DISCUSSION PAPER SERIES

No. 8882

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INTERNATIONAL TRADE AND REGIONAL ECONOMICS

Centre for Economic Policy Research

www.cepr.org

Available online at: www.cepr.org/pubs/dps/DP8882.asp

ISSN 0265-8003

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Discussion Paper No. 8882
March 2012

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CEPR Discussion Paper No. 8882

March 2012

ABSTRACT

Infrastructure and regional growth in the European Union*

Transport infrastructure has represented one of the cornerstones of development and cohesion strategies in the European Union (EU) and elsewhere in the world. However, despite the considerable funds devoted to it, its impact remains controversial. This paper revisits the question of to what extent transport infrastructure endowment—proxied by regional motorways—has contributed to regional growth in the EU between 1990 and 2004. It analyses infrastructure in relationship to other factors which may condition economic growth, such as innovation, migration, and the local 'social filter', taking also into account the geographical component of intervention in transport infrastructure and innovation. The results of the two-way fixed-effect (static) and GMM-diff (dynamic) panel data regressions indicate that infrastructure endowment is a relatively poor predictor of economic growth and that regional growth in the EU results from a combination of an adequate 'social filter', good innovation capacity, both in the region and in neighbouring areas, and a region's capacity to attract migrants. The meagre returns of infrastructure endowment on economic growth raises interesting questions about the opportunity costs of further infrastructure investments across most of Western Europe.

JEL Classification: R11, R12, R42 and R58
Keywords: economic growth, European Union, infrastructure, innovation, regions and spillovers

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* The authors are grateful to the editors of the special issue and to the anonymous referees for their stimulating suggestions to an earlier version of this paper. The financial support of the European Research Council under the European Union's Seventh Framework Programme (FP7/2007- 2013)/ERC grant agreement nº 269868 and of a Leverhulme Trust Major Research Fellowship. The research is also part of the Prociudad-CM programme and of the UK Spatial Economics Research Centre. The usual disclaimer applies.

Submitted 20 February 2012

1. Introduction: transport infrastructure as a key element of development policies

The European Union (EU), as other areas of the world, has placed huge emphasis on infrastructure investment, in general, and, especially, on transport infrastructure as a means to bring about territorial cohesion, reduce economic disparities, and promote economic development. Transport infrastructure has been for a long time – and to a large extent remains – the cornerstone of its regional development policy. For the 2007-2013 programming period, over 28 percent of EU Regional Development Funds (ERDF) and of the Cohesion Fund are being devoted to infrastructural investments (European Commission, 2008). The weight of infrastructure in EU development budgets reflects a widespread belief in the power of transport infrastructure as one of the key – if not the key – mechanisms in order to achieve economic development and convergence.

The European transport infrastructure effort has taken many forms and guises. Most of it can be considered as part of the European Spatial Development Perspective, which constitutes a non-binding framework to reorganize, coordinate and simplify territorial development policies across the EU. This framework stresses the need for transport and communications strategies in order to reduce accessibility gaps between places (Mirwaldt, McMaster and Bachtler, 2005). Specific transport infrastructure intervention takes different forms. It varies from the more concrete infrastructure construction within each region through the ERDF to the creation of trans-European networks (TENs). The TENs are large pan-European transport infrastructure projects aimed at:

> "…the smooth functioning of the internal market and the strengthening of economic and social cohesion…ensuring the sustainable mobility of persons and goods under the best possible social, environmental and safety conditions and integrating all modes of transport, taking account of their comparative advantages". (European Commission, 2007: 3).

Of the 76 billion Euros allocated to transport in the ERDF budget for 2007-2013, 38 billion correspond to TENs projects (European Commission, 2008). The roads, high speed rail lines, freight shipping ports, and airports financed through TENs schemes are expected to bring about major EU-wide transformations, not only by removing bottlenecks and breaks in the EU transport system, but also in terms of improving regional GDP per capita, promoting employment, facilitating mobility, and enhancing accessibility, as reflected in the assessment criteria for these policy measures (ESPON, 2003).

The firm belief in the returns of transport infrastructure investment is not exclusive to the EU. On the other side of the Atlantic the faith in the growth-enhancing capabilities of transport infrastructure investment are equally high. At the height of the economic downturn, President Obama announced a 6-year plan to expand US infrastructure including the foundation of a National Infrastructure Bank with an initial endowment of $50 billion and six years of reauthorization potential. This plan is expected to "rebuild 150,000 miles of roads, construct and maintain 4,000 miles of passenger rail, rehabilitate and reconstruct 150 miles of runways…" among other projects (U.S.White House, 2010: 4). The report announcing this programme cites 'long-term economic benefits', benefits to the middle-classes (including jobs that support infrastructure investment and reduced transportation costs), the implementation of under-utilized resources, and satisfying a strong public demand for more and improved transport infrastructure as its rationale. Additionally, recent press releases from the Department of Transport described high-speed rail as having the ability to allow American workers to "out-build, out-innovate, and out-compete the rest of the world" (U.S.Department of Transportation, 2011).

International organisations, such as the World Bank, also share the enthusiasm for transport infrastructure. Around 20 percent of World Bank lending has, in recent years, been devoted to transportation infrastructure projects. This represents a larger share than that of the resources allocated to health, education and social services combined (World Bank, 2007). Moreover, the World Bank Report 2009 has suggested that the first step in any development strategy is to implement spatially-blind policies that ensure the supporting infrastructure is in place for local strategic investments to be successful. Therefore, in order to facilitate economic growth between lagging and leading regions, the focus should first be on investing in the infrastructure that facilitates the movement of people, goods and information across space. People seek opportunities, and providing the spatial connectivity for them to do so increases accessibility to places where their skills can be put to productive use (World Bank, 2008).

However, whether a good endowment of transport infrastructure delivers greater economic development and promotes territorial cohesion remains controversial. Theoretical and empirical analyses of the returns of transport infrastructure point in different directions, making it difficult to extract any firm conclusions about the impact of transport infrastructure investment. In this paper, and given the importance that transport infrastructure has acquired over the years in the European regional development effort, we revisit the question by looking at the returns of transport infrastructure endowment – proxied by kilometres of motorways – across 120 regions in the EU during the period 1990-2004. The main novelty of our approach lies in confronting regional transport infrastructure endowment with other factors, such as innovation, migration and the local socio-economic conditions, which also may play a crucial role both in determining regional economic growth and in the make-up of development and cohesion policies. We also take into account the geographical component of intervention in transport infrastructure and innovation, by allowing for territorial spillovers in both dimensions. Finally, we conduct the analysis using both two-way fixed-effect (static) and GMM-diff (dynamic) panel data regression estimation methods. The former method allows to simultaneously control for all time invariant unobservable characteristics of the regions (e.g. institutional pre-conditions and geographical factors) and all common time trends (e.g. general evolution of EU-level economic conditions and/or policies). The latter method makes it possible to explicitly account for the dynamic nature of the genesis of economic growth, by introducing past levels of GDP per capita as predictors of current performance, as well as for the potential endogeneity of the relationship between infrastructure and economic dynamism.

The results of the analysis highlight that, in the case of the regions of the EU, there is little evidence of an impact of the transport infrastructure endowment of any given region or of its neighbouring regions on economic growth. Once innovation, social conditions, and migration are taken into account, the coefficients for transport infrastructure endowment become insignificant, while, by contrast, local R&D capacity, local social conditions, and migration are much better predictors of economic performance.

In order to get to these results, the paper is structured along the following lines. The next section looks at how transport infrastructure is expected to affect regional economic development from a theoretical perspective. In this section, the economic mechanisms underlying the link between transport infrastructure and economic performance are directly contrasted with other 'conditioning' endogenous and exogenous factors which are deemed to affect regional economic development in Europe. Section 3 introduces the model for the empirical analysis, while section 4 – after discussing some estimation issues, the data availability and the units of analysis – presents the empirical results. The conclusions and some policy implications are included in Section 5.

2. Transport infrastructure and regional economic development

2.1 Transport infrastructure and regional economic development from a theoretical perspective

The belief that transport infrastructure plays a capital role for development and cohesion is not confined to policy circles. In many ways, it stems from economic theory. Public capital, in general, and infrastructure, in particular, have traditionally been regarded as "'unpaid factor(s) of production' which directly encourage increased output; 'augmenting factors' which enhance the general productivity of private capital and labour inputs; and in a more dynamic sense incentives for firm and household (re)location and long term economic growth" (Lewis, 1998: 142). Transport infrastructure is also deemed to generate significant multiplier effects in investment flows. In addition, infrastructure is considered to trigger 'amenity value', which contributes to enhance personal welfare and generate environmental externalities (Kessides, 1993). Transport infrastructure projects can also bring about considerable political and managerial benefits, as they provide highly-visible and tangible forms of public spending which are easy to manage and please constituents. Altogether, it can be stated that politicians and planners have important incentives to invest in transport infrastructure.

Many theoretical contributions have underlined the potential economic returns of transport infrastructure investment. Aschauer's (1989) seminal paper on infrastructure stocks and productivity spawned a new focus within economic development policy and research on the ability of infrastructure to bring about high returns for economic growth. In Aschauer's (1989) view, differences in the stock of public infrastructure are at the root of differences in productivity, national output and, ultimately, levels of development. Countries with higher stocks of public infrastructure have, therefore, higher private sector activity. Consequently, improvements in infrastructure endowment have a direct impact on productivity, as well as on labour costs (Biehl, 1991). This results in a relationship between labour costs and productivity which determines the competitive position of any territory. In those cases where productivity exceeds labour costs, regions will enjoy considerable economic dynamism, attracting greater flows of capital and migrants. Hence, when productivity exceeds labour costs, investments in transport infrastructure would lead to increases in regional economic output which exceed its potential GDP. A number of subsequent analyses applying Aschauer's approach have come to support the view of important returns of transport infrastructure investment (Holtz-Eakin 1993; Glomm and Ravi-Kumar 1994).

The supposedly high returns of transport infrastructure endowment and investment are corroborated by classical location theory. This perspective has tended to underline that greater accessibility and lower transportation costs facilitates trade and leads to a reduction in the prize of traded goods, by allowing different territories to maximise their comparative advantage. New transportation systems reduce general transport costs and extend the maximum trade and shipping distance for firms (Pol, 2003). The former effect increases the profitability of firms by reducing costs (Seitz and Licht, 1995), while the latter raises revenues by expanding new markets. In addition, improvements in trade lead to an equalization of factor prices between places. All these mechanisms contribute to raise the market potential of different locations and to an increase in regional wages (Niebuhr 2006).

Given these theoretical views, it is therefore not surprising that policy-makers in Europe and elsewhere have considerable faith on transport infrastructure as the dominant development type of intervention, in order to deliver both greater efficiency and greater territorial equity.

However, this optimistic view of the returns of public infrastructure investment has come under increasing criticism on both theoretical and empirical grounds. First, doubts have been cast on the direction of causality of Aschauer's regressions (Gramlich, 1994). Second, the resort to different concepts of infrastructure may have affected the consistency of results. There are strong contrasts between the results of Aschauer-type empirical models and models which try to determine the stock of capital endogenously. Vanhoudt et al. (2000: 102), for example, not only find that "causality does not run from public investment to growth, but rather the opposite way". They also hint at the fact that public investment "can hardly be considered as an engine for long-run structural growth" (Vanhoudt et al., 2000: 102).

Second, Aschauer-style analyses soon started to 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) and, at the same time, with an increasing body of evidence which suggested that trade between regions and nations could bring about convergence or divergence at different levels. De la Fuente (2004) brings the example of inter-regional infrastructure investment in Portugal to the fore; Lisbon's rapid growth – which contributed to a significant rise in national-level wages – took place at the expense of further divergence in income between regions [Pereira and Andraz (2006) reach a similar result). Ahlfeldt and Fedderson (2009) find a positive and significant impact on local economic dynamism of high speed rail in Germany, underlining its ability to bring about easier and wider market access. Similarly, Bronzini and Piselli (2009) demonstrate that a 1 percent increase in public infrastructure leads to a 0.11 percent increase in total factor productivity in Italy and Deliktas et al. (2009) find similar evidence for Turkish regions. However, this stream of research also highlights that these returns are highly localized and do not facilitate an even territorial spread of economic growth. This evidence is in line with the results of broader EU-level studies: while, on the one hand, the EU Regional Development Funds may have contributed to national convergence within the EU as a whole, on the other, infrastructure investments may simultaneously have brought regional convergence to a stand-still (Puga, 2002; Capellen et al., 2003). Studies for the US tend to reach similar results. While the development of highways has raised the level of economic activities in those counties through which they pass, they often have detrimental economic effects on adjacent counties (Chandra and Thompson, 2000; Sloboda and Yao, 2008). The largest states also tend to disproportionally benefit from highway investment, leading to regional concentrations of economic activity (Pereira and Andraz, 2010). Evidence from emerging countries confirms similar trends: "results indicate that transport facilities are a key differentiating factor in explaining the growth gap [between Chinese provinces] and point to the role of telecommunication in reducing the burden of isolation" (Démurger 2001: 95)

The key message from this large body of literature is that changes in accessibility induced by infrastructure development often lead to a widening (rather than to a reduction) of regional disparities: by providing central and peripheral regions with a similar degree of accessibility, lagging regions may be at a disadvantage, as their firms – unless other advantages are developed simultaneously – are in a weaker position to compete than firms in the core (Puga, 2002). In these cases, fostering the development of adequate intra-regional transport networks may be a more sensible option than improving inter-regional connectivity in order to reinforce the competitiveness of local firms (Martin and Rogers, 1995; Vickerman, 1995).

The New Economic Geography (NEG) (Krugman, 1991; Fujita et al., 1999; Puga, 2002) has added a new dimension to this apparently contradictory evidence. Where explicitly accounting for increasing returns to scale under monopolistic competition and horizontal differentiation of goods, it becomes apparent that infrastructure investments reduce transaction costs between agents, changing the relative balance between agglomeration and dispersion forces: reduced transportation costs provide less protection from distant competitors, while internal product market competition from other markets increases. The development of transport infrastructure, by increasing the accessibility of 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: 396). By allowing a priori identical regions to endogenously differentiate between an industrialised core and a backward periphery in response to changes in their degree of accessibility, NEG models have formally accounted for the potentially ambiguous effect of changes in the degree of accessibility ('two-way' roads effect). Changes in transport costs modify the balance between agglomeration and dispersion forces, eventually generating new core-periphery patterns that transport infrastructure policies may (or may not) be able to alter.

However, this approach has important limitations represented, in particular, by multiple equilibria and high path-dependency (Martin, 1999; Neary, 2001). This means that how certain places gain their initial advantage in different geographical/historical contexts, as well as the sustainability of existing equilibria, is left unexplained. In addition, the spatial scale upon which policies should set their sights is not clearly defined, thus running the risk of neglecting (in the same way as other approaches have done) the role of geography in influencing growth performance. As a result, the regional policy implications of such an approach are not as robust as they should be for policy-making purposes.

In light of all these considerations, it seems realistic to conclude with Button (1998: 154 and 156) that "the exact importance of infrastructure as an element in economic development has long been disputed (…, as) the body of evidence available is far from conclusive".

2.2. 'Conditioning' the returns of infrastructure: other drivers of growth.

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 economic dynamics (Holl, 2006), which the NEG, as well as other strands of literature, have fundamentally left unexplored or confined to the background (Cheshire and Magrini, 2002; Ottaviano, 2008). The awareness of these other drivers of economic growth has important implications for regional policy, as not only locational, but also educational, innovation, and institutional variables become critical elements in regional intervention decisions. Hence, the consideration of different drivers of regional growth is bound to have important implications for how the impact of transport infrastructure on economic development is perceived (e.g. Fagerberg et al., 1997; Crescenzi et al., 2007; Rodríguez-Pose and Crescenzi, 2008).

Among the factors 'conditioning' the returns of transport infrastructure, innovation and the transfer of technology and technical capabilities is one of the most important (Badinger and Tondl, 2002). Technological catch-up is facilitated by intensive trade relationships and, therefore, spatially connective infrastructure is a necessary condition not only for trade between places, but also for the transfer of technology and knowledge diffusion. R&D investments also generate knowledge spillovers in neighbouring regions that are highly localised within the functional borders of the regional economy (Bronzini and Piselli, 2009; Sonn and Storper, 2008), making transport connectivity a relevant means for knowledge diffusion. As specialized knowledge is usually held by a limited number of people, it is difficult to pass it on without face-to-face interactions and collaborations (Storper and Venables, 2004) and transport infrastructure facilitates the spread of knowledge between people and firms within a defined area.

However, the line of causality from infrastructure, to trade, to R&D investment and innovation should not be taken for granted. Bilbao-Osorio and Rodríguez-Pose (2004: 434) find that "R&D investment, as a whole, and higher education R&D investment in peripheral regions of the EU, in particular, are positively associated with innovation". However, the strength of this relationship rests on the region-specific capabilities for transforming R&D investment into innovation. Therefore, R&D and innovation policies can play an important role for economic growth and development, but their impact needs to be assessed jointly with that of human capital (Crescenzi, 2005) and other socio-institutional pre-conditions which may shape the economic returns of any investment in transport infrastructure.

The ability of places to convert investment in innovation and knowledge spillovers into increased innovative capacity and economic growth depends on a number of regional socio-economic and institutional conditions (Rodríguez-Pose and Crescenzi, 2008). This is what is known as the 'social filter' of a place, which can be understood as the set of "elements which favour or deter the development of successful regional innovation systems" (Rodríguez-Pose, 1999: 82). The social filter determines the permeability of new ideas and technology to existing knowledge stocks. Places without the appropriate socio-institutional capacity to absorb new ideas and transform them into economically-useful knowledge will thus not reap the benefits from targeted innovation investments and, in most cases, from infrastructure investment. Hence, infrastructure investments aimed at boosting economic growth by supporting agglomeration and connectivity need to be assessed in light of the socio-economic context in which the agglomeration occurs, as some places may lack the adequate social filter conditions to reap the knowledge spillovers and the inter-regional trade benefits that investment in transportation may help produce.

The development of transport infrastructure also has clear implications for the mobility of individuals which, in turn, may lead to greater innovation, knowledge circulation, and economic efficiency. However, the presence of an adequate infrastructural endowment is only a necessary condition for mobility to take place, but its ability to promote mobility will rest on a combination of local socio-cultural characteristics, as well as on the perceived frictions related to job-seeking in a new place. On the one hand, while the transportation costs of goods are now almost negligible, the costs of transporting people remain substantially higher (Glaeser and Kolhase, 2004). On the other, people are tied to places to differing degrees, due to family, cultural, and social constraints which generate potential inefficiencies and distortions both in the job-matching (Vandamme, 2000) and in the knowledge-matching processes (Puhani, 2001) This is for example reflected in the large inter- and intra-regional differences in the propensity to migrate between the US and the EU, with the US being more highly mobile, with generally lower unemployment rates (Puga, 2002; Zimmerman, 2005) and a better innovative performance (Dosi et al., 2006).

Consequently, levels of innovative efforts, local social filter and institutional characteristics, and differing degrees of labour mobility condition the capability of transport infrastructure to bring about economic benefits and to determine which places will take advantage from greater connectivity – potentially at the expense of others. These interactions also raise questions about the opportunity cost of further infrastructure investment versus focusing on people- and innovation-based strategies. The economic returns of transport infrastructure projects will thus be 'conditioned' by the social, economic, and institutional features of the areas where the investment takes place – as well as by those of their neighbours – and these factors need to be assessed in order to understand the context in which lower transport costs affect the economic performance of specific places.

3. The model

The empirical analysis aims at integrating the role of infrastructure in shaping regional economic growth in Europe into a model that takes into consideration not just transport infrastructure endowment and investment, but also other endogenous and external conditioning factors.

In accordance with the framework developed in the previous section, the choice of empirical variables to be included in the model is determined according to the following matrix (Table 1):

Table 1. Endogenous and exogenous factors 'conditioning' the economic returns of infrastructure.

	Internal Regional Factors	**External Factors (Spillovers)**
Infrastructure endowment and investment	Kilometres (Kms) 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 in previous year	
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	
National effects	National growth rate	

By developing the framework above, and following Blundell and Bond (2000) and Bond et al. (2001), we obtain the standard equation for regional GDP per capita specified in levels with a lagged dependent variable:

$$\ln y_{i,t} = \beta \ln y_{i,t-1} + \delta Inf_{i,t} + \zeta x_{i,t} + \vartheta SpillInf_{i,t} + \kappa Spillx_{i,t} + \lambda Nay_{i,t} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (1)$$

From model (1) the following empirical model for regional growth rates can be derived:

$$\gamma_{it} = \ln y_{i,t} - \ln y_{i,t-1} = (\beta - 1)\ln y_{i,t-1} + \delta Inf_{i,t} + \zeta x_{i,t} + \vartheta SpillInf_{i,t} + \kappa Spillx_{i,t} + \lambda Nay_{i,t} + \mu_i + \tau_t + \varepsilon_{i,t}$$
(2)

where:

γ is the regional GDP growth rate (as customary, approximated by the log difference in regional GDP per capita);
ln y is the Natural Logarithm of the level of regional GDP per capita;
Inf denotes infrastructure endowment;
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 greater detail, the variables included in the model are as follows:

Growth rate/Level 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. The level of GDP per capita is introduced in the model in order to account for the dynamic evolution of a region's economic performance. The significance and magnitude of the coefficient associated with the lagged dependent variable allows us, on the one hand, to test the existence of a process of convergence in regional per capita income and measure its speed and, on the other, to explicitly control for the evolution over time of regional economic wealth, making it possible to correctly identify the effect of infrastructural development.

Transport infrastructure: The impact of transport infrastructure on regional economic performance is captured by means of a set of alternative proxies that differ in terms of their standardisation. Regional kilometres (Kms) of motorways (Canning and Pedroni, 2004) standardised by regional population is used in order to account for the different size of regions; the standardisations by 'total regional surface' and 'total regional GDP' are instead used to purge for potential biases linked to the different geographical and economic size of the EU regions (see Appendix A for the detailed definition of these variable). As there is no agreement (or 'common best practice') in the empirical literature on the most appropriate standardisation procedure for infrastructural indicators, the empirical model will be re-estimated for alternative proxies, confirming that results are not qualitatively different across specifications.

While these proxies are customary in the literature about the economic impact of infrastructure, they are not without problems. In addition to the standardisation problems discussed above, the Kms of motorways say little about the different quality and condition of the roads (e.g. number of lanes, level of congestion, etc.) and do not reflect differences in construction and maintenance cost. Hence, it would have been ideal to resort to additional, more sophisticated indicators of transport infrastructure. However, there are substantial data availability constraints for regions in the EU-15 which prevent us from resorting to alternative proxies. As a consequence it should be borne in mind that the length of motorways (and change thereof, when the model is specified in differences) captures and quantifies the direct impact of (changing) regional accessibility in a homogeneous fashion across regions and countries, irrespective of the inevitably disparate efforts and expenditure levels necessary in order to achieve the same transport infrastructure endowment in different geographical and institutional contexts. Moreover, when compared to other modes of transport (e.g. railways), motorways are particularly suitable for the purposes of this paper for two reasons. First, they exert a more direct and stronger impact on the (re)location of economic activity (Button, 2001; Puga, 2002), due to their intensive use in the shipment of intermediate and final goods. Second, they have benefitted from EU policy support for a long enough time span as to allow a meaningful policy assessment.[1] More generally, Kms of motorways is only an approximation to the real improvement in total regional accessibility produced by new investments that – as discussed above – is highly contingent on a correct diagnosis of the relevant infrastructural bottlenecks, on the quality of the infrastructure actually built, and on its integration with other modes of transport. The estimation strategy implemented in this paper will try to minimise these contingencies.

As extensively discussed in the conceptual section of the paper, the impact of transport infrastructure can only be assessed within a fully specified model of regional economic growth, including proxies for other relevant drivers of regional economic performance as independent variables including:

R&D expenditure: From an endogenous growth perspective, the generation of new knowledge and ideas is regarded as a key driver for the long-term growth of productivity and income. But new knowledge is not the only innovation-related source of economic growth. The absorption and adaptation of existing external knowledge to the needs of the local firms has also been identified by the literature as a basic requirement for economic dynamism (Cohen and Levinthal, 1990; Maurseth and Verspagen, 1999). In the empirical literature, both innovative and absorptive capabilities tend to be jointly proxied by means of R&D intensity (the 'percentage of regional GDP devoted to R&D activities' in our model). However, as with other proxies, this indicator has a number of limitations that should be explicitly acknowledged and taken into account for the interpretation of our results. R&D activities may exert their influence in a very heterogeneous fashion – in terms of both magnitude and timing – across industrial sectors and technology fields: large investments in radically new fields (e.g. biotech) may become profitable after a long time lag or not pay off at all. Conversely, incremental (product or process) innovation, not always necessarily linked to formal R&D, may produce substantial short-term economic returns. All these sources of heterogeneity – in terms of both the relevant lag structure of their economic impact and the operational difficulties in capturing their different forms – significantly constrain our capability to assess the impact of innovative efforts on economic growth (Griliches, 1979). As a consequence, this paper assumes 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: 6) in order to capture the existence of a system of incentives (in the public and the private sector) towards intentional innovative activities.

Socio-Economic Conditions: The capability of both transport infrastructure and R&D efforts (as well as of their mutual interaction in terms of knowledge and skills circulation) to impact on any local economy is heavily influenced by the regional socio-economic environment. Although quantitative analyses are bound to be unable to account for these contextual conditions in full, the literature on regional innovation and growth has shown that a composite index (the 'social filter' index) based on the combination of a set of proxies depicting the socio-economic dynamism of the regions can provide a reliable quantitative account for the structural pre-conditions conducive to a favourable response to change, regardless of whether change is the result of either variations in accessibility, due to investment in new transport infrastructure, of new innovations, or both. The reaction capabilities of a region can be proxied by variables related to two main domains: educational achievements (Lundvall, 1992; Malecki, 1997) and the productive employment of human resources (Fagerberg *et al.,* 1997; Rodríguez-Pose, 1999). From the former domain – always taking into account regional data constrains – we use the share of the population with completed tertiary education, both relative to the labour force and to the overall population (human capital

[1] The emphasis of TENs on high speed trains is, by contrast, relatively more recent.

accumulation in the labour force and in the population respectively). From the latter domain, the percentage of the labour force employed in agriculture and the percentage of long-term unemployment are used in the empirical model. Employment in agriculture captures the traditionally low productivity of agricultural jobs due to the limited capital accumulation and the 'hidden unemployment' in many rural areas (Caselli and Coleman, 2001). The long-term component of unemployment represents a proxy of the degree of rigidity of local labour-markets and of the potential stratification of inadequate skills (Gordon, 2001).

Principal component analysis (PCA) is used in order to avoid problems of multicollinearity which would limit the possibility of including all these variables simultaneously in our model. PCA merges all these variables into a single indicator, preserving as much as possible of the variability of the original indicators (Table B-1 in Appendix B). The first principal component alone is able to account for around 57 percent of the total variance and its coefficients (listed under PC1 in Table B-2 in Appendix B) are used for the computation of our 'social filter' index. All variables enter the composite index with the expected sign: educational achievement – which also displays the greatest relative weight – has a positive sign, while long-term unemployment and the share of agricultural labour, by contrast, enter the 'social filter' index with a negative sign.

The conceptual analysis of the drivers of regional growth developed in the previous section has suggested that both endogenous and external factors shape local economic dynamism. As a consequence, our model includes a set of proxies for the potential spillovers from neighbouring regions accruing to any given region and which may affect its economic performance. The spillover variables are:

Extra-Regional Infrastructure: The economic performance of any territory is not only directly related to the relative density of infrastructure within its borders, but also to the endowment of infrastructure in neighbouring regions (Laird et al., 2005). In particular, if transport infrastructure is not to be reduced to mere components of the 'aggregate' neo-classical production function, the potential for networking and connectivity among individuals and firms should be fully accounted among the drivers of regional growth (Pereira and Roca-Sagalés, 2003). Hence, the endowment of transport infrastructure in neighbouring regions is introduced in the model as a proxy for the degree of inter-regional connectivity (Deliktas et al., 2009). Where a good endowment in neighbouring regions reinforces the internal provision of infrastructure, 'optimal' conditions should be in place, preventing the emergence of bottlenecks and inefficiencies which may otherwise negatively affect the accessibility of the region.

The average of infrastructure intensity in neighbouring regions is computed in order to proxy extra-regional infrastructure endowment ($SpillInf_i$) and is calculated as:

$$SpillInf_i = \sum_{j=1}^{n} Inf_j w_{ij} \qquad (3)$$

Where Inf_j is a proxy for the infrastructure endowment of the j-th region and w_{ij} is a generic 'spatial' weight. The *k nearest neighbours* (with k=4)[2] are considered in order to minimize both the

[2] Other definitions of the spatial weights matrix could have been considered. Two potential alternatives are distance weights matrices (using the inverse of the distances) and other binary matrices (rook and queen contiguity matrices). However, the k-nearest-neighbours weighting scheme can be considered as the most adequate in order to capture neighbourhood effects, while, at the same time, reducing the potential endogeneity problem linked to the higher density of infrastructure in core regions. The choice of k-4 neighbours is, admittedly, arbitrary. However, the use of different

endogeneity induced by travel-time distance weight and the potential bias due to the different number of neighbours of central and peripheral regions:

$$w_{ij} = \begin{cases} 1/k \text{ if } j \text{ is one of the k nearest neighbours to i} \\ 0 \text{ otherwise} \end{cases} \quad \text{with } i \neq j \tag{4}$$

Extra-Regional Innovation: Following the same line of reasoning (and in agreement with a large body of literature), innovative activities pursued in neighbouring regions can be expected to exert an influence on local economic performance by means of knowledge spillovers. Given that innovative efforts pursued in one region can spill over into another, thereby influencing its economic performance, transport infrastructure may affect the accessibility to extra-regional innovation facilitating/hampering the inter-regional transfer of knowledge. As a consequence, the potential for knowledge transmission should be controlled for in order to assess the impact of infrastructure 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 (3). For each region *i*:

$$SpillR\&D_i = \sum_{j=1}^{n} R\&D_j w_{ij} \tag{5}$$

Where *R&D* is regional innovative efforts and *w* is as in (4).

Migration: Internal[3] labour mobility – proxied by the regional net migration rate – is an additional feature of the regional economy that shapes the potential impact of transport infrastructure and that should be appropriately controlled for. As discussed in the previous section, the capability to attract a net inflow of people increases the size of the local labour pool, improves its quality in terms of variety and (potentially) skills composition and eases the exchange of non-redundant knowledge.

4. Results of the analysis

4.1 Estimation issues, data availability, and units of analysis

The model is estimated by means of Two-way Fixed-Effect and GMM-Diff[4] Panel Data regressions[5] (Blundell and Bond 2001; Bond et al., 2001). GMM-SYS estimations have been also

alternative values for the parameter k resulted in very similar coefficients to those reported in the paper, underlining the robustness of the exercise.

[3] Given the absence of comparable migration data for all the countries included in the analysis, we calculate migration using other demographic statistics from Eurostat. We derive net migration using the population change, plus deaths, minus births (Puhani, 2001: 9). We then standardise net migration by the average population in order to obtain the net migration rate. The key disadvantage of this method is that it is not possible to distinguish between different types of migration flows.

[4] Following Bond et al.2001 we report the results for the one-step robust GMM estimators that are asymptotically robust to heteroskedasticity "but have also been found to be more reliable for finite sample inference" (p.18)

[5] The Hausman indicates that fixed effects is the preferred estimation, rejecting the random-effects specification. In addition the F-Test confirms that the region-specific effects are statistically significant.

implemented but are not presented in the output tables given that, due to the limited size of the dataset and the high number of potentially endogenous explanatory variables, the instrument count that they tend to generate always outnumbers the available observations, making the corresponding results unreliable (Roodman, 2007). These problems with GMM-SYS are customary in existing studies on regional growth dynamics due to the well-known data availability constraints and 'there is no evidence that a significant gain can be obtained using the GMM-SYS estimation, either in terms of statistical significance or in terms of theoretical consistency' (Esposti, 2007:131). 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 aim to minimise by means of GMM estimators that use appropriate lags of the explanatory variables as instruments of their own currents values. In addition, in order to resolve the problem of different accounting units, all explanatory regional variables are expressed, as a percentage of the respective GDP or population.

The model is run for 1990-2004 for the EU-15 in line with data availability. Unfortunately it is impossible to cover the EU-25 or the EU-27 (i.e. to include the 'new' member states of the Union in the analysis), the reason being that, for these countries, only some (limited) data is available from 1995 to 2004 i.e. a time span too short for our dynamic panel analysis. The constraints in terms of regional data availability – that have prevented us from considering a finer geographical scale or any sort of 'functional' regions – lead us to rely on a combination of NUTS1 and NUTS2 regions, selected in order to: a) maximise their homogeneity in terms of institutional and governance features; b) capture the relevant target area for the decision of developing new transport infrastructure by the national government and/or the European Commission. Consequently, the analysis is based on NUTS1 regions for Belgium, Germany[6] and the United Kingdom and NUTS2 for all other countries (Austria, Finland, France, Italy, the Netherlands, Portugal, Spain and Sweden). This combination of different NUTS levels maximises the homogeneity of the units of observation and is thus particularly important in order to minimise any potential bias of the different standardisations for the infrastructure variable. As a consequence of the need to control for national growth rates, countries without equivalent sub-national regions for the whole period of analysis (Denmark, Ireland and Luxembourg) are excluded from the analysis[7]. Lack of adequate regional data on infrastructure from either Eurostat or national authorities has forced the exclusion of Greece from the empirical analysis.

Eurostat Regio data have been used for the development of the dataset with the only exception of the statistics on educational achievement – used to compute the social filter index – which are based on Labour Force Survey Data provided by Eurostat through the European Investment Bank. In a few cases (detailed in Appendix A), missing data in Eurostat Regio have been complemented by information from National Statistical Offices where fully comparable data are available and, where information for a specific year and region was missing in all sources, the corresponding value has been calculated by linear interpolation or extrapolation.

[6] The NUTS2 level corresponds to *Provinces* in Belgium and to the German *Regierungsbezirke* which are in both cases: administrative units with little political and institutional meaning. In these two countries *Régions* and *Länder* (NUTS1) carry a much greater political weight and are, therefore, used in our analysis.

[7] Lack of data further prevents the introduction of the French Départments d'Outre-Mer (FR9) and of Trentino-Alto Adige (IT31). Given the introduction of spatially-lagged variables, remote islands (PT2 Açores, PT3 Madeira, ES7 Canarias) or enclaves [Ceuta y Melilla (ES 63)] could not be considered in the analysis.

4.2 Transport infrastructure and regional growth in the EU regions: Some Stylised Facts

As suggested by the European Commission in its Fifth Report on Economic, Social and Territorial Cohesion (2010): "Endowment of transport infrastructure varies widely across the EU, especially in terms of roads. (…) In 7 Member States, 6 of which are EU-12 countries, density is less than half the EU average. Differences are even more marked between EU regions with big differences in motorway density. (…) Between 2000 and 2008, new investment in motorways tended to be concentrated in less developed regions of the EU: (…) In the EU-15, investment was especially high in regions in Spain, Portugal and Germany" (European Commission 2010: 57).

Table 2 shows the key descriptive statistics for the EU regional infrastructure endowment and its evolution over time with alternative standardisation procedures. All indicators confirm the generalised increase in regional motorway density of at the EU-level. However, the improvement in average density over time comes with a simultaneous increase in its regional 'variability' (as measured by the Standard Deviation), suggesting the lack of a 'convergence' trend in infrastructure endowment across EU regions.

Table 2. Infrastructure Endowment in the Regions of the European Union, 1990-2004

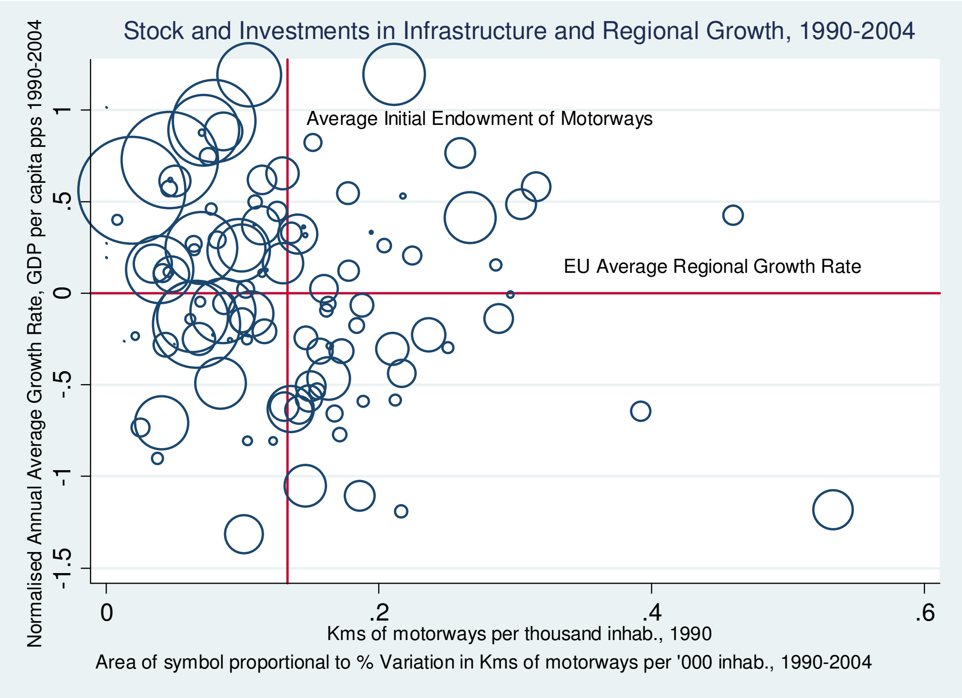
	Year	Mean	Std. Dev.	Min	Max
Kms of motorways per Sq Kilometre of land area	1990	0.026203	0.026457	0	0.113777
	1997	0.02989	0.026997	0	0.118724
	2004	0.034993	0.034945	0.000225	0.225162
Kms of motorways per thousand inhabitants	1990	0.132515	0.09256	0	0.533175
	1997	0.168914	0.117458	0	0.874057
	2004	0.204607	0.142712	0.008838	0.961463
Kms of motorways per million Euro of GDP	1990	0.008927	0.006664	0	0.04033
	1997	0.012261	0.009468	0	0.055371
	2004	0.016092	0.016328	0.000322	0.104534

Source: Authors' elaboration using Eurostat Data

Figure 1 combines regional growth dynamics and infrastructure endowment and investment in the same picture. The graph plots information on initial infrastructure endowment (x-axis), the normalised[8] annual 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 (Kms per thousand inhabitants).

Figure 1. Stock and Investments in Infrastructure and Regional Growth, 1990-2004

[8] Normalised with reference to the EU average over the same period.



Source: Authors' elaboration using Eurostat Data

The regions with an initial infrastructure density below the EU average are clustered in the upper-left area of the graph. They tend to perform above the EU average in terms of economic growth (over the 1990-2004 period). The areas of the corresponding circles suggest that many of these 'catching-up' regions (mainly in Portugal and Spain) have benefitted from large improvements in their infrastructure endowment (large % change in motorways density). There is, however, also a non-negligible number of regions with a lower than average initial endowment of infrastructure which, despite a considerable investment in expending the motorway network, have not managed to catch up. Moreover, the correlation between economic growth (y-axis) and investments (area of symbols) is substantially weaker when looking at the regions with above-average initial endowments (plotted in right-hand side area of the graph). In regions where an appropriate infrastructure endowment is already in place the relationship between further investments in infrastructure and economic growth remains unclear. This initial evidence seems to suggest that the impact of infrastructure investment is highly dependent upon initial endowment. However, the variety of possible outcomes calls for a 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.

4.3 Empirical Results

The estimation results based on the model (1) are presented in Tables 2, 3 and 4, which show results with different proxies for transport infrastructure (Kms of motorways per million inhabitants, per square-kilometre and per unit of regional GDP, respectively).[9]

[9] The relatively short time span covered in the analysis implies a 'large N /small T' panel, that is a larger cross-sectional (N) than time dimension in the panel (T). This *a priori* prevents non-stationarity from affecting our estimates through spurious correlation. Three different unit root tests for panel data (the Im-Pesaran-Shin, the augmented Dickey-Fuller and the Phillips-Perron tests) confirm this hypothesis (Table C-1 in Appendix C).

Fixed Effect 'Within' estimations are presented in regressions 1-4 of each table, followed by GMM-Diff results using all available lags of the endogenous variables as instruments (in regressions 5-9) and – in order to minimise the potential bias due to 'too many instruments' – only the second order lags (in regressions 10-13).

The results for each estimation approach are organised as follows: in the first specification the selected proxy for infrastructural endowment is introduced together with the autoregressive term (Log of GDP per capita in t-1), the controls for spatial autocorrelation and time trends (*i.e.*, the national growth rates and year dummies, respectively). In the following specification the impact of the same indicator in neighbouring regions is assessed. Subsequently, the analysis is broadened from an endogenous growth perspective by introducing into the model proxies for local innovative efforts and knowledge spillovers. In a further step, the variables depicting the socio-economic conditions ('Social Filter' Index) and labour mobility (migration rate) are introduced in line with more institutional approaches to the genesis of regional growth.

The test statistics for all specifications are presented in the lower section of each table and confirm the robustness of the results discussed below. In particular the Arellano-Bond test for serial correlation in the first differences of the residual always rejects the hypothesis of no first-order serial correlation, while it fails to reject it at higher orders as desired. This allows us to exclude the presence of residual serial correlation in the original error term. In addition, the Hansen statistic is used to test for overidentifying restrictions: the Hansen coincides with the Sargan test for 'non-robust' GMM but, if non-sphericity is suspected as in the case of our robust GMM estimations, the Sargan test would be inconsistent and the Hansen test is to be preferred (Roodman, 2006). The Hansen test confirms the validity of selected instruments in all specifications, showing fully realistic values when the instrument count is more limited as in columns 10-13.

In Table 3, we first control for the autoregressive term – i.e. the lagged level of regional GDP per capita – whose significantly negative (albeit small) coefficient suggests a weak trend towards regional convergence. Concerning the impact of infrastructure on regional economic performance, our initial results (Table 3, regression 1) show a lack of statistical significance in the 'Two-way Fixed Effect Within' estimations. However, one of the downsides of this estimation is that it is prone to endogeneity. We therefore re-estimate the same basic model by means of GMM-DIFF, which accounts more effectively for potential endogeneity problems, and uncover a small and mildly significant positive effect in line with analyses *à la* Aschauer (Table 3, regressions 5 and 9), that is without including any conditioning variables. As expected the GMM-Diff estimation corrects the downward bias in the Fixed Effect Within estimation and coefficients remain qualitatively similar irrespective of the number of instruments, confirming the correct specification of the model in line with the Hansen Test. However, this picture of the regional growth mechanics changes immediately when the impact of the infrastructure endowment of neighbouring regions is included

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Even if N is relatively large with respect to T, it should be borne in mind that consistency of GMM estimators depends on the cross-sectional dimension of the dataset. In this regard, our sample size – although limited to 120 observations – is in line with the existing literature at both national and regional level for the EU.

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" (Wooldridge, 2002: 275-6). The national growth rate is included in all equations as a way to minimise spatial correlation problems. The absence of spatial correlation is confirmed by conducting Moran's I test for each year. The results of these tests are not significant for the majority of the years.

in the analysis (Table 3, regressions 2, 6, and 10). The spatially lagged endowment of transport infrastructure is positive and significant only in the Fixed Effect Within specification (regression 2), but this is not the case in any GMM specifications. In addition, the inclusion of the spatially lagged term makes the coefficient of the internal regional infrastructure endowment insignificant. When the geography of transport infrastructure is fully accounted for (i.e. the spatial autocorrelation of this variable is explicitly modelled) and a correction (although partial) for the endogeneity of both terms is implemented, the link between infrastructure and regional growth vanishes completely (Table 3, regressions 6 and 10).

Insert Table 3 around here

These results underline what some of the literature has now been highlighting for some time: that attempts to explain economic growth solely by resorting to transport infrastructure endowment and investment have been rarely successful (Vickerman *et al.*, 1997). Our results fail to identify any robust evidence of a systematic relationship between transport infrastructure and economic growth at a regional level in the EU15. Hence, the presence of a good level of infrastructure endowment 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 (intra- and inter-) regional infrastructural endowment (Vanhoudt *et al.*, 2000), making infrastructure a factor that accompanies the process of regional development, rather than one of its engines. Once all these processes are fully controlled for, by mitigating the influence of endogeneity problems on the estimated coefficient and including in the empirical model both the (time) lagged dependent variable (modelling the dynamic evolutionary pattern of the regional economy) and the spatially lagged proxy for infrastructural endowment, the impact of infrastructure on growth becomes insignificant. The ‘real’ impact of infrastructure investments on economic growth might be partially hidden by a ‘political economy bias’ in their spatial allocation: when purely political decisions prevail over opportunity-cost considerations the economic returns of infrastructure projects might be jeopardised. However, our empirical model is able to account (at least partially) for the different capability of the regions to bargain for the attraction of both European and national-level infrastructural projects. The fixed effect specification with time dummy variables makes it possible to control for a) all unobservable time-invariant factors (i.e. long-term structural characteristics including the institutional, administrative and ‘bargaining’ capabilities of the regions that might impact on the regional ‘demand’ for new infrastructure); b) any potential time-varying process impacting all regions simultaneously (i.e. economic and political cycles, evolution of European policies and other factors that might impact on the ‘supply’ of new projects).

Overall, our results suggest that the impact of new motorways is heavily dependent upon the nature of the connection developed and on the underlying conditions of the territories involved in the project: “transport improvements have strong and positive impacts on regional development only where they result in removing a *bottleneck” (*Vickerman *et al.* 1997, p. 3) and more generally the direct impact of infrastructure development may be absent where the appropriate conditions are not met (Sloboda and Yao, 2008).

It must, however, be borne in mind that our proxy for infrastructure endowment – when compared to other existing studies of the same sort – may tend to underestimate part of its impact on economic performance for two reasons. First it is not equipped to capture the Keynesian impact of the construction phase: it is based on the actual kilometres of motorways (i.e. ‘quantity’ of infrastructure actually built and currently in use) and is not complemented by any expenditure data.

Second, since official statistics only record new infrastructure after final completion, our proxy captures mainly the *ex-post* impact of transport infrastructure on the spatial re-organisation of economic activity. Third, the current availability of comparable regional data makes it difficult to capture long time-lags between the completion of new infrastructure and the expansion of local economic activity. Not only it is hard to identify the most appropriate lag structure, but it should also be borne in mind that different infrastructural projects may produce benefits at different moments in time, reducing the precision and reliability of estimates based on aggregate data[10]. Finally, GMM estimators – even when implemented with extreme care by testing alternative estimations based on different instruments counts (as recommended in Roodman, 2007) – can only mitigate the effect of potential endogeneity problems, not correct for them in full.

The insertion, in line with the theoretical discussion, of other potential determinants of economic growth in the analysis does not make a significant difference for the transport infrastructure coefficients. When local innovative efforts and knowledge spillovers are taken into consideration (Table 3, regressions 3, 7, and 11), the coefficients point towards the importance of local R&D and innovative activities in the generation of economic growth. Regions which invest a greater proportion of their GDP in R&D tend to perform better than regions with a lower share of investment and innovation. Exposure to knowledge spillovers, while displaying a positive and significant association with economic growth in the FE analysis (regression 3), becomes less relevant for growth in the GMM results (regressions 7 and 11). In any case, taking into consideration innovation and knowledge spillovers does not affect the potential returns of regional motorway infrastructure endowment for economic growth. The coefficients for kilometres of motorways per thousand inhabitants and other spatially lagged transport infrastructure variable remain insignificant in the GMM estimations, stressing that, at least for the case of European regions, the economic returns of transport infrastructure tend to be considerably lower than those of local investment in R&D.

The results for the innovation variables confirm those of previous analyses looking at how the spatial dimension of innovation affects regional growth in the EU (Crescenzi *et al.* 2007; Crescenzi and Rodriguez-Pose, 2011). Technology thus emerges as a more robust predictor of economic growth and the availability of transport structure.

The full specification of our empirical model includes not only transport infrastructure and R&D and innovation variables, but also our social filter and migration indicators (Table 3, regressions 4, 8 and 12). The introduction of both the socio-economic conditions of each region and its migration rate are always positively and significantly connected to economic growth. Regions with a good endowment of human capital, low levels of agricultural employment, and with low rates of long-term unemployment tend to have had a better economic performance during the period of analysis, as was the case of regions with positive migration rates and thus more capable of attracting new and changing skills into the local labour pool and to foster diversity and social change. In fact, the introduction of the social filter index has implications for the R&D variables. European regions with more favourable social conditions, in general, and with a better endowment in human capital, in particular, also achieve greater returns from their own investment in R&D. The GMM coefficients for total intramural R&D expenditure in regressions 8 and 12 increase as a result of the

[10] The inclusion of additional lags of the variable of interest (Kms of Motorways) has been attempted in order to test this time-lag structure. However, given the limited time-dimension of the available data, this significantly affects the number of available observations making GMM-Diff estimations progressively less reliable and preventing us from including these additional results in the paper.

introduction of the social filter index and migration rates. By contrast, the introduction of the social filter and migration has no effect whatsoever on the returns of transport infrastructure endowment, as the coefficients remain insignificant.

In order to test the robustness of our results, we reproduce the analysis substituting our independent variable of interest (kilometres of motorways per thousand inhabitants), by two alternative indicators of transport infrastructure: kilometres of motorways per square kilometre and kilometres motorways per million Euro of GDP, presented in Tables 4 and 5, respectively. By and large, the results do not change. Whether we use endowment of motorways per square kilometres or per million Euro of GDP, the results of Table 3 stand: there is a robust connection between local innovation capacity, the local social filter and migration trends, on the one hand, and regional economic growth, on the other. The only main difference concerning these ‘conditioning’ variables is that, in the case of Table 5, regions surrounded by other regions with a high level of investment in R&D also tend to perform better. The coefficients for the spatially lagged R&D variable in regressions 7 and 11 are both positive and mildly significant.

Insert Tables 4 and 5 here

The infrastructure variables, however, remain largely insignificant. The only exceptions are the local endowment of motorways in regressions 7 and 8 in Table 4 and the spatially lagged transport infrastructure endowment in regressions 6, 7 and 8 in Table 5. In the case of the former, when the kilometres of motorways per square kilometre are used as our proxy of infrastructure endowment, regions with a better endowment of motorways tend to perform better from an economic standpoint, but this enhanced performance only emerges when other conditioning factors are controlled for. The economic returns of infrastructure endowment only emerge after controlling for the regional capacity to innovate and on its social filter. However, this effect is not robust to the restriction of the instruments set to second order lags only (Table 4, regressions 11 and 12).

Using kilometres motorways per million Euro of GDP as our proxy for regional infrastructure endowment makes regions surrounded by other regions with a good level of transport infrastructure more dynamic (Table 5, regressions 6, 7 and 8). The coefficient is strongest when the R&D variables are included (regression 7), pointing to an interaction between transport infrastructure and knowledge spillovers: the economic performance of regions with a good endowment of motorways is enhanced when they have – and are surrounded by regions with – high levels of investment in R&D. Once again, the effect tends to wane when GMM estimations with second order lags only are considered as instruments (Table 5, regressions 10 and 12, but not 11).

5. Conclusions

This paper has revisited the question of to what extent transport infrastructure endowment across regions of the EU is a fundamental determinant of regional economic growth and territorial cohesion. The paper has looked at the impact of the evolution of infrastructure endowment – proxied by kilometres of motorways – in 120 regions of 11 EU-15 countries on regional economic growth for the period 1990-2004. The potential returns of transport infrastructure endowment have been contrasted with that of other factors which may shape future growth, such as a region’s innovation capacity, its local socioeconomic conditions (or ‘social filter’) and its migration trends, controlling also for the importance of the geographical dimension of transport and innovation spillovers.

The results of the two-way fixed-effect (static) and GMM-diff (dynamic) panel data regression estimations, conducted using different weights in order to measure the dimension of transport infrastructure and test the robustness of the results, indicate that the impact of transport infrastructure endowment on regional growth is well below what could be expected from its prominent role in regional development strategies in the EU. Neither having a good endowment of roads, nor being surrounded by regions with good transport infrastructure has had a significant impact on regional economic growth. Hence, there is little evidence that the bet on transport infrastructure as the fundamental mechanism for regional economic growth has paid off in Europe. By contrast, other factors which may also condition growth seem to have had a much greater sway on regional economic performance in the EU. The presence of an adequate social filter and a good investment in R&D not only contribute to generate greater innovation, but also facilitate the absorption of innovation and increases in productivity. Migration is a third key element in this equation.

These results raise interesting questions about the prominence of transport infrastructure in the European regional development effort and, in particular, about its opportunity costs. Transport infrastructure has been and remains a basic component of the EU development policies. Although less prominent than in the past, still more than a quarter of the EU Regional Development and Cohesion funds are devoted to transport infrastructure. Perhaps more importantly, transport infrastructure still seems to capture the minds of decision-makers in the EU and elsewhere in the world. However, as our results show, there seems to be little evidence that, once a minimum threshold of basic transport infrastructure has been achieved, as is the case in most Western European regions, infrastructure endowment and new infrastructure investment can become a catalyst for sustainable economic growth. It is possible that the potentially beneficial effect of transport infrastructure investments is jeopardised by the predominance of purely political considerations in the selection of the projects and in their spatial allocation. This certainly calls for a re-consideration of the existing decision-taking mechanisms in this field and for a more rigorous assessment of infrastructure projects on opportunity/cost grounds and against alternative uses of the same resources. Indeed, our results link regional economic growth to a combination of human resources and greater investment in innovation, in adequate socio-economic and institutional environments. Yet, these elements still often play second fiddle to transport infrastructure in development strategies almost everywhere in the world and, in particular, in the European regional development effort.

Hence, in times of scarce availability of public resources, there may be a need to rethink the role allocated to transport infrastructure in development policies, linking it more to more integrated and inclusive development policies based on human capital and innovation, in order to guarantee not just greater and better returns from public funds, but also a greater sustainability of the development effort.

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Table 3 - Impact of Infrastructure on Regional Growth in the EU-15, Panel Data Analysis, 1990-2004 (Kms of motorways per thousand inhabitants)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY
	Fixed Effect WITHIN				GMM-Diff (all suitable lags as instruments)				GMM-Diff (second order lags only)			
Log of GDP per capita (t-1)	-0.177***	-0.182***	-0.182***	-0.240***	-0.0609***	-0.0677***	-0.0725***	-0.126***	-0.0654	-0.0596	-0.0124	-0.198***
	(0.0187)	(0.0187)	(0.0185)	(0.0256)	(0.0215)	(0.0205)	(0.0161)	(0.0212)	(0.0689)	(0.0655)	(0.0368)	(0.0599)
Kms of motorways per thousand inhabitants	0.0175	-0.00365	0.00821	0.000539	0.0398*	0.0267	0.0131	0.0252	0.0774*	0.0870	-0.00289	0.0287
	(0.0166)	(0.0178)	(0.0167)	(0.0159)	(0.0239)	(0.0283)	(0.0221)	(0.0277)	(0.0461)	(0.0742)	(0.0479)	(0.0687)
Spat.Weigh.Ave of Kms of motorways/thousand inhab.		0.0616**	0.0917***	0.0678***		0.0275	0.0374	0.0301		-0.0230	0.0547	0.0349
		(0.0245)	(0.0265)	(0.0258)		(0.0293)	(0.0286)	(0.0287)		(0.0697)	(0.0536)	(0.0904)
Total intramural R&D expenditure (all sectors) as % of GDP			0.000521***	0.000519***			0.000481***	0.000567***			0.000498***	0.000512**
			(7.34e-05)	(6.82e-05)			(0.000101)	(0.000105)			(0.000109)	(0.000214)
Spat.Weigh.Ave of Total R&D expenditure			0.000955***	0.000637*			0.000751				0.000956	
			(0.000332)	(0.000377)			(0.000621)				(0.000800)	
Social Filter Index				0.00999***				0.00493***				0.0124*
				(0.00239)				(0.00169)				(0.00764)
Migration Rate				0.000432**				0.000418**				0.000844*
				(0.000187)				(0.000175)				(0.000452)
Annual National Growth Rate	0.00379***	0.00381***	0.00354***	0.00361***	0.00834***	0.00828***	0.00840***	0.00818***	0.00744***	0.00741***	0.00860***	0.00687***
	(0.000374)	(0.000378)	(0.000395)	(0.000335)	(0.000470)	(0.000465)	(0.000432)	(0.000439)	(0.00137)	(0.00129)	(0.000844)	(0.000888)
Constant	1.703***	1.750***	1.740***	2.304***								
	(0.178)	(0.179)	(0.177)	(0.246)								
Observations	1,680	1,680	1,680	1,680	1,560	1,560	1,560	1,560	1,560	1,560	1,560	1,560
R-squared	0.403	0.406	0.413	0.443								
Number of id	120	120	120	120	120	120	120	120	120	120	120	120
Hansen J statistic					111.7	114.2	96.47	109.7	42.41	51.28	90.44	101.0
p value of Hansen statistic					1	1	1	1	0.214	0.347	0.323	0.100
AR(1) test statistic					-5.600	-5.549	-5.719	-5.870	-4.831	-4.842	-5.966	-4.634
p value of AR(1) statistic					2.14e-08	2.88e-08	1.07e-08	4.37e-09	1.36e-06	1.29e-06	2.42e-09	3.58e-06
AR(2) test statistic					-0.823	-0.825	-0.794	-0.808	-0.920	-0.950	-0.852	-0.995
p value of AR(2) statistic					0.411	0.410	0.427	0.419	0.358	0.342	0.394	0.320
Number of instruments					280	371	634	644	52	65	104	104

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4 - Impact of Infrastructure on Regional Growth in the EU-15, Panel Data Analysis, 1990-2004 (Kms of motorways per Sq-Kms)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY
	Fixed Effect WITHIN				GMM-Diff (all suitable lags as instruments)				GMM-Diff (second order lags only)			
Log of GDP per capita (t-1)	-0.177***	-0.176***	-0.175***	-0.239***	-0.0527***	-0.0539***	-0.0651***	-0.123***	-0.0207	-0.0268	-0.00723	-0.228***
	(0.0186)	(0.0185)	(0.0184)	(0.0256)	(0.0178)	(0.0170)	(0.0152)	(0.0210)	(0.0387)	(0.0328)	(0.0259)	(0.0796)
Kms of motorways per Sq Kilometer of land area	0.0801*	0.0964**	0.126***	0.192***	0.0475	0.0485	0.144*	0.124*	0.00904	0.0736	0.111	0.230
	(0.0421)	(0.0408)	(0.0453)	(0.0474)	(0.0719)	(0.0758)	(0.0784)	(0.0653)	(0.104)	(0.112)	(0.109)	(0.174)
Spat.Weigh.Ave of Kms of motorways/Sq-KM		-0.114	0.0243	0.00526		0.131	0.0863	0.0831		0.0885	0.217	0.300
		(0.0844)	(0.123)	(0.146)		(0.109)	(0.121)	(0.101)		(0.151)	(0.155)	(0.316)
Total intramural R&D expenditure (all sectors) as % of GDP			0.000368***	0.000427***			0.000404***	0.000452***			0.000523***	0.000479*
			(6.88e-05)	(7.12e-05)			(8.11e-05)	(7.63e-05)			(0.000114)	(0.000271)
Spat.Weigh.Ave of Total R&D expenditure			0.000560	0.000495			0.000705				0.00105	
			(0.000366)	(0.000347)			(0.000637)				(0.000863)	
Social Filter Index				0.0105***				0.00565***				0.0151**
				(0.00238)				(0.00173)				(0.00708)
Migration Rate				0.000524***				0.000462**				0.00118**
				(0.000185)				(0.000189)				(0.000536)
Annual National Growth Rate	0.00380***	0.00378***	0.00363***	0.00370***	0.00828***	0.00835***	0.00830***	0.00817***	0.00771***	0.00812***	0.00852***	0.00690***
	(0.000372)	(0.000370)	(0.000378)	(0.000329)	(0.000484)	(0.000453)	(0.000417)	(0.000424)	(0.00131)	(0.00107)	(0.000757)	(0.000950)
Constant	1.700***	1.698***	1.678***	2.302***								
	(0.178)	(0.176)	(0.176)	(0.245)								
Observations	1,680	1,680	1,680	1,680	1,560	1,560	1,560	1,560	1,560	1,560	1,560	1,560
R-squared	0.402	0.403	0.406	0.442								
Number of id	120	120	120	120	120	120	120	120	120	120	120	120
Hansen J statistic					114.8	109.3	102.6	111.7	45.97	58.26	90.82	88.74
p value of Hansen statistic					1	1	1	1	0.123	0.147	0.313	0.341
AR(1) test statistic					-5.597	-5.599	-5.651	-5.746	-5.513	-5.639	-5.926	-4.293
p value of AR(1) statistic					2.18e-08	2.16e-08	1.60e-08	9.12e-09	3.53e-08	1.71e-08	3.10e-09	1.77e-05
AR(2) test statistic					-0.853	-0.826	-0.826	-0.814	-0.956	-0.862	-0.874	-1.033
p value of AR(2) statistic					0.393	0.409	0.409	0.416	0.339	0.389	0.382	0.302
Number of instruments					280	371	634	644	52	65	104	104

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5 - Impact of Infrastructure on Regional Growth in the EU-15, Panel Data Analysis, 1990-2004 (Kms of motorways per million Euro of GDP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY	DeltaY
	Fixed Effect WITHIN				GMM-Diff (all suitable lags as instruments)				GMM-Diff (second order lags only)			
Log of GDP per capita (t-1)	-0.177***	-0.184***	-0.187***	-0.245***	-0.0660***	-0.0665***	-0.0774***	-0.132***	-0.195*	-0.214*	-0.0415	-0.217***
	(0.0184)	(0.0189)	(0.0186)	(0.0260)	(0.0218)	(0.0212)	(0.0168)	(0.0220)	(0.110)	(0.111)	(0.0373)	(0.0581)
Kms of motorways per million Euro of GDP	0.0604	-0.166	0.0138	-0.0745	0.265	-0.0620	0.0234	0.00841	1.013***	1.767**	-0.145	-0.00434
	(0.117)	(0.111)	(0.101)	(0.106)	(0.191)	(0.120)	(0.132)	(0.136)	(0.346)	(0.769)	(0.214)	(0.413)
Spat.Weigh.Ave of Kms of motorways/million GDP		0.510***	0.894***	0.786***		0.413***	0.476**	0.344**		-0.841	0.672**	0.419
		(0.138)	(0.154)	(0.140)		(0.137)	(0.191)	(0.154)		(0.807)	(0.298)	(0.584)
Total intramural R&D expenditure (all sectors) as % of GDP			0.000614***	0.000576***			0.000556***	0.000533***			0.000482***	0.000512***
			(0.000108)	(9.26e-05)			(0.000150)	(0.000159)			(0.000117)	(0.000161)
Spat.Weigh.Ave of Total R&D expenditure			0.00154***	0.00116***			0.00130*				0.00133*	
			(0.000368)	(0.000385)			(0.000685)				(0.000719)	
Social Filter Index				0.0101***				0.00551***				0.0138**
				(0.00242)				(0.00171)				(0.00694)
Migration Rate				0.000407**				0.000414**				0.000729*
				(0.000189)				(0.000176)				(0.000440)
Annual National Growth Rate	0.00379***	0.00383***	0.00350***	0.00357***	0.00831***	0.00826***	0.00827***	0.00816***	0.00613***	0.00581***	0.00812***	0.00670***
	(0.000372)	(0.000372)	(0.000391)	(0.000331)	(0.000472)	(0.000463)	(0.000427)	(0.000424)	(0.00147)	(0.00147)	(0.000829)	(0.000880)
Constant	1.704***	1.770***	1.791***	2.352***								
	(0.176)	(0.180)	(0.178)	(0.250)								
Observations	1,680	1,680	1,680	1,680	1,560	1,560	1,560	1,560	1,560	1,560	1,560	1,560
R-squared	0.402	0.406	0.417	0.448								
Number of id	120	120	120	120	120	120	120	120	120	120	120	120
Hansen J statistic					532389	112.8	101.3	108.5	46.57	57.91	88.14	98.69
p value of Hansen statistic					0	1	1	1	0.112	0.155	0.386	0.130
AR(1) test statistic					-5.512	-5.514	-5.656	-5.791	-3.298	-3.099	-5.957	-4.587
p value of AR(1) statistic					3.54e-08	3.50e-08	1.55e-08	7.00e-09	0.000972	0.00194	2.56e-09	4.50e-06
AR(2) test statistic					-0.815	-0.828	-0.822	-0.793	-0.872	-0.936	-0.903	-0.963
p value of AR(2) statistic					0.415	0.408	0.411	0.428	0.383	0.349	0.366	0.335
Number of instruments					280	371	634	644	52	65	104	104

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix A. Description of the variables

Table A-1. Description of the variables

Variable	Definition	Notes
Dependent variable	Annual growth rate of regional GDP (1990-2004).	
Internal factors		
Infrastructure		
Motorways* (Inhab.)	Kms of motorways per thousand inhabitants	Italy: missing data for all regions after the year 2000. Missing have been replaced by means of comparable ISTAT data Greece: data are missing from 1996. Greece has been excluded from the analysis Portugal: missing data for Centro, Lisboa and Alentejo from 1990 to 2002 Regional surface in 2003 has been used to calculate the density of transport infrastructure to avoid generating noise in the density variable due to changes in the calculation of the regional surface. Regional GDP and average population in 1990 have been used to standardize the variables included in the regressions.
Motorways (GDP)	Kms of motorways per million EUR of GDP	
Motorways (Region area)	Kms of motorways per square-kilometre	
Control variables		
Log of GDPpc	Natural logarithm of regional GDP per capita at time t-1	
National growth	Annual growth rate of national GDP (1990-2004).	
Innovation		
R&D	Total intra-regional 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)	Data on educational attainment are available from the Labour Force Survey and have been provided by Eurostat through the European Investment Bank, Economic & Financial Studies Division .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		
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 (Kms of motorways per 1000 inhab., million EUR of GDP or square-kilometre)	
Extra-regional Innovation	Spatially weighted average of neighbouring regions' R&D expenditure	

* 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.

Appendix B –Results of the Principal Component Analysis

Table B-1- Principal Component Analysis: Eigenanalysis of the Correlation Matrix

EU 15				
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.2744	1.30682	0.5686	0.5686
Comp2	0.96758	0.233347	0.2419	0.8105
Comp3	0.734233	0.710447	0.1836	0.9941
Comp4	0.0237857	.	0.0059	1

Table B-2 - Principal Component Analysis: Principal Components' Coefficients

EU 15				
Variable	PC1	PC2	PC3	PC4
Agricultural Labour Force	-0.3942	0.3369	0.855	0.0098
Long Term Unemployment	-0.2551	0.851	-0.4537	0.0698
Education Population	0.632	0.233	0.1914	0.7139
Education Employed People	0.6165	0.3288	0.1627	-0.6967

Appendix C - Table C-1 - EU15: Unit root tests

	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***
Kms of motorways per thousand inhabitants	13.291	-1.237*	416.324***	623.802***	377.252***	438.065***
Spat.Weigh.Ave of Kms of motorways/thousand inhab.	16.138	4.132	206.563	249.137	299.115***	447.128***
Log of GDPpc	-4.081***	-9.101***	38.722	925.186***	50.357	263.707*
Total intramural R&D expenditure (all sectors) as % of GDP	-11.139***	-4.071***	260.287*	359.048***	187.576	293.751***
Spat.Weigh.Ave 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***
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*

significant at 10%; ** significant at 5%; *** significant at 1%

* significant at 10%; ** significant at 5%; *** significant at 1%

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