergo a similar change from negative to positive, while the coefficient of the level of education remains significant and positive throughout the period of analysis (Table 2a), although not in the case of the enlarged EU (Table 2b). This reliance on local human capital and on the innovation potential of neighbouring regions for economic development in the medium term implies that the regional convergence detected initially wanes and becomes divergence in the medium run (Table 2a). Regions with better endowments in human capital and surrounded by innovative regions tend not only to be richer, but also to perform better in the medium term.

Growth effects of transport infrastructure endowment and investment are rather short-lived.

This overall picture of lack of medium term relevance of infrastructure investment for regional economic performance in Europe relative to human capital and R&D variables is further confirmed in Tables 3a and 3b, which analyse the dynamic association of investment in transport infrastructure within a region and in the rest of the EU with economic growth in a cumulative manner. The results indicate that while investment in infrastructure in any given region tends not to be robustly associated with the region's economic performance over time, investment in infrastructure in the rest of the EU is generally negatively associated with growth in any given region. Such a result is an indicator of the existence of 'two-way road' effects, whereby regions with a weaker endowment in human capital and a lower capacity to generate innovation become increasingly exposed and vulnerable to investment in new transport infrastructure in the rest of Europe.

5. Conclusions

Inspired by favourable theoretical and empirical accounts about the impact of infrastructure on economic growth, the European Union has bet on investment in infrastructure in general, and transport infrastructure in particular, as its main development axis. The aim of this strategy is not only to achieve greater economic growth but also to generate greater social and economic cohesion. Infrastructure expenditure has, so far, represented roughly half of the structural and cohesion expenditure by the EU (Rodríguez-Pose and Fratesi 2004). The question is whether this important effort is paying off and whether it is delivering greater medium and long-term growth, especially in the periphery of the EU.

This paper has addressed this issue by analysing the role of transport infrastructure endowment and investment in regional growth for the EU-15 between 1990 and 2004 and for the enlarged EU-25 between 1995 and 2004. It has done so by contrasting the effect on economic growth of infrastructure with that of other factors, most notably education and investment in R&D, and by controlling for the spatial spillover effects linked to endowments and investment not just in any given region, but also in the remainder of the EU. It has adopted both a static and a dynamic approach in order to discern the impact of different factors on growth over time.

The results highlight that a good infrastructure endowment is a precondition for economic development. Regions with adequate initial motorway networks tend to perform better than regions lacking this type of basic infrastructure. But the analysis has also revealed that the effects of infrastructure are much more complex than initially predicted by Aschauer-type analyses. Whereas regions benefit from having good initial levels of infrastructure and from being surrounded by regions with equally good endowments, new investment in infrastructure seems to be completely disconnected from growth performance, and investment in neighbouring regions is, on the whole, negatively associated with regional growth. Moreover, the positive effects of infrastructure endowment wane quickly in time, becoming insignificant shortly after the initial positive impact. In contrast, the negative effect on the regional growth potential of investment in transport infrastructure in the neighbourhood seems to be longer lasting.

Longer-lasting benefits stem more from high human capital and R&D activity than from additional transport infrastructure.

Infrastructure endowment and investment also appear to be less relevant for economic growth in the medium-term than human capital and innovation endowments. The level of education is, and remains in time, one of the main predictors of economic growth, while a region surrounded by others investing heavily in R&D tends to outperform other regions.

The geographical concentration of human capital and R&D investment in Europe thus leads to a reversal of the regional convergence trend observed in the static regression analysis. Since the effects of human capital and knowledge spillovers on economic growth last longer than those of other factors, short-term regional convergence gives way to divergence in the medium term as a consequence of the better endowment of core regions with these factors. New investment in transport infrastructure has, by and large, contributed to enhance the centripetal effect as new roads linking the periphery with the core seem to be fostering the dynamism of the regions in the core, at the expense of regions in the periphery, through a 'two-way road' effect.

The main policy implication that can be drawn from this analysis of European regions is the need to consider infrastructure policies within the framework of balanced strategies. If the aim is to maximise the regional economic return to any new infrastructure investment and to enhance economic cohesion, investment in infrastructure has to be coordinated with policies aimed at developing human capital and the innovative potential of regions.

The timing of infrastructure investment is also crucial. Invest in transport infrastructure too early, and you may expose uncompetitive regions to stronger areas and markets, leading to even greater concentration. Invest too late, and you may prevent the development of the periphery. Only by paying attention to the complex relationship in time and space of the factors that influence growth will we be able to maximize the positive effects of delivering greater accessibility and connectivity of the regions in Europe, while minimising the economic and welfare risk of exposure of regions with weak economic tissues that are often ill-prepared to compete in more integrated markets.

Annex 1. Description of the variables

The dependent variable is the annual growth rate of regional GDP (1990-2004 for the EU-15 and 1995-2004 for the EU-25).

Table A1. Description of the independent variables

Variable	Definition	Notes
Internal factors		
Infrastructure		
Motorways* (Inhab.)	Km of motorways per thousand inhabitants	Italy: Missing data for all regions after the year 2000. Missing data have been replaced by means of comparable ISTAT data. Greece: Data are missing from 1996. Greece has been excluded from the analysis. Poland: Data are missing in the Eurostat databank for some regions without any explanatory note. Data are also missing from the Polish National Statistical Institute databank. By inspecting a map of motorways in Poland (2004) the km of motorways in these regions appears to be zero. Portugal: Missing data for Centro, Lisboa and Alentejo from 1990 to 2002 Region area in 2003 has been used to calculate the density of transport infrastructure for all periods to avoid generating noise in the density variable due to changes in the calculation of the region area. Regional GDP and average population in 1990 and 1995 have been used to standardize the variables included in the EU-15 and EU-25 regressions respectively.
Motorways (GDP)	Km of motorways per million EUR of GDP	
Motorways (region area)	Km of motorways per square-kilometre	
Δ Motorways (Inhab.)	Annual change in km of motorways per thousand inhabitants	
Δ Motorways (GDP)	Annual change in km of motorways per million EUR of GDP	
Δ Motorways (region area)	Annual change in km of motorways per square-kilometre	
Control variables		
Log of GDP per capita	Natural logarithm of regional GDP per capita at time t	
National growth	Annual growth rate of national GDP (for the EU-15 1990-2004; for the EU-25 1995-2004).	
Innovation		
R&D	Total intraregional R&D expenditure (all sectors) in percent of GDP	
Socio-Economic Conditions		
Education employed people	Ratio of employed people with completed higher education (ISCED76 levels 5-7) in percent of total employment	Data on educational attainment are available from the Labour Force Survey and have been provided by Eurostat. There are two sets of tables presenting data collected on the basis of two different versions of the International Standard Classification of Education (ISCED) of 1976 and 1997. Data based on ISCED76 classification cover the period 1993-2002 while data based on ISCED97 are available from 1999 only. The series based on the two different standards are not comparable thus forcing us to rely upon ISCED76 only and interpolate or extrapolate the data for the rest of the period. The variables are calculated as the percentage of the population/employed people aged 25-64 who attained a "higher-education qualification" (ISCED76 = Levels 5-7).
Education population	Percentage of population with higher education (ISCED76 levels 5-7)	

Agricultural labour force	Agricultural employment in percent of total employment	
Long-term unemployment	Long-term unemployed in percent of all unemployed	
Young people	People aged 15-24 in percent of total population	
Social Filter Index	The index combines, by means of Principal Component Analysis, the variables describing the socio-economic conditions of the region (listed above).	
Territorial structure of the local economy		
Total GDP	Total regional GDP, absolute level	
Migration rate	Regional net rate of migration	Migration data are provided by Eurostat in the "Migration Statistics" collection. However data for Spain and Greece are not provided at all. Consequently, in order to obtain a measure consistently calculated across the various countries included in the analysis we calculate this variable from demographic statistics. "Data on net migration can be retrieved as the population change plus deaths minus births. The net migration data retrieved in this way also includes external migration" (Puhani 1999, p. 9). The net migration is standardised by the average population thus obtaining the net migration rate.
External factors (Spillovers)		
Extra-regional infrastructure endowment	Spatially weighted average of neighbouring regions' infrastructure endowment (km of motorways per 1000 inhabitants, million EUR of GDP or square-kilometre)	
Extra-regional infrastructure investment	Spatially weighted average of neighbouring regions' annual change in infrastructure endowment (Δ km of motorways per 1000 inhabitants, million EUR of GDP or square-kilometre)	
Extra-regional innovation	Spatially weighted average of neighbouring regions' R&D expenditure	

Note: * Definition of 'Motorway' (Eurostat Regio Guide Book 2006): Road, specially designed and built for motor traffic, which does not serve properties bordering on it, and which: is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other, either by a dividing strip intended for traffic, or exceptionally by other means; does not cross at level with any road, railway or tramway track, or footpath; is specially sign-posted as a motorway and is reserved for specific categories of road motor vehicles. Entry and exit lanes of motorways are included irrespectively of the location of the sign-posts. Urban motorways are always included.

Annex 2. Results of the Principal Component Analysis

Table A2. Principal Component Analysis: Eigenanalysis of the correlation matrix

Component	Eigenvalue	Difference	Proportion	Cumulative
EU-15				
Comp1	2.2744	1.3068	0.5686	0.5686
Comp2	0.9676	0.2334	0.2419	0.8105
Comp3	0.7342	0.7104	0.1836	0.9941
Comp4	0.0238	.	0.0059	1
EU 25				
Comp1	2.3032	1.3384	0.5758	0.5758
Comp2	0.9648	0.2502	0.2412	0.8170
Comp3	0.7146	0.6972	0.1786	0.9957
Comp4	0.0174	.	0.0043	1

Table A3. Principal Component Analysis: Principal Components' coefficients

Variable	PC1	PC2	PC3	PC4
EU-15				
Agricultural Labour Force	-0.3942	0.3369	0.8550	0.0098
Long Term Unemployment	-0.2551	0.8510	-0.4537	0.0698
Education Population	0.6320	0.2330	0.1914	0.7139
Education Employed People	0.6165	0.3288	0.1627	-0.6967
EU-25				
Agricultural Labour Force	-0.4009	0.3471	0.8478	0.0046
Long Term Unemployment	-0.2662	0.8389	-0.4697	0.0686
Education Population	0.6271	0.2478	0.1912	0.7133
Education Employed People	0.6125	0.3381	0.1549	-0.6975

Annex 3. Results of unit root tests

Table A4a. Unit root tests for EU-15

Variable	IPS	IPS-trend	ADF	ADF-trend	Phillips-Perron	Phillips-Perron Trend
Regional GDP per capita (annual growth rate)	-17.683***	-12.595***	888.473***	782.099***	1089.491***	807.405***
Km of motorways per 1000 inhabitants	13.291	-1.237*	416.324***	623.802***	377.252***	438.065***
Change in km of motorways per 1000 inhabitants	-15.674***	-14.025***	1145.003***	1054.442***	1697.867***	1454.49***
Spatial weighted average of km of motorways/1000 inhab.	16.138	4.132	206.563	249.137	299.115***	447.128***
Spatial weighted average Change in km motorways	-9.474***	-8.494***	714.773***	733.721***	1547.743***	1323.908***
Log of GDP per capita	-4.081***	-9.101***	38.722	925.186***	50.357	263.707*
Total intraregional R&D expenditure in percent of GDP	-11.139***	-4.071***	260.287*	359.048***	187.576	293.751***
Spatial weighted average of total R&D expenditure	-18.341***	-8.39***	263.937*	379.222***	198.743	272.432***
Social Filter Index	7.123	-3.898***	144.34	311.765***	115.158	328.813***
Ratio of employed people with completed higher education	5.506	-0.727	96.514	286.352***	115.94	362.169***
Log of total Gross Value Added (levels)	-2.716***	-8.662***	29.039	897.83***	65.681	266.386*
Migration rate	-2.606***	1.042	448.617***	258.53*	392.791***	269.98*
Annual national growth rate	-7.393***	-4.715***	519.446***	385.279***	734.582***	522.976*

Notes: * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level; IPS – Im-Pesaran-Shin test for unit roots; the W[t-bar] test statistic is standard-normally distributed under the null hypothesis of non-stationarity; ADF – Augmented Dickey-Fuller Test; combines N independent unit root tests under the null hypothesis of non-stationarity of all series; Phillips-Perron - Combines N independent unit root tests under the null hypothesis of non-stationarity of all series.

Table A4b. Unit root tests for EU-25

Variable	IPS	IPS-trend	ADF	ADF-trend	Phillips-Perron	Phillips-Perron-Trend
Regional GDP per capita (annual growth rate)	-10.192***	-6.75***	749.3579***	832.0173***	1429.499***	1138.108***
Km of motorways per 1000 inhabitants	10.319	-4.524V	1043.642***	1032.489***	676.3293***	440.2294***
Change in km of motorways per 1000 inhabitants	-15.594	-10.331***	859.8299***	913.1505***	1385.309***	1062.309***
Spatial weighted average of km of motorways/1000 inhab.	0.9	-2.842***	550.951***	845.0921***	699.6489***	608.3887***
Spatial weighted average Change in km motorways	-10.863***	-9.132***	975.392***	887.1509***	1372.871***	1157.184***
Log of GDP per capita	-2.505***	-4.561***	491.6397***	714.3495***	355.1378*	293.5088
Total intraregional R&D expenditure in percent of GDP	-0.995	-0.131	552.1283***	648.7965***	809.5998	532.2063***
Spatial weighted average of total R&D expenditure	-2.667***	1.037	615.6541***	677.3552***	1262.95	771.9879***
Social Filter Index	3.395	-2.854***	271.1387	520.4754***	228.2082	458.8831***
Ratio of employed people with completed higher education	0.999	-3.196***	274.5315	462.6828***	338.92	549.1543***
Log of total Gross Value Added (levels)	-5.3***	-5.143***	455.2618***	780.0859***	349.1037	330.5161
Migration rate	-0.781	1.772	474.7355***	460.9955***	497.2357***	394.0539
Annual national growth rate	-10.666	-3.76	470.7466	1143.498	951.6454	688.7744

Notes: See Table A4a.

Annex 4. Regression results with different proxies for transport infrastructure (EU-15 only): Km of motorways per square-km and km of motorways per million Euro of GDP

The structure of the tables in this annex exactly matches that of Tables 1a, 2a and 3a in the main text, including the numbering of the regressions.

Table A5. EU-15: Regional growth and transport infrastructure, 1990-2004

Regression number	(7)	(8)		(7)	(8)
Dependent variable: Regional GDP per capita (annual growth rate)					
Km of motorways					
per square kilometre of land area	0.494***	0.474***	*per million euro of GDP*	0.184	0.195
	(0.099)	*(0.098)*		*(0.179)*	*(0.175)*
Log of GDP per capita	-0.137***	-0.206***		-0.130***	-0.224***
	(0.013)	*(0.034)*		*(0.013)*	*(0.035)*
Annual national growth rate	0.004***	0.004***		0.004***	0.004***
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Change in km of motorways					
per square kilometre of land area	-0.130	-0.144	*per million euro of GDP*	-0.338	-0.373
	(0.218)	*(0.218)*		*(0.285)*	*(0.289)*
Spatial weighted average of km of motorways					
per square kilometre of land area	0.686***	0.612***	*per million euro of GDP*	1.380***	1.462***
	(0.132)	*(0.133)*		*(0.222)*	*(0.230)*
Spatial weighted average Change km of motorways					
per square kilometre of land area	-0.588	-0.563	*per million euro of GDP*	-0.879*	-0.892*
	(0.361)	*(0.360)*		*(0.485)*	*(0.491)*
Total intraregional R&D expenditure in percent of GDP	0.001***	0.001***		0.001***	0.001***
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Spatial weighted average of total R&D expenditure	-0.000	-0.000		0.001	0.001
	(0.000)	*(0.000)*		*(0.001)*	*(0.001)*
Ratio of employed people with higher education in percent	0.002***	0.002***		0.002***	0.002***
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Log of total GDP (levels)		0.070**			0.090***
		(0.029)			*(0.028)*
Migration Rate		-0.000**			-0.001***
		(0.000)			*(0.000)*
Social Filter Index					
Constant	1.249***	1.212***		1.202***	1.193***
	(0.122)	*(0.123)*		*(0.118)*	*(0.119)*
Observations	1560	1560		1560	1560
Number of group (NUTS)	120	120		120	120
R-squared	0.22	0.23		0.22	0.23
R-squared within	0.22	0.23		0.22	0.23
R-squared overall	0.03	0.00		0.05	0.01
R-squared between	0.08	0.01		0.19	0.01

Notes: Robust standard errors in parentheses, * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table A6. EU-15: Regional growth and transport infrastructure with annual lags, 1990-2004

Regression number	(1)	(4)		(1)	(4)
Dependent variable: Regional GDP per capita (annual growth rate)					
Number of annual Lags in all variables	2	5		2	5
Km of motorways					
per square kilometre of land area	0.417***	0.101	*per million euro of GDP*	0.308	0.542***
	(0.112)	*(0.171)*		*(0.201)*	*(0.148)*
Change in km of motorways					
per square kilometre of land area	-0.148	-0.034	*per million euro of GDP*	-0.025	0.049
	(0.210)	*(0.300)*		*(0.249)*	*(0.287)*
Spatial weighted average of km of motorways					
per square kilometre of land area	0.720***	0.162	*per million euro of GDP*	1.430***	0.354*
	(0.158)	*(0.194)*		*(0.271)*	*(0.214)*
Spatial weighted average of Change in km of motorways					
per square kilometre of land area	-1.260***	0.081	*per million euro of GDP*	-0.804*	-0.197
	(0.371)	*(0.402)*		*(0.443)*	*(0.400)*
Log of GDP per capita	-0.249***	-0.051		-0.260***	-0.056
	(0.044)	*(0.051)*		*(0.045)*	*(0.050)*
Total intraregional R&D expenditure in percent of GDP	0.000	0.000		0.001**	0.001***
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Spatial weighted average of total R&D expenditure	-0.001***	0.001***		-0.000	0.002***
	(0.000)	*(0.000)*		*(0.001)*	*(0.000)*
Ratio of employed people with higher education in percent	0.002***	0.000**		0.002***	0.000
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Log of total GDP (levels)	0.094**	-0.025		0.108***	-0.020
	(0.036)	*(0.046)*		*(0.037)*	*(0.045)*
Migration rate	-0.000	0.000		-0.000**	0.000
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Annual national growth rate	0.001***	-0.001***		0.001***	-0.001***
	(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
Constant	1.384***	0.740***		1.371***	0.743***
	(0.139)	*(0.136)*		*(0.133)*	*(0.131)*
Observations	1440	1080		1440	1080
Number of groups (NUTS regions)	120	120		120	120
R-squared	0.14	0.12		0.15	0.13
R-squared within	0.14	0.12		0.15	0.13
R-squared overall	0.00	0.03		0.00	0.04
R-squared between	0.00	0.09		0.01	0.12

Notes: Robust standard errors in parentheses, * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

Table A7. EU-15: Regional growth and the impact transport infrastructure over time, 1990-2004

Dependent variable: Regional GDP per capita (annual growth rate)					
Annual Lags (Infrastructure) / Regression number	2	5		2	5
Km of motorways					
per square kilometre of land area	0.398***	0.275**	per million euro of GDP	0.220	0.754***
	(0.108)	(0.131)		(0.215)	(0.291)
Change in km of motorways					
per square kilometre of land area	-0.091	-0.276	per million euro of GDP	-0.365	-0.965***
	(0.204)	(0.203)		(0.299)	(0.309)
Spatial weighted average of km of motorways					
per square kilometre of land area	0.686***	0.669***	per million euro of GDP	1.333***	0.560**
	(0.153)	(0.232)		(0.267)	(0.281)
Spatial weighted average of Change in km of motorways					
per square kilometre of land area	-0.638*	-0.832**	per million euro of GDP	-0.948*	-0.223
	(0.369)	(0.391)		(0.534)	(0.506)
Log of GDP per capita	-0.192***	-0.050		-0.205***	-0.061
	(0.040)	(0.051)		(0.041)	(0.051)
Total intraregional R&D expenditure in percent of GDP	0.001*	0.003***		0.001**	0.004**
	(0.000)	(0.001)		(0.000)	(0.002)
Spatial weighted average of total R&D expenditure	-0.001*	0.002*		0.001	0.003**
	(0.001)	(0.001)		(0.001)	(0.001)
Ratio of employed people with higher education in percent	0.002***	0.001***		0.002***	0.001***
	(0.000)	(0.000)		(0.000)	(0.000)
Log of total GDP (levels)	0.056*	-0.075		0.072**	-0.067
	(0.034)	(0.046)		(0.034)	(0.045)
Migration rate	-0.000	-0.000		-0.000**	-0.000
	(0.000)	(0.000)		(0.000)	(0.000)
Annual national growth rate	0.004***	0.002***		0.004***	0.002***
	(0.000)	(0.000)		(0.000)	(0.000)
Lag 2 Change in km of motorways					
per square kilometre of land area	-0.011	-0.200	per million euro of GDP	0.067	-0.496**
	(0.175)	(0.232)		(0.246)	(0.248)
Lag 2 Spatial weighted average Change in km motorways					
per square kilometre of land area	-1.113***	-0.911***	per million euro of GDP	-0.709*	-1.000*
	(0.355)	(0.333)		(0.429)	(0.516)
Lag 3 Change in km of motorways					
per square kilometre of land area		-0.145	per million euro of GDP		-0.734**
		(0.252)			(0.298)
Lag 3 Spatial weighted average Change in km motorways					
per square kilometre of land area		-0.151	per million euro of GDP		-0.475
		(0.384)			(0.504)
Lag 4 Change in km of motorways					
per square kilometre of land area		-0.612***	per million euro of GDP		-0.584**
		(0.206)			(0.253)
Lag 4 Spatial weighted average Change km of motorways					
per square kilometre of land area		-0.735*	per million euro of GDP		-1.530***
		(0.398)			(0.451)
Lag 5 Change in km of motorways					
per square kilometre of land area		-0.221	per million euro of GDP		-0.142
		(0.243)			(0.276)
Lag 5 Spatial weighted average Change km of motorways					
per square kilometre of land area		-0.508	per million euro of GDP		-0.511
		(0.422)			(0.388)
Constant	1.226***	1.205***		1.205***	1.247***
	(0.132)	(0.148)		(0.129)	(0.144)
Observations	1440	1080		1440	1080
Number of groups (NUTS regions)	120	120		120	120
R-squared	0.20	0.20		0.20	0.22
R-squared within	0.20	0.20		0.20	0.22
R-squared overall	0.00	0.01		0.01	0.03
R-squared between	0.01	0.04		0.02	0.08

Notes: Robust standard errors in parentheses, * significant at 10-percent level; ** significant at 5-percent level; *** significant at 1-percent level.

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