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Infrastructure investment, growth and cohesion

The economics of regional transport investment

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Infrastructure investment, growth and cohesion

The economics of regional transport investment

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Preface

Torsten Gersfelt
Vice-President

Infrastructure investment tends to be considered as economically productive and useful almost by definition. But surprisingly little is still known about the productivity of infrastructure investment – or even about how much of such investment there is in the first place. Therefore, it is worth investigating how much governments, and others, invest in infrastructure and what exactly is known about the impact on output. In taking investment decisions, governments often face difficult trade-offs between competing uses of public funds, and they also need to consider the costs and benefits of such decisions for the rest of the economy.

The composition and productivity of government investment as well as its fiscal implications are key topics addressed in the companion issue (Volume 13, Number 1) to this issue of the *EIB Papers* (Volume 13, Number 2).

This issue broadens the perspective on infrastructure by considering how it interacts with economic geography. This is done in two dimensions. First, the conceptual underpinnings for considering the link between infrastructure and economic geography are spelled out. It turns out that infrastructure can contribute to both agglomeration and dispersion of economic activity; consequently, the challenge is to articulate clearly how exactly different types of infrastructure affect the location of economic activities. Infrastructure crossing borders has its own peculiarities, especially when there are significant economic differences between or within the regions connected by infrastructure.

The second dimension in considering the link between infrastructure and economic geography is empirical. There are formidable challenges involved in assessing the determinants and impact of regional infrastructure investment empirically. Nevertheless, the contributions to this issue are a testimony to the fact that such challenges can be overcome and that interesting and policy-relevant conclusions can be drawn from such studies. Of particular interest is to consider how the determinants and productivity of regional infrastructure investment go together; for example, do redistribution considerations imply less productive investment? Also, transport infrastructure is a prime example of a good with spillover effects, but how significant are they really?

The insights, experience, and lessons compiled in this volume of the *EIB Papers* are intended to contribute to a better understanding of the nexus between infrastructure, growth and economic geography. This should be particularly useful in considering the policy choices and challenges facing policy makers in furthering economic integration and cohesion in Europe.

Infrastructure investment, growth and cohesion

The economics of regional transport investment

The *2008 EIB Conference in Economics and Finance* – held at EIB headquarters in Luxembourg on June 12 – examined the role of infrastructure investment in economic growth and cohesion, shedding light on a wide range of policy-relevant issues. These included the composition of government investment; its fiscal implications; the determinants and productivity effects of infrastructure investment; and the effects of infrastructure on the location of economic activities.

Speakers included:

Riccardo CRESCENZI
of the European University Institute,
Florence, Italy

Jakob de HAAN
of the University of Groningen,
The Netherlands

Somik LALL
of the World Bank, USA

Gianmarco OTTAVIANO
of the University of Bologna, Italy

Diego PUGA
of the Madrid Institute of Advanced Studies,
Spain

Armin RIESS
of the EIB

Andrés RODRIGUEZ-POSE
of the London School of Economics,
Great Britain

Gerd SCHWARTZ
of the International Monetary Fund, USA

Andreas STEPHAN
of the Jönköping International
Business School, Sweden

Timo VÄLILÄ
of the EIB

ABSTRACT

This essay provides an overview of the role of infrastructure on economic geography in the light of both theoretical and empirical findings. *Two main lessons stand out. First, infrastructural improvements affect the geographical distribution of economic activities. Second, even when localized, infrastructure investment generates externalities that may diffuse quite far across the economy. These two lessons have two far-reaching policy implications. First, effective infrastructure projects require knowledge on their impacts on the spatial distribution of economic activities. These impacts depend crucially on the specific details of the projects and the specific sources of agglomeration economies they affect. Second, regions need to coordinate not only in terms of interregional infrastructure projects but also in terms of intraregional ones if they want to avoid beggar-thy-neighbour and self-defeating outcomes.*

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Infrastructure and economic geography: An overview of theory and evidence

1. Introduction

Gianmarco Ottaviano

How important is infrastructure for regional development? What is its impact on the geographical distribution of economic activities? Does it promote agglomeration or dispersion?

The aim of this essay is to provide an overview of the role of infrastructure in affecting economic geography. In so doing, it summarises both theoretical and empirical findings pertaining to why, how and how much infrastructure contributes to the agglomeration or the dispersion of economic activities. It also discusses the implications of those findings for policy design.

Along the years countless studies have been devoted to uncovering the economic mechanisms driving the spatial distribution of economic activities. The availability of adequate analytical tools has been the main constraint on this endeavour. Indeed, for quite some time inadequate analytical tools kept space away from mainstream economics by classifying as irrelevant issues that were instead simply intractable. So, while what is really puzzling is the sheer extent of geographical concentration found at any scale of observation, "economists understood why economic activity spreads out, not why it becomes concentrated – and thus the central model of spatial economics became one that deals only with the way competition for land drives economic activities away from a central market" (Krugman 1995, p. 12).

The missing tools were models able to deal with increasing returns to scale and imperfect competition, possibly in a general equilibrium framework. In the last decades, however, these tools having become available, spatial economics has made a giant leap forward and regained its status in mainstream economics (see Fujita and Thisse 2002 for a detailed account). More practically, it has started to generate new insights to inform the design of economic policies (Baldwin *et al.* 2003).

Surveys of spatial economics abound covering both theoretical and empirical aspects (see, for example, all the chapters in Henderson and Thisse 2004). Rather than adding the *n*-th survey to an already long list, the present essay prefers to distil the key insights of spatial economics by means of a simple unified theoretical framework that provides an internally consistent and parsimonious way to relate the evolution of the economic landscape to a restricted number of parameters on which infrastructure is shown to act.

The essay in organized in five more sections. Section 2 presents the theoretical framework. Section 3 discusses how the framework can be interpreted to allow for the various sources of agglomeration economies highlighted in the literature. Section 4 uses the framework to discuss the role of infrastructure in regional development. Section 5 highlights specific empirical findings that are consistent with the implication of the theoretical framework. Section 6 concludes drawing some policy implications.

2. The location choice

Theoretical explanations of the geographical distribution of economic activities rest on modelling the location decision of firms. This decision is not trivial when two things are true. First, goods and factors can be transported across space only at some cost. Second, the fragmentation of the production process reduces its efficiency, which happens when returns to scale are increasing at the plant level. Without transport costs space would be immaterial. Without plant-level scale economies, when faced with dispersed customers, firms would use the geographical fragmentation of production to circumvent transport costs by adapting to scattered demand and intermediate supply through many small local plants ('backyard capitalism'). In other words, "without recognizing indivisibilities – in human person, in residences, plants, equipment, and in transportation – urban location problems, down to those of the smallest village, cannot be understood" (Koopmans 1957, p. 154).

Both transport costs and scale economies are therefore necessary for a location problem to arise: Costly transportation gives physical substance to the concept of geography and increasing returns generate an economic trade-off between the 'proximity' to customers and the 'concentration' of production in as few plants as possible.[1]

2.1 Market seeking and cost saving attraction

The centrality of scale economies has important implications in terms of market structure. Indeed, since plant-level returns to scale are necessarily associated with market power, imperfect competition is inherent to the location problem.[2]

A simple monopolistic setup is enough to see how the relationship between proximity and concentration generates a location problem for any firm no matter whether involved in any interaction with other firms. Specifically, consider a situation in which there are two locations, H and F.[3] The former offers a larger local market for the monopolist's product and cheaper costs of production. Shipments between locations are hampered by trade barriers and technological constraints are such that the monopolist can profitably run one plant only. This indivisibility and costly shipments give substance to the monopolist's location problem.

Firms are attracted to locations with larger markets – production costs become more important as trade barriers fall.

Where will a profit maximizing monopolist place the plant? The answer is: In location H. Indeed, locating its plant in H allows the monopolist to minimize production costs ('cost saving attraction'). Moreover, it also allows the monopolist to minimize trade costs as, once in H, it can serve a larger share of overall demand locally, thus foregoing costly shipments ('market seeking attraction').

Since the monopolist would always locate in the place offering lower production costs and larger local demand these two factors act as agglomeration forces. The strength of these forces depends, however, on the level of trade barriers. In particular, lower trade barriers increase the relative importance of cost saving compared to market seeking. The reason is that, as trade barriers fall, firm location becomes increasingly immaterial in terms of access to customers.

2.2 Competition

A firm's location decision becomes more complex when it faces competitors. The reason is that geographical positioning can be used by the firm to relax competitive pressures and enhance its market power. This is the case both when competitors are a 'small group' of oligopolistic firms

1 Scotchmer and Thisse (1992) call this the 'folk theorem of spatial economics'.
2 This is the essence of the 'spatial impossibility theorem' proved by Starrett (1978).
3 See Behrens *et al.* (2007a) for a formal presentation of the theoretical framework underlying this section.

selling homogeneous products and when they are a 'large group' of monopolistically competitive firms selling differentiated products *à la* Chamberlin (1933). In both cases, location turns out to be a crucial decision variable for profit maximization.

To see this, let us introduce a competitor in the simple monopolistic setup. In particular, let us now assume the existence of two firms such that firm 1 is more efficient than firm 2. Each firm supplies one variety of a horizontally differentiated good. As before, technological constraints are such that each firm can profitably run one plant only and shipments between locations face trade barriers. Firms compete in two stages. First they decide where to locate, and then they choose how much to sell in the two markets.

Where will the profit maximizing duopolists place their plants? Under reasonable conditions, the strategic interaction between firms generates only two possible equilibrium outcomes. In the first, the firms co-locate in the low-cost/large-size location H ('agglomeration'). In the second, they are based in different locations with the low-cost firm serving the low-cost/large-size location ('sorting').

In order to understand under which conditions an outcome prevails over the other, it is useful to start from a situation in which there are no differences between locations, in terms of both market size and production costs, and between firms, in terms of efficiency. In this case, if firms chose the same location, they would face strong competition in their local market and weak competition in their distant market. Therefore, as the two locations are identical, one of the two firms would always find it profitable to relocate. The more so, the higher the substitutability between the products of the two firms and the higher the trade barriers protecting the distant market. Accordingly, competition promotes dispersion, especially in the presence of limited product differentiation and high trade costs.

Let us now introduce market size and production cost differences between locations, which reinstates the agglomeration forces described in the case of monopoly. This implies that, notwithstanding the dispersion force due to competition, the two firms may still prefer to co-locate in H provided that its size and cost advantages are large enough. This is more likely when product differentiation is pronounced and when trade costs are low as under these conditions competitive repulsion is weak.

Finally, let us see how efficiency differences between firms interact with differences in production cost and market size. While the focus on efficiency stresses the technological dimension of firm heterogeneity, it is worthwhile pointing out that similar results in terms of location choice can be obtained by focusing instead on the quality of the products offered by the firms. In this respect, while the elasticity of substitution between firms' products measures 'horizontal' product differentiation, the difference in firm efficiency measures 'vertical' product differentiation.

When efficiency differences between firms are introduced together with market size and production cost differences between locations, the less efficient firm 2 has a stronger incentive to avoid the fierce competition associated with agglomeration in the advantaged region H. As a result, firm heterogeneity acts as an additional dispersion force, the more so the higher the trade costs and the smaller the differentiation of products.

Less efficient firms dislike locations with strong competition – even more so with higher trade barriers.

Hence, firm heterogeneity fosters dispersion when matched with market size and production cost differences between locations. In other words, while horizontal differentiation favours the spatial concentration of economic activities, vertical differentiation hampers it.

3. Agglomeration economies

The simple theoretical framework discussed in Section 2 suggests that asymmetries (*i.e.*, differences) in market size and production cost between locations promote the geographical concentration of economic activities.

There are two different ways of looking at those asymmetries. In a first perspective, asymmetries in market size and production cost are taken as exogenously given. As such, they reflect respectively the relative advantage that location H has in terms of local production and consumption amenities deriving from climatic conditions, natural resources and natural means of communication.

While places do have different abundance of natural resources, proximity to natural means of communication, and climatic conditions, these features (also known as 'first nature') provide only a partial explanation of the pronounced differences in development existing even between areas that are fairly similar in terms of such exogenous characteristics. For this reason it has been argued that regional imbalances have to be driven also by additional, 'second nature' forces that are inherent to the functioning of economic interactions and are able to cause uneven development even across ex-ante identical places.[4] In this second perspective, market size differences and production cost differences are endogenously determined as increasing functions of the relative scale of economic activities taking place in one of the locations (H in our example).

Through the years a rich list of 'second nature' forces has been proposed by geographers, regional scientists and urban economists.[5] These forces are also called 'agglomeration economies' and exist as long as the scale of the local economy adds to the performance of local firms. They are 'external economies' as long as the benefits of localized interactions are not fully reflected in the prices of market transactions.

Firms' and workers' location decisions determine market size and production cost asymmetries, and vice versa.

An important common implication of agglomeration economies is that they are able to generate self-sustaining clustering insofar as the movements of firms and workers, attracted to places with larger local markets and lower production costs, end up reinforcing these differences and thus spatial imbalances ('cumulative causation'). In this respect, agglomeration economies give strength to 'second nature' against 'first nature', detaching the emerging economic landscape from the physical attributes of its underlying geography. Thus, while there is *a priori* great flexibility on where particular activities locate, once the agglomeration process has started, spatial differences take shape and become quite rigid ('putty clay geography', see Fujita and Thisse 1996).

While sharing this common characteristic of making the spatial concentration of economic activities self-sustaining, agglomeration economies nonetheless differ substantially from one another in terms of two crucial features: Their 'scope' and their 'source'. The taxonomy below follows Rosenthal and Strange (2004).

3.1 Scope

Agglomeration economies may extend along three main dimensions. The notion of 'scope' refers to the extent to which each dimension is developed.

First, agglomeration economies may extend across industries in a certain location or be confined inside them. This difference in 'industrial scope' is the most familiar one in urban economics where

4 The distinction between 'first nature' and 'second nature' is due to Cronon (1991).

5 See Fujita and Thisse (2002) for a thorough assessment of the relative merits of the different approaches.

specific names have been assigned to the two polar cases. When agglomeration economies spread across industries, they are called 'urbanization economies'. When they are confined inside industries, they are called 'localization economies'.

Agglomeration economies have an industry, geographical, and time dimension.

The second dimension along which agglomeration economies may extend is the spatial one. This is the 'geographic scope' and refers to the extent to which external economies depend on the proximity between firms and thus decay with distance.

Finally, there is the 'temporal scope' that refers to the external economies generated by interactions among firms located in the same place but occurring at different times. A typical example is knowledge creation through cumulated local learning.

3.2 Sources

The notion of 'source' refers to a micro-founded explanation of the existence of agglomeration economies. Four explanations have attracted special attention.[6]

3.2.1 Marshall

Three explanations are known as the 'Marshallian triad': 'Knowledge spillovers', 'labour market pooling', and 'input sharing' (Marshall 1890).

'Knowledge spillovers' arise when knowledge is transferred between agents thanks to sheer physical proximity irrespective of market transactions between them. Knowledge, ideas and, above all, tacit information, can be considered as impure public goods that generate spillover effects from one firm or institution to another. Consequently, if economic agents possess different pieces of information, pooling them through informal communication channels can benefit everyone, hence the importance of proximity (Feldman 1994). In this perspective, agents co-locate to take advantage of knowledge that is someway 'in the air', which makes them more efficient. Accordingly, in terms of the theoretical framework of Section 2, the cost advantage of location H becomes an increasing function of the relative number of its resident agents.

'Labour market pooling' refers to two related phenomena that arise when firms and workers face search and matching frictions. First, the spatial concentration of workers with different skills and firms with different needs increases the likelihood of good matches and, hence, the expected quality of a match (Helsley and Strange 1990). Second, if employer-employee matches face an idiosyncratic risk of being undone, spatial concentration reduces the duration of unemployment spells and unfilled vacancies. Co-location allows firms and workers to benefit from both opportunities. Through these channels, in terms of the framework of Section 2, both the cost production advantage and the market size advantage of location H become increasing functions of the relative number of its resident agents.

'Input sharing' generates agglomeration economies when the production of intermediate inputs faces increasing returns to scale and their transportability is limited. When this is the case, the input producing sector is able to reach an efficient scale of production only when its local market is large enough, which requires the spatial concentration of downstream customers. Accordingly, in terms of the framework of Section 2, the cost advantage of location H becomes an increasing function of the relative number of agents residing in that location.

6 See Duranton and Puga (2004) for a theoretical survey of the microfoundations of agglomeration economies.

'Urban consumption opportunities' are sometimes considered as a fourth explanation of urban primacy. They are, however, partly a variation on the theme of input sharing and partly a variation on the theme of knowledge spillovers. As to the former, when the supply of final goods and services faces increasing returns to scale and their transportability is limited, large local demand associated with the spatial concentration of people allows final production to achieve an efficient scale. As to the latter, the spatial concentration of people fosters social interactions that may be valuable *per se* even in the absence of knowledge transmission. A similar argument is readily applied to the provision of all sorts of goods and facilities characterized by some degree of indivisibility (road, schools, *etc.*). As long as some of these are publicly provided through local funds, the spatial concentration of economic activities generates the tax base needed to finance them ('fiscal externality'). In terms of the framework of Section 2, the market size advantage of location H becomes an increasing function of the relative number of its resident agents.

Knowledge spillovers, labour market pooling, input sharing, and consumption amenities foster firm performance.

To summarise, in a Marshallian perspective the effects of spatial concentration on market size and production cost asymmetries may be due to:

- Knowledge spillovers that increase the production cost asymmetry;
- Labour market pooling that increases both market size and production cost asymmetries;
- Input sharing that increases the production cost asymmetry; and
- Consumption amenities that increase the market size asymmetry.

3.2.2 Krugman

While Marshallian explanations have a long standing tradition, more recently a specific approach, the so called 'new economic geography' (henceforth, NEG), has gained momentum in mainstream economics. The distinguishing feature of NEG with respect to alternative approaches is the focus on market rather than non-market interactions in a 'general equilibrium' framework stressing the endogenous determination of good and factor prices as well as the importance of economy-wide budget constraints.[7]

One way to relate NEG to the 'Marshallian triad' is to think of its contribution as bringing the idea of input sharing and urban consumption opportunities one step further by adding a richer understanding of industrial organization and its implication for factor prices. In doing so, imperfect competition plays centre stage, differently from Marshallian explanations that traditionally rely on economies of scale at the industry level and, hence, are compatible with the assumption of perfectly competitive product markets (as in Henderson 1974; Fujita and Ogawa 1982; Helsley and Strange 1990).

Two scenarios have received particular attention. Both stress the impact of firms' location decisions on other firms' profits. The first scenario considers the effect of firm relocation when matched by labour migration ('demand linkage', see Krugman 1991 as well as Ottaviano *et al.* 2002). In this case, as the firm moves, it reduces demand in the place of origin while increasing it in the place of destination. As profits rise with demand, the firm's relocation harms competitors in the place of origin and benefits competitors in the place of destination. In terms of the theoretical framework of Section 2, the market size advantage of location H becomes an increasing function of the relative number of agents residing in that location.[8]

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7 The advantage of the general equilibrium approach is nicely summarized by Fujita and Krugman (2004, p. 141): "[…] you want a *general-equilibrium* story, in which it is clear where the money comes from and where it goes".

8 When agglomeration fosters capital accumulation, the outcome is similar to the one with migration since both expand the local market through the additional income they generate (Baldwin 1999 as well as Baldwin *et al.* 2001).

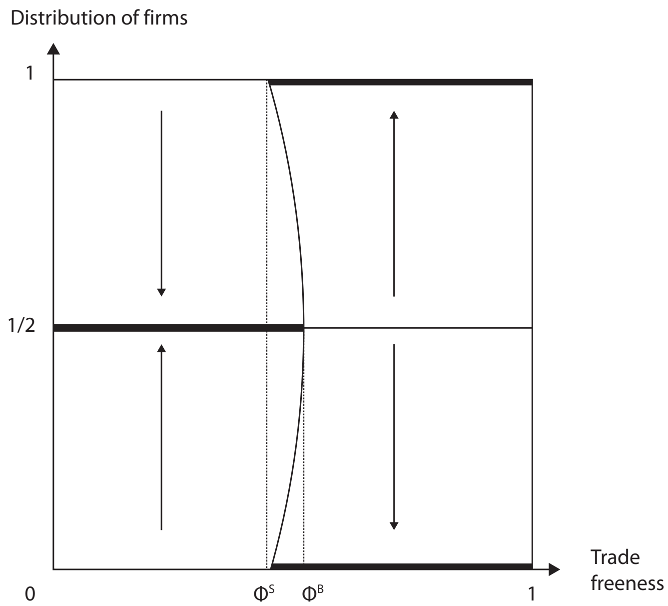
In the second scenario, firms have input-output linkages between each other: What is output for one firm is input for the other and *vice versa* ('cost linkage', see Krugman and Venables 1995; Venables 1996). When a firm relocates, it depresses both final demand and intermediate supply in the country of origin, whereas it reinforces them in the country of destination. Accordingly, other firms' profits suffer in the former and thrive in the latter. In terms of the theoretical framework of Section 2, the production cost advantage of location H becomes an increasing function of the relative number of its resident agents.

Demand and cost linkages determine the scale of the local economy – and firm performance.

The fact that, due to demand and cost linkages, the market size and production cost advantages of H grow with the local concentration of economic activities once more supports self-sustaining agglomeration. As already discussed, this is a common implication of agglomeration economies whatever their sources may be. The crucial contribution of NEG is that its solid microeconomic foundations allow the evolution of the spatial landscape to be related to observable microeconomic parameters such as the level of trade obstacles and the strength of firms' market power.

The following example illustrates how an understanding of the microeconomic foundations of NEG allows gaining sometimes unexpected insights. Consider the impact of trade barriers on clustering. The relation between these barriers and the spatial distribution of economic activities in simple NEG models is summarized in Figure 1.

Figure 1. The role of trade freeness



This figure portrays the possible long-run spatial configurations of our stylized two-location economy. It considers the special case in which there are neither market-size nor production cost asymmetries so that locations are identical in terms of 'first nature'. The extent of trade freeness is measured along the horizontal axis whereas the share of firms located in region H appears along the vertical one. The trade freeness index is an inverse measure of trade costs. When shipments are impossible, the trade freeness index is equal to its minimum value 0; when shipments are costless, the trade freeness index reaches its maximum at 1. A share of firms in H equal to 0 or 1 corresponds to agglomeration in locations F or H, respectively. Heavy solid lines indicate long-run outcomes, *i.e.*, geographical distributions of firms towards which the economy evolves as pointed out by the vertical arrows. Figure 1 shows that, for low trade freeness (*i.e.*, values smaller than the threshold value φ^S), a dispersed geographical distribution of firms is the only long-run outcome. For high trade freeness (*i.e.*, values larger than the other threshold value φ^B), agglomeration in either location is the only long-run outcome. For intermediate values of trade freeness (*i.e.*, values between the two thresholds φ^S and φ^B) both dispersion and agglomeration can emerge in the long run. The values φ^B and φ^S are called 'break point' and 'sustain point' respectively: As trade freeness crosses φ^S from below agglomeration becomes 'sustainable' as a long-run outcome; as it crosses φ^B from below, the symmetric dispersion is 'broken'. The reason is that for large trade costs, the perfect symmetry of 'first nature' drives the location decisions of firms as these find it hard to serve both locations from a single production site. As trade costs fall, this becomes possible and 'second nature' leads to agglomeration.

Low trade costs lead to agglomeration when the supply of non-tradable goods and factors can easily adjust to demand.

Figure 1 is associated with models in which agglomeration does not affect the prices of non-traded goods and factors, such as land or, to some extent, unskilled labour. However, as firms cluster, the markets of non-tradables may be put under pressure on the demand side and their prices may therefore rise. When this happens, in terms of the framework developed in Section 2, the agglomerated location suffers a production cost disadvantage that increases in the share of its resident agents. If the price increase of non-tradables is strong enough, agglomeration may then be unwound. Whether this happens or not depends, among other things, on the level of trade barriers (Puga 1999).

To see this point, consider, for example, the implications of labour immobility. When workers are immobile, they play a double role. They give rise to localized labour supply, and their expenditures also generate localized final demand. For both reasons, as long as they are geographically dispersed, immobile workers lure firms away from congested areas. More generally, the anti-agglomeration effect of labour immobility is stronger the larger the share of immobile workers in the labour force (Krugman 1991).

Now enter trade barriers. Low trade barriers make it cheaper for firms to reach dispersed demand without producing locally. This weakens the anti-agglomeration effect of dispersed final demand. On the other hand, the level of trade barriers has no influence on the anti-agglomeration effect of dispersed labour supply, whose services are non-tradable by assumption. Accordingly, for high trade barriers, the clustering of supply in location H is hampered by the incentive that some firms still find in locating close to customers in location F. For low trade barriers, it is labour market pressure in location H that makes F an attractive production site. Accordingly, agglomeration is more likely to be sustainable for intermediate levels of trade barriers.

To summarise, NEG supplements the Marshallian perspective by suggesting that the market size and production cost effects of spatial concentration can be also due to:

- Demand linkages that increase the market size asymmetry; and

- Cost linkages that increase the production cost asymmetry.

In so doing, NEG highlights the complex interactions between goods and factors characterized by different degrees of tradability. In particular, rising demand for local non-tradables hampers agglomeration. If the supply of non-tradables is elastic enough to absorb any relevant impact of rising demand on their prices, agglomeration emerges when locations are highly integrated (low trade costs). In contrast, if higher demand maps into higher non-tradable prices, agglomeration emerges when locations are neither too isolated nor too highly integrated.

3.3 Welfare

Being driven by external economies, the economic landscape is inherently inefficient: The prices, on which consumers and firms base their consumption, production and location decisions, do not fully reflect the corresponding social values. Thus, proximity generates 'side effects' for which no quid-pro-quo is paid.

In the case of NEG, such side effects are associated with market transactions in an imperfectly competitive environment. Being intertwined with money transfers, they are called 'pecuniary externalities'. Marshallian sources belong instead to 'technological externalities'.[9] These are independent from any market interaction as they materialize through sheer physical proximity (Marshall 1890; Henderson 1978; Ciccone and Hall 1996). An example of positive pecuniary externality for a localized downstream industry is the fall in intermediate input prices due to the increase in upstream competition triggered by the entry of a new technologically advanced supplier; an example of positive technological externality is the increase in productivity that other upstream suppliers may experience through informal knowledge transmission generated by their proximity to the new technologically advanced rival.

Hence, whatever the sources of agglomeration economies, the implied geographical distribution of economic activities is generally inefficient from a social point of view.

4. The role of infrastructure

In the theoretical framework developed in Section 2 the spatial concentration of economic activities is fostered by more pronounced market size asymmetries ('market seeking') and production costs asymmetries ('cost saving'). Concentration is also promoted by easier tradability of products and factor services between locations as well as by larger differentiation of firms in terms of products ('horizontal differentiation') and smaller differentiation in terms of quality/productivity ('vertical differentiation'). Once agglomeration economies are at work, Section 3 has argued that market size and production cost asymmetries become endogenous as they not only determine but are also determined by firms' location decisions. This section discusses how different types of infrastructure act on those asymmetries, thus affecting the evolution of the economic landscape.

Different types of infrastructure may act on different sources of market size and production cost asymmetries.

4.1 Attraction and accessibility

To understand the impacts of different types of infrastructure on market size and production cost asymmetries one has to figure out the specific sources of agglomeration economies they affect. In so doing, one can exploit the fact that different sources naturally map into different geographical scopes.

An important distinction between the foregoing Marshallian and NEG sources is in terms of their geographical scope. In particular, the relative relevance of the two types of forces depends on the scale of the analysis (Ottaviano and Thisse 2001). Cities are replete with technological externalities (Anas *et al.* 1998). The same holds in local production systems (Pyke *et al.* 1990). Thus, to explain geographical clusters of somewhat limited spatial dimension such as cities and industrial districts, it seems reasonable to appeal to technological externalities that are the hallmark of Marshallian sources. However, when one turns to a larger geographical scale, it seems reasonable to think that direct physical contact provides a weaker explanation of interregional agglomerations such as the

9 The distinction between pecuniary and technological externalities is due to Scitovsky (1954).

'Manufacturing Belt' in the US and the 'Hot Banana' in Europe. This is the realm of NEG pecuniary externalities that arise from imperfect competition in the presence of market-mediated linkages between firms and consumers/workers.

Hence, while in the Marshallian perspective market size and production cost asymmetries only reflect the economic scale of local economic activity, in the NEG perspective those parameters also reflect the economic scale of all other connected locations from which inputs can be sourced and to which products can be sold. Two concepts can be usefully borrowed from spatial interaction theory to clarify this point (Smith 1975). In particular, if one visualizes the spatial economy as a network of interconnected markets, then according to Behrens *et al.* (2007b, 2008) the appeal of a market as a production site for firms depends on both its relative size ('attraction') and its relative centrality in the network of trading markets ('accessibility'). In this respect, the market size asymmetry and the production cost asymmetry would respectively measure the 'market seeking' and 'cost saving' dimensions of both attraction and accessibility.[10]

'Market potential' reflects that a location's appeal depends on own and other locations' market size and costs.

These two dimensions are embedded in a location's 'market potential'. This notion, introduced by Harris (1954) and recently refined by Head and Mayer (2004), has a nominal and a real definition. Whereas the 'nominal market potential' (henceforth, NMP) is a measure of customer proximity, the 'real market potential' (henceforth, RMP) is a combined measure of customer and competitor proximity. Formally, assume that location H is now only one of many alternative locations. The nominal market potential of H is then the weighted average of expenditures across all locations that plants can tap if located in H. In turn, the real market potential of H is the weighted average of real expenditures ('purchasing power') across all locations that plants can tap if located in H. In both cases, the weight of each location is a decreasing function of its distance from H due to trade barriers. The underlying idea is that NMP is a good proxy for total sales that plants can expect to make on average if located in H while RMP is a good proxy of the profits an average firm can make. In the long run, since firms can freely pick plant locations, profits should reach the same normal level everywhere. Therefore, in the long run RMP differences should eventually vanish as NMP differentials are capitalized in local price differences of non-tradables. Accordingly, short-run RMP differences should predict the future evolution of the economic landscape as firms are attracted towards areas temporarily boasting higher RMP.

4.2 Types of infrastructure

The distinction between attraction and accessibility is useful to classify the effects of different types of infrastructure on the differences in market size and production costs between locations.

A general definition of infrastructures is provided by the U.S. National Research Council (NRC), which adopts the term "public works infrastructures" to include "both specific functional modes - highways, streets, roads, and bridges; mass transit; airports and airways; water supply and water resources; wastewater management; solid-waste treatment and disposal; electric power generation and transmission; telecommunications; and hazardous waste management - and the combined system these modal elements comprise. A comprehension of infrastructure spans not only these public works facilities, but also the operating procedures, management practices, and development policies that interact together with societal demand and the physical world to facilitate the transport of people and goods, provision of water for drinking and a variety of other uses, safe disposal of

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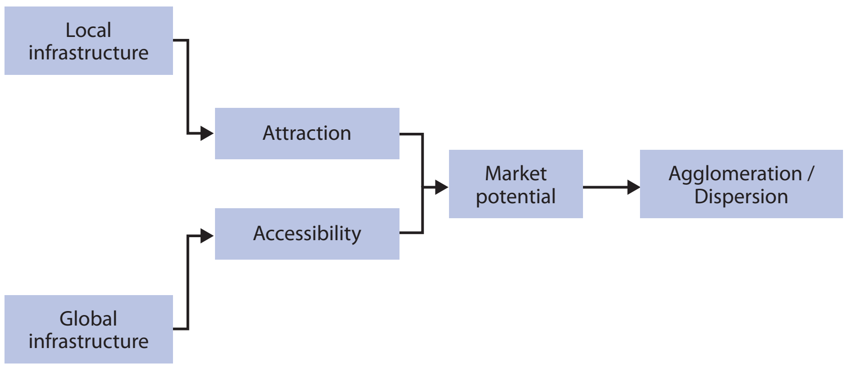
10 Attraction and accessibility are also the main ingredients of gravitational models of international trade (see *e.g.* Head and Mayer 2004).

society's waste products, provision of energy where it is needed, and transmission of information within and between communities" (NRC 1987, p. 4).

Such different types of infrastructure affect the strength of agglomeration economies differently depending on the corresponding sources. A crucial distinction is between 'local infrastructure' that mainly affects short-distance interactions and 'global infrastructure' that mainly affects long-distance interactions. The former mainly alters attraction whereas the latter mainly alters accessibility. While any classification is someway arbitrary, it is tempting to consider the provision of water for drinking and a variety of other uses, the safe disposal of society's waste products, the provision of energy where it is needed, the formation of human capital *etc.* as pertaining to local infrastructure, while the transportation of goods and people as well as the transmission of information as pertaining to both local and global infrastructure.

The foregoing considerations are synthetized in Figure 2, which summarizes the channels through which infrastructure affects the economic landscape in the economic geography literature.

Figure 2. Infrastructure and economic geography



4.3 Infrastructure and geographical disparities

Infrastructural changes may affect the geographical distribution of firms and workers between locations ('external geography') or within locations ('internal geography') (Martin and Rogers 1995).

4.3.1 External geography

When the focus is on the geographical distribution of firms and workers between locations ('external geography'), as far as NEG sources are concerned, the discussion in Section 4.1 implies that only infrastructural changes improving the market potential of a certain location are able to attract economic activities towards that location.

Better global infrastructure between rich and less developed locations can decrease the latter's attractiveness.

This has important (and someway unexpected) consequences. As a first consequence, improved global transport infrastructure between a developed location enjoying a market size advatange and a less developed one can decrease the attractiveness of the latter. This is called the 'straw effect' because economic activities migrate to developed locations through new infrastructure as juice in a glass is sucked up by a straw (Behrens *et al.* 2007b, 2008). The reason is easily understood in the wake of the simple two-location theoretical framework of Section 2, which shows that, as trade barriers fall, the dispersion push of competition weakens faster than the agglomeration pull of size differences. In other words, unless the prices of non-tradables are much higher in the developed region, better transportation improves its market potential more than it improves the market potential of its less developed trading partner.

Improved local infrastructure does not always make a location more attractive.

Another, even more unexpected, consequence is captured by the 'shadow effect', according to which improved local transportation does not necessarily make a location more attractive. To see this, one has to move away from the simple two-location model (Martin 1999a, b; and Behrens *et al*. 2007b, 2008). For example, in the presence of a third location T, if this is large (*i.e.*, it has strong 'attraction') and well connected to both H and F (*i.e.*, it has good 'accessibility'), an increase in H's market size or a decrease in H's production costs due to better local transportation may well map into a decrease in its output share. The reason is that the improved local infrastructure of H is disproportionately used for shipments to and from T, which 'casts a shadow' on H's attractiveness. That would be the case, for instance, if location T were a transport 'hub' or 'gate'. A 'hub' is a location with better accessibility to all other locations; a 'gate' is a location through which goods mostly flow in and out of a region (Behrens *et al*. 2006). Favourable demand or cost shocks to any other location could result in supply expanding in the hub or in the gate and contracting elsewhere. Hence, clustering is more likely to take place in the presence of and close to hubs and gates (Krugman 1993; Behrens *et al*. 2006).

Better global infrastructure may nonetheless reduce geographical disparities. That would happen in three leading cases. First, as already discussed, if the prices of non-tradables are much lower in less developed locations, improved transport connections with developed locations result in firms and workers relocating to the less developed location (Puga 1999). Second, if better global infrastructure allows for long-distance commuting, the concentration of firms in developed regions is partly detached from local market size as workers spend their income elsewhere. This favours some dispersion of economic activities (Borck *et al.* 2007). Third, better global means of communication (*e.g.* improved ICT) foster the diffusion of local knowledge to distant places. Whenever knowledge spillovers are the main source of agglomeration economies, production cost asymmetries fall, thus promoting a more even economic geography (Baldwin *et al.* 2001).

To summarize, improved global infrastructure supports a more even distribution of economic activities when the prices of non-tradables are much lower in less developed locations, when it promotes long-distance commuting and when it is conducive to knowledge transmission from developed to less developed locations.

4.3.2 Internal geography

When the focus of the analysis is on the geographical distribution of firms and workers within locations ('internal geography'), one has, of course, to introduce some internal spatial dimension in the simple theoretical framework of Section 2. The simplest way is to think of a location as composed of many different sites. In this case, the presence of gates (*i.e.*, sites within locations with a 'geographical advantage' in terms of better access to other locations) makes the internal geographies of locations interdependent. In particular, agglomeration in one location reduces the occurrence of agglomeration in the other one.

In addition, remoteness need not be a geographical disadvantage since a landlocked region may well be the location that attracts the larger share of firms. This is so when internal transport costs are high and, therefore, act as a barrier to competition from abroad (Behrens *et al*. 2006). Finally, when locations comprise many sites, one has also to keep in mind that labour mobility is easier within than between them. In this more complex scenario, agglomeration within locations is mainly shaped by internal trade impediments. *Vice versa*, agglomeration between locations is mainly shaped by external trade barriers (Krugman and Livas 1996; Monfort and Nicolini 2000; Paluzie 2001; Crozet and Koenig-Soubeyran 2002; Behrens *et al*. 2006).[11]

To summarize, when improved local infrastructure affects the economic landscape within a region, this can indirectly change the internal landscape in other locations.

5. Empirical evidence

The impact of infrastructure on economic performance is hard to disentangle from other concurrent effects. In particular, it is hard to figure out whether quality infrastructure is a cause or rather an effect of local economic development. Moreover, direct tests of the effects of infrastructure do not take explicitly into account the role of agglomeration economies, not to mention the specificities of their scope and sources.

It is hard to tell whether infrastructure is a cause or an effect of local economic development.

This implies that what is currently available is a wide array of empirical findings that provide only partial pieces of information on the relevance of the theoretical framework discussed in the foregoing. Against this background, the present section reviews some of the most relevant findings. These, when taken together, seem to support the structure and the implications of the theoretical framework (Ottaviano and Pinelli 2005).

5.1 Growth and inequality

The empirical relevance of infrastructure for global and local economic development can be hardly overstated (World Bank 1994). The role of infrastructure has been stressed along two main dimensions: Effects on economic growth and effects on income inequality (Calderon and Serven 2004). As to the effects on growth, most studies focus on the impact of infrastructure on aggregate output and find this impact to be positive.[12] In particular, they identify positive and significant impacts on output of three types of infrastructure (telecommunications, transport, and energy) and show that such impacts are significantly higher than those of non-infrastructure capital (Calderon and Serven 2003).

The link between infrastructure and long-run growth is much less explored. Some studies find that public expenditure on transport and communications foster growth (Easterly and Rebelo 1993). This finding is also confirmed in the case of physical infrastructure (Sanchez-Robles 1998) and in the case of communications, measured by telephone density (Easterly 2001; Loayza *et al*. 2003). On the other hand, it is argued that sometimes the inefficiency of infrastructure provision can curb and even reverse the sign of the long-run growth impact (Devarajan *et al*. 1996; Hulten 1996; Esfahani and Ramirez 2003).

Turning to income inequality, the issue is whether infrastructure has a disproportionately positive impact on the income and welfare of the poor (World Bank 2003). The presence of a disproportionately positive impact finds some support in the existing evidence (see Brenneman and Kerf 2002 for a survey). Several studies point at the effects of infrastructure on human capital accumulation: Better transportation and safer roads promote school attendance; electricity allows more time for study and the use of computers; access to water and sanitation reduces child and maternal mortality.

11 Similar results hold true in the absence of interregional migration whenever firms are linked by strong input-output ties (Puga and Venables 1997; Monfort and Van Ypersele 2003).

12 This is highlighted in a seminal contribution by Aschauer (1989), who finds that the stock of public infrastructure capital is a significant driver of aggregate TFP. Even though subsequent efforts question Aschauer's quantitative assessment, overall his qualitative insight survives more sophisticated econometric scrutiny (see *e.g.* Gramlich 1994; Röller and Waverman 2001).

Infrastructure also connects poor people in underdeveloped areas to core economic activities, thus expanding their employment opportunities (Estache 2003). Finally, better infrastructure in poorer regions reduces production and transaction costs (Gannon and Liu 1997).

Efficient supply of the right infrastructure in the right place is more important for growth than the amounts spent.

Overall, existing studies show that infrastructure is an important determinant of economic growth and income inequality. The exact impact may depend, however, on the type of infrastructure. All in all, there is a broad consensus that: "Infrastructure is a necessary but not sufficient ingredient of economic growth, and (…) the efficient supply of the right kind of infrastructure (material and institutional) in the right place is more important than the amount of money disbursed or the pure quantitative infrastructure capacities created" (Sugolov *et al*. 2003, p. 3).

This is consistent with the discussion in Section 4 insofar as the impacts of different types of infrastructure depend on the specific scope and sources of agglomeration economies.

5.2 Spillovers

Knowledge spillovers are the Marshallian source that has by far received most attention. Two main research strategies have been implemented to assess their relevance. A first strategy exploits information that can be indirectly extracted from wage and price variations across locations. A second strategy measures the presence of spillovers directly in terms of knowledge creation.

5.2.1 Wage and rent gradients

Localized spillovers make firms and workers more productive when geographically clustered. As firms and workers move to take advantage of differential productivities, these end up being entirely capitalized in local price differences that exactly match the geographical variation of wages due to productivity differences. Therefore, if wages and prices were higher in areas with a higher density of firms and workers, there would be evidence of a productivity-enhancing spillover. Moreover, if wages and prices were found to be positively associated with the density of human capital, there would be specific evidence of a productivity-enhancing knowledge spillover.

Both skilled and unskilled wages do tend to be higher in locations where the labour force is more educated, and the quantitative effect is not negligible. A one-year increase in local average education raises the average wage by 3 to 5 percent. A one percentage point rise in the local share of college educated workers increases the average wage by 0.6 to 1.2 percent. At the same time, the presence of more educated workers is associated with higher local prices. As discussed above, this is supportive evidence for the presence of productivity-enhancing knowledge spillovers (Rauch 1993; Moretti 2004).

Some understanding of the channels through which knowledge transmission happens can be obtained from the behaviours of young and old workers. Even though the former earn less than the latter in denser areas such as cities, they tend to be over-represented in those areas. As argued by Peri (2002), a possible explanation of the fact that young workers accept lower wages in denser areas is that they value the learning opportunities density offers. Differently, as people get older, the expected return to learning decreases, giving more weight to the congestion costs associated with density. This causes younger workers to move to denser areas and older workers to move to less dense areas (selection effects).

The study of wage gradients also allows understanding why the empirical literature devotes special attention to knowledge spillovers when compared with other Marshallian sources. In decreasing order of importance, learning spillovers, better matching between firms and workers, and selection effects are all responsible of the wage structure observed in denser areas (Glaeser and Maré 2001; Combes *et al*. 2004).

Thus, wages and rents are positively correlated with the geographical variation in the density of economic activities, which can be interpreted as the result of productivity-enhancing spillovers in denser areas.

Finally, some studies have also investigated the geographical scope of spillovers. Conley *et al.* (2003) reach the conclusion that knowledge transmission between two individuals vanishes starting from 90-minute-trip distances.

5.2.2 Knowledge creation

The second strategy to spillover measurement focuses directly on the process of knowledge creation. This is modelled through a 'knowledge production function' that explains the output of innovation such as patents in terms of knowledge inputs such as R&D spending and human capital (see Audretsch and Feldman 2004 for a detailed survey). When brought to data, this simple mechanism works at the level of areas and industries, but it does not work at the level of the individual firm. This is particularly evident in the case of small firms that are able to generate innovative output with negligible amounts of R&D. Such phenomenon is interpreted as evidence of the existence of knowledge spillovers that allow the firms in an area to benefit from research carried out by other institutions (universities or firms) located in the same area (Acs *et al.* 1994).

Using this research strategy, the study of the location pattern of patent families (*i.e.*, patents that reference or cite each other) allows one to establish the geographical scope of knowledge spillovers. The corresponding findings are in line with those obtained in the case of wage and rent gradients, revealing that the positive impact of spillovers fades away quite rapidly with distance. As the probability of cross-citation is much higher when inventors come from the same area, cross-fertilization is highly localized (Jaffe *et al.* 1993; Jaffe and Trajtenberg 2002). Thus, knowledge spillovers fade away quite rapidly with distance.

Knowledge spillovers fade away quite rapidly with distance.

Finally, some studies measure the overall impact of knowledge spillovers on plant productivity. According to the benchmark estimate, each year the contribution of spillovers to aggregate output growth is 0.1 percent. This estimate is essentially driven by high-tech plants since it is virtually zero for low-tech plants (Moretti 2002).

To summarize, the overall evidence is quite supportive of Marshallian sources.

5.3 Market potential

Turning to NEG sources, the discussion in Section 4.1 has highlighted the key role of market potential. In particular, it argued that demand and costs linkages attract firms and workers to places with higher 'market potential'.[13] As in the case of knowledge spillovers, the associated geographical advantage is capitalized in local price differences that exactly compensate the spatial variation of

13 Head and Mayer (2005) compare alternative measures of real and nominal market potential. Complex measures lead to results that are essentially the same as the ones associated with the simple measure devised by Harris (1954), *i.e.*, distance-weighted average expenditures of connected markets. That is why, to alleviate the reading, the distinction between NMP and RMP is dropped.

wages due to differential production and consumption amenities. This suggests two natural tests of the empirical validity of NEG arguments (see Head and Mayer 2004 for a survey). On the price side, higher market potential should be associated with higher wages and higher prices. On the quantity side, higher market potential should attract both firms and workers.

5.3.1 Price effects

Market potential variations explain about 35 percent of the cross-country income variation.

The price predictions have been tested at both international and interregional levels. In cross-country studies market potential variations explain around 35 percent of the cross-country income variation. This result does not depend on institutions, natural resources, and physical geography. Interestingly, a country's access to the coast raises the local nominal wage by over 20 percent, which reveals the dominant role of gate regions (see *e.g.* Redding and Venables 2000).

The prediction that higher market potential should be associated with both higher wages and higher land rents finds clear support in cross-region studies for the US (*e.g.* Hanson 1998). These also highlight the dominant role of transport hubs and gates. For example, a 10 percent increase of the distance from them reduces the nominal wage by 1-2 percent in Mexico (Hanson 1997).

To sum up, wages and rents are higher in locations with higher market potential, which can be interpreted as showing that demand and cost linkages enhance local productivity.

5.3.2 Quantity effects

The quantity predictions stem from the idea that local shocks to final demand or intermediate supply generate compensating movements by firms and workers. As for firms, most studies focus on foreign direct investment as this is considered the relatively footloose part of their activities.[14] A general conclusion is that foreign firms indeed favour locations with higher market potential: A 10 percent rise in market potential yields a 10.5 percent rise in the probability that a location is chosen by foreign investors.

As to workers, studies measuring the impact of customer and supplier proximity are scarce. The few existing ones suggest that migrants do respond to market potential differentials in the predicted way. Their response is nonetheless limited by distance, which may signal the presence of mobility costs and migration barriers. For example, in a study for European regions Crozet (2000) shows that a region with 100 km radius attracts workers within a radius of no more than 120 kilometres.

To summarize, the empirical literature that closely matches the theoretical predictions based on market potential is still quite thin. Nonetheless, the existing results lend support to the implications of NEG.

5.4 Trade barriers

NEG arguments imply a non-linear relation between trade barriers and the geographical concentration of economic activities: When trade costs are either high or low, economic activities are dispersed; when trade costs are intermediate, economic activities cluster (see Section 3.2).

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14 Coughlin *et al.* (1991) study the location decision of all foreign investors across US states. Head *et al.* (1999) concentrate on Japanese firms only. Head and Mayer (2002) analyze the behaviour of Japanese firms across European regions.

Trade costs have declined over time due to both improvements in the transport technology and, after World War II, reductions in tariffs. Some scholars have, therefore, tried to infer the impact of trade costs on agglomeration from the evolution of industrial location over time. For example, the geographical concentration of manufacturing across US states fell until 1900, then rose to a climax around 1927, and finally fell again until 1987 when it reached its level in 1860 (Kim 1995). The geographical concentration of manufacturing across EU countries rose sharply between 1972 and 1996 but slowed down after the implementation of the Single Market Programme in 1986 (Brülhart 2001). While these patterns are broadly consistent with NEG predictions, they can hardly be interpreted as evidence of any clear-cut impact of trade costs on agglomeration since many other variables are likely to have affected industry location over time.

A more direct approach is implemented by a so-called 'concentration regression', which regresses alternative indices of geographical concentration on various measures of 'trade costs' such as administrative barriers, geographical size (with larger areas implying greater average distance), expenditure on transport and communication as well as road/railway/communication density.[15] Existing analyses are typically cross-country. Studies on the effects of external trade barriers on cross-country agglomeration are inconclusive and their results somewhat contradictory (Combes and Overman 2004). Studies on the effects of internal and external trade barriers on within-country agglomeration have produced more clear-cut results, showing that agglomeration is more pronounced when both external and internal interactions are more costly. This is consistent with NEG as long as the average integration of the sampled countries is low enough (Ades and Glaeser 1995; Rosenthal and Strange 2001).

Empirically, agglomeration is more pronounced for intermediate than for high or low trade costs.

Clearly, the main challenge in assessing whether there exists a non-linear relation between trade barriers and agglomeration comes from the fact that it is hard to tell whether the observed level of trade barriers is 'high', 'low' or 'intermediate'. An interesting way of circumventing this problem has been recently proposed in a study that represents the first attempt to explicitly investigate the impact of transport policy on industry location within a NEG framework (Teixeira 2006). The proposed approach is a mixture of regression and simulation analyses. In particular, using data on Portugal over the period 1985 to 1998, regressions confirm the empirical relevance of the underlying NEG theoretical framework over different periods of time.[16] They also find that Portuguese transport policy has not contributed to spatial equity. However, the simulation of a further planned expansion of the transport network shows that, if transport costs are lowered sufficiently, industry will eventually spread. This suggests a bell-shaped relationship between transport costs and agglomeration, as suggested by theory.

The existing empirical evidence on the impact of infrastructure on economic performance may be summarised with the words of Rosenthal and Strange (2004, p. 2160): "Taking all of these results together, an interesting pattern emerges, with industry attributes sensitive to shipping costs (reliance on manufactured inputs, reliance on natural resource inputs, marketing of perishable products) influencing agglomeration at the state level, knowledge spillovers impacting highly localized agglomeration, and labour impacting agglomeration at all levels of geography".

15 Additional controls are introduced for the potential impact of other variables (such as development stage, industrial composition, and institutions).

16 Holl (2004) reaches a similar conclusion in the case of Spain.

5.5. An illustration: Portuguese public investment in transport infrastructure

The following analysis of the Portuguese case, drawing on a study by Teixeira (2006),[17] provides a convincing and concrete example of how the theoretical framework discussed in the present essay can be effectively used to evaluate and forecast the effects of transport policies on the spatial distribution of economic activities.

The Portuguese case exhibits several features of an ideal natural experiment. From 1985 to 1998 Portuguese public investment in transport infrastructure represents more than 1.9 percent of GDP. More than 70 percent of such investment is related to road networks. Moreover, in those years transport infrastructure absorbs 13.5 percent of the European structural funds received by Portugal, 62.2 percent of which allocated to road networks, increasing the motorway network from 234 to 1393 kilometres.

The analysis implements an empirical NEG model of the Portuguese economy, with a breakdown of 18 regions and 25 sectors, with the aim of explaining the evolution of employment across regions and industries. It estimates the importance of transport costs for interregional trade by industry and relates their variation to sectoral indexes of spatial concentration of employment. Reliance on very detailed data accounting for several types of congestion (such as the percentage of long vehicles in traffic) is used to compute the total distance and time costs between districts. As a result, one finds that Portuguese transport costs have fallen dramatically (45 percent on average) among the Portuguese districts over the reference period.

Massive infrastructure investment in Portugal has not reduced interregional income inequalities.

Contrary to the Portuguese authorities' expectations, however, such a massive decrease in transport costs has not reduced regional imbalances. The reason lies in the specific details of the infrastructural project and the specific sources of agglomeration economies. These, being of the NEG type, give a strong 'network character' to the Portuguese economic space.

That NEG forces are at work is suggested by the sectoral pattern of agglomeration. From 1985 to 1998, while transport costs fall in all sectors and spatial concentration rises for Portugal as a whole, only 12 out of 25 sectors experience increased agglomeration. In particular, as predicted by NEG, these are sectors with significant increasing returns to scale and inter-industry linkages, such as the high-tech industries (*e.g.* Medical-surgical and optical, Electronic machinery, Equipment for treatment of information) and some capital goods industries (*e.g.* Basic metallurgy, Metal products, and Machinery industries). On the contrary, sectors with limited returns to scale and weak inter-industry linkages tend to become more dispersed (*e.g.* Textile, Clothing, and Leather and footwear).

That the specific details of the project (including the original status quo) matter is testified by the simulated effects of further plans by the Portuguese Ministry of Transports for the transport road network design in 2010. Again the planned investment is huge implying overall transport cost savings of about 42 percent from 1998 to 2010. Nevertheless, the analysis predicts that this time transport cost reductions would lead to substantial spatial dispersion of economic activity with 21 out of 25 sectors reducing their agglomeration.

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17 A related study is that of Venables and Gasiorek (1999) who use a calibrated general equilibrium (CGE) model to investigate the effects of road projects in Cohesion countries.

6. Conclusion

This essay has provided an overview of the role of infrastructure in affecting economic geography in the light of both theoretical and empirical findings. As simple as it may sound, the single most important lesson is that infrastructural improvements affect the geographical distribution of economic activities. This casts a shadow on traditional cost-benefit analysis as this usually does not try to assess the impact of infrastructure projects on regional economic development (Puga 2002).

Infrastructure affects economic geography in various (and sometimes unexpected) ways. Most naturally, interregional infrastructure affects interregional location. However, it also affects intraregional location. For example, with the development of a higher order transport network, such as the Trans-European Networks (TENs), intraregional reallocations are becoming increasingly pronounced depending on differential access to the new networks (Vickerman 1995). Analogously, intraregional infrastructure affects both intraregional and interregional location. In particular, infrastructural changes in a certain region affect not only its internal geography but, precisely because they affect own internal geography, they may also alter the internal geography of connected regions.

The reason is the 'network character' of the space economy itself, which implies that the attractiveness of locating in a certain site depends not only on its market size and production cost advantages but also on its centrality with respect to alternative sites (no matter whether they belong to the same region or not). It is this network feature of attractiveness that underlies the concept of 'market potential'.

The market potential is a rather successful tool to predict the reallocations of economic activities triggered by infrastructural investment. This is true even in the case of its most unexpected implications such as the 'straw effect'. For example, in France there is some informal evidence that the construction of the Paris-Lyon high-speed rail line led to the relocation of headquarters from Lyon to Paris (Puga 2002). In Spain there are concerns that the Madrid-Barcelona high-speed rail line may reinforce the process of headquarters relocation towards Madrid (Vives 2001). In Italy it has been argued that the reduction in transport costs between North and South in the 1950s accelerated the deindustrialization process of the *Mezzogiorno* (Faini 1983).

A second important lesson is, therefore, that infrastructure investment generates externalities that may diffuse quite far. As this essay has shown, this may be true even for localised infrastructure projects.

Infrastructure investment generates far-diffusing externalities, hence the need for interregional coordination.

For example, there is evidence that, as economic activities relocate, the benefits that a region obtains from improved own intraregional infrastructure come at the expense of competing regions (*e.g.* see Boarnet 1998 for California). Similar evidence is found in the case of interregional infrastructure as earnings rise in regions receiving new national highways and fall in adjacent regions.[18]

These two lessons have two far reaching policy implications. First, effective infrastructural projects require knowledge on their impacts on the spatial distribution of economic activities. These impacts depend crucially on the specific details of the projects and the specific sources of agglomeration economies they affect. Second, regions need to coordinate not only interregional infrastructure projects but also intraregional ones to avoid beggar-thy-neighbour and self-defeating outcomes.

18 See, for example, Chandra and Thompson (2000) for a study on earnings impacts of interstate highways in US non-metropolitan counties. Additional evidence on infrastructure externalities is surveyed by Holl (2004).

Effective infrastructure projects require knowledge on the spatial impacts on economic activities.

A concrete example to see these implications at work comes from the analysis of the impact of Portuguese public investment in transport infrastructure on regional disparities mentioned in Section 5.5. This analysis convincingly shows how the theoretical framework discussed in the present essay can be effectively used to evaluate and forecast the effects of specific transport policies on the spatial distribution of economic activities.

To sum up, not only effective infrastructural projects require knowledge of their impacts on the spatial distribution of economic activities but there is also evidence that NEG provides a useful means of developing that knowledge. Therefore, NEG concepts and modelling strategies should supplement the standard toolbox of impact studies on infrastructural projects.

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ABSTRACT

We study the determinants and productivity effects of regional transportation infrastructure investment in France, Germany, Italy, and Spain. *We estimate productivity effects with regional production functions for each country controlling for the potential endogeneity of public infrastructure investment. In analyzing the determinants of public infrastructure investment two broad categories are considered: First, the normative principles such as efficiency, equity, and redistribution; and second, political factors such as electoral competition and electoral rents. The evidence shows that road infrastructure positively contributes to regional production. As to the determinants, efficiency and redistribution are consistently found to be the dominant norms while equity considerations appear to be less important. However, we find remarkable differences across countries regarding the political determinants. Which political factors matter for infrastructure investment is related to the different political systems of the various countries.*

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The politico-economic determinants and productivity effects of regional transport investment in Europe

Achim Kemmerling

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1. Introduction

Considerable research efforts have been devoted to measure the contribution of infrastructure investment to productivity and growth. There appears to exist a consensus by now about the growth-enhancing effects of public infrastructure investment, even if some studies have not found positive effects at all (for recent surveys, see Bom and Ligthart 2008, Romp and de Haan 2007 and OECD 2007). Compared to its consequences, we know considerably less about the determinants of regional infrastructure investment. Most studies treat regional infrastructure investment as an exogenously determined input to private production. However, more and more scholars have questioned this assumption (*e.g.* Crain and Oakley 1995; Duffy-Deno and Eberts 1991). Kemmerling and Stephan (2002) investigate whether the allocation of infrastructure investment across German cities is influenced by political or by economic concerns. They find that "political congruence", *i.e.*, same party affiliation of local and higher-tier governments, matters for the distribution of federal investment grants. They also find that local governments with a higher probability of re-election show a higher propensity to invest in local infrastructure projects and that, at the federal level, redistributive concerns matter more than the return on investment.

Cadot *et al.* (2006) propose a simultaneous-equation approach to estimate the contribution of transport infrastructure accumulation to French regional growth. They estimate not only the contribution of public investment to growth but also the political determinants of public investment in a panel of French regions from 1985 to 1992. The empirical findings suggest that electoral concerns and influence activities are indeed significant determinants of the cross-regional allocation of transportation infrastructure investment. By contrast, they find little evidence of concern for the maximization of economic returns to infrastructure spending after controlling for these political effects. Castells and Solé-Ollé (2005) and Golden and Picci (2008) find political determinants of infrastructure spending for Spain and Italy, respectively. Since the political systems in these countries are rather diverse, the precise channels of political influence on transport infrastructure differ from country to country. Hence, political institutions play an important role in the determination of public investment. Most prominently, federalism and the electoral system have an impact on the political economy of fiscal policies (Persson and Tabellini 2002) and the distribution mechanism of transfers.

In this article we focus on a comparison of four major European countries and their respective political institutions: France, Germany, Italy, and Spain. All four countries are similar in population size and GDP per capita but have very different political systems. Germany and Spain are both federalist countries, whereas France and Italy are not. Italy and Spain both have proportional voting systems, whereas France and Germany have hybrid voting systems that mix proportional and majoritarian elements. By comparing the four different polities we are able to shed some light onto the nature of distribution mechanisms in the four countries and on their impact on the efficiency of public investment in infrastructure. This is done by estimating a system of two equations to allow for mutual endogeneity of productivity effects and political origins of public investment.

In the following section we briefly review the literature on both productivity effects of public capital and its political economy. We derive a set of hypotheses to be tested later on. As the data collection and operationalization of our key variables are crucial in a four-country comparison, we describe these steps at some length in Section 3. We also give some descriptive evidence of how investment in road infrastructure is regionally distributed. In Section 4 we explain our estimation methodology and describe the results. We also present a battery of specification and robustness checks to gauge the validity of our results. The last section concludes with some qualifications to and broader (policy) implications of our findings.

2. Literature review and hypotheses

2.1 Productivity effects of public capital

In this subsection we briefly review the results of empirical studies on infrastructure productivity based on the production function approach, which will guide the following sections of our paper.[1] Early studies such as Mera (1973a, 1973b), Aschauer (1988, 1989a, 1989b, 1989c) or Munnell (1990a, 1990b, 1992) have documented strong correlation between public capital investment and private sector performance, concluding that public capital is key for economic performance.

However, other studies have reached different conclusions, for example Tatom (1991). Hulten and Schwab (1991) find that public infrastructure does not have an effect on regional total factor productivity (TFP) growth in U.S. manufacturing. Later studies carried out mainly for the US have also found rather diverse results. While some find positive and significant effects of infrastructure, others find only negligible or insignificant effects (*e.g.* Holtz-Eakin 1994; Evans and Karras 1994). Furthermore, the size of the estimated elasticity of output with respect to infrastructure capital (ε_{YG}) differs considerably across studies (Sturm *et al.* 1996).

For Germany Hofmann (1996) examines the impact of infrastructure on Hamburg's business sector. In this study a Cobb-Douglas production function is specified and estimated in a dynamic framework (error correction model). Utilizing data from 1970 to 1992 Hofmann finds an elasticity of output with respect to public capital that appears to be either insignificant or significant with a negative sign. This result turns out to be robust to variations in the econometric specification. In another study at the regional level, using data from 99 German cities from 1980 to 1989, Seitz (1995) finds a positive and significant contribution from infrastructure to private output, with an estimated elasticity ε_{YG} between 0.08 and 0.19. Finally, Stephan (2002) estimates the impact of public capital on private production using a panel data set from the manufacturing sector of the eleven West German *Bundesländer* (federal states) from 1970 to 1996 and finds that public capital is a significant input for production in the manufacturing sector.

The estimated impact of public capital on output tends to be positive in studies using a production function.

Also for the other Western European countries scholars have found a positive contribution of infrastructure investment to growth and productivity. For Italy Bonaglia *et al.* (2000), among others, find a positive contribution of public capital to regional growth in productivity. Mas *et al.* (1998) find similar effects for Spanish regions. Again, the magnitude of the effect and its significance depend not only on the empirical approach chosen but also on the theoretical framework in which the productivity effect of infrastructure capital is modeled. Considering the various findings of previous studies we formulate our first hypothesis.

Hypothesis 1: The regional transportation infrastructure stock contributes positively to regional production.

This first hypothesis claims that infrastructure is an important factor for regional production and growth. In the next section we turn to the determinants of public infrastructure. As argued in the introduction, the link between public investment and the level of regional output hinges on the

1 For more comprehensive surveys including studies employing the dual cost or profit function approach see for instance Gramlich (1994), Pfähler *et al.* (1997) or Sturm (1998).

allocation process of infrastructure investment. It is by no means granted that politicians optimize aggregate social welfare by strictly directing investment in an efficient way.

2.2 Determinants of public infrastructure investment

2.2.1 Economic rationales: Efficiency, redistribution, and equity

Regarding the economic rationales for the regional allocation of infrastructure investment, we follow previous research by Mera (1973a), Anderstig and Mattson (1989), Fuente and Vives (1995), Yamano and Ohkawara (2000) and Stephan (2007). Along the lines of these scholars we develop three normative principles that politicians may use as guidelines for the distribution of infrastructure investment across regions:

The government may favour regions with high infrastructure productivity, low income or low endowment in allocating funds.

- $\text{Efficiency}_i = \dfrac{y_i}{g_i}$
- $\text{Redistribution}_i = \dfrac{y_i}{l_i}$
- $\text{Equity}_i = \dfrac{g_i}{s_i}$

where y_i denotes output in region i, g_i the regional infrastructure stock, l_i the regional labour force, and s_i the size of the geographic territory (*i.e.*, the area in square-kilometres).

Efficiency implies that infrastructure spending should be beneficial particularly for those regions where its expected impact on growth is highest. We would expect investment flows to be highest to those regions where its marginal productivity is highest. This allocation of investment would ensure that the aggregate national income is maximized. Based on a Cobb-Douglas production function, marginal productivity of infrastructure is given by $\alpha y_i/g_i$, where α is the elasticity of output with respect to infrastructure capital. We simplify this insight by defining our measure of efficiency as the ratio between the gross domestic product (y_i) and the infrastructure stock (g_i) for region *i*, and assuming $\alpha_i = \alpha$ for all regions.

Hypothesis 2: According to the efficiency hypothesis, central or regional governments should target infrastructure investment to those regions where the marginal productivity of infrastructure is highest.

Redistribution implies in our simple terminology that the distribution of funds follows the principle of using infrastructure investment as a means of regional policy to promote the development of poorer regions. If governments follow this logic, infrastructure investment should be targeted on those regions where per-capita GDP is lowest.

Hypothesis 3: If the national government is concerned about promoting the development of poorer regions, it should target the infrastructure investment on regions with the lowest per-capita income.

It should be noted that the redistribution objective is in most cases in conflict with the efficiency objective. Indeed, we find negative correlation between the ranking of regions according to the efficiency criterion and that according to the redistribution criterion in all countries under investigation.[2]

2 A negative correlation of these two criteria is also reported in the case of Japan (Yamano and Ohkawara 2000).

Equity, our third normative principle, refers to the idea of guaranteeing equal living conditions in all regions. We calculate a proxy measure for it as the ratio between infrastructure endowment (g_i) and the geographical size of the territory (s_i) of a region. For instance, a fundamental norm of German federalism, which is stated in the constitution is to guarantee the equality of living conditions in all regions. The German Federal Court is known to base its judicial review of public policy on the basis of such norms. Our criterion measures to what extent a government tries to equalize the public infrastructure endowment (in terms of "infrastructure density" g_i/s_i). Regional inflows should therefore be inversely related to public capital stocks adjusted for regional geographical differences.

Hypothesis 4: If the national government has the objective of equal infrastructure endowment across regions, it should target its investment on regions with the lowest infrastructure endowment.

2.2.2 Political factors

The four countries under inspection have very different constitutions. Therefore it appears difficult to develop a uniform framework for explaining the political factors behind regional public investment policies across countries. To simplify the exposition we assume that the central government is the decisive political actor in all four countries. Of course, this is not true for federalist countries but it is possible to show the effects of departing from this assumption by comparing the results with those for the highly centralized countries Italy and France. There are several hypotheses explaining why for central politicians some regions are politically more important than others.

Regions ruled by left parties are traditionally expected to spend more on infrastructure due to a 'big-government' bias.

The traditional political-science approach to public spending relates transfers to ideological preferences of parties (*e.g.* Klingemann *et al.* 1994). The most common example is the idea that left-wing parties have a stronger inclination to spending and 'big government' than right-wing parties. Although the salience of infrastructure investment as compared to other policy areas is not necessarily very high for left wing parties, preference for high spending usually affects most policy areas. Indeed, there is some empirical evidence for such a proposition in the context of spending on regional infrastructure. Grossman (1994), for instance, finds that U.S. regions in which the Democrats were the dominant party received more transfers than other regions.

Yet the ideological distribution of voters on issues of regional infrastructure is unlikely to be one-dimensionally left-*versus*-right (Kemmerling and Bodenstein 2006). Regional interests also loom large in the political process so that even conservative parties with a strong regional base will favour higher level of spending in their regions. Examples of such parties can be found in many European countries. In Spain, for example, there are the Catalan and Bask seperatist parties, and in Italy there are seperatist parties in the northern part of the country. This leads to our first hypothesis on the political-economy determinants of infrastructure spending.

Hypothesis 5: Infrastructure investment is higher in regions with strong left parties and in regions with strong regional or seperatist parties.

Another approach to the explanation of more spending does not depend on any notion of voters' preferences. Infrastructure investment at the regional level is to a large part financed by investment grants from higher-tier governments. Both political and economic studies on intergovernmental grants or transfers have traditionally focused on normative principles such as those described in the previous subsection (Scharpf 1988; Oates 1999). Yet political economy considerations are important, since in real life the issues of efficiency of investment and its political determinants are mutually dependent: Economic efficiency of infrastructure investment depends on its political allocation, and politicians' electoral success depends on infrastructure investment and its efficiency. Thus more and more positive explanations for intergovernmental grants have been sought (*e.g.* Inman 1988).

Again, the fundamental question of these new approaches is why some regions are more successful in receiving grants than others. The politico-economic theory of multi-tiered political systems holds it that regions are unlikely to receive equal shares of public transfers or shares in accordance with equity or efficiency considerations if (a) some regions have relatively more political clout to influence the allocation of funds from the central government or (b) national policymakers rely on some regions more than on others to muster electoral support. These two claims allow deriving all our remaining hypotheses on the political factors influencing infrastructure investment.

Some regions receive more funds from the government because of strong political clout or high importance in general elections.

To start with the first claim, regions may differ either in their lobbying power or in their institutionalized political clout. Cadot *et al.* (2006), for instance, argue that lobby groups such as big companies depending on road infrastructure may be concentrated in some regions more than in others. Regions with stronger lobbies will attract higher transfers since they are able to make campaign contributions to local politicians who, in turn, press for increased grants at the national level. A concentration of political power in the hands of a few minority groups can increase the grants (Becker 1983). Moreover, local politicians themselves differ in the extent to which they lobby the national government, as the cases of intergovernmental grants in Norway (Sørensen 2003) and the United States (Grossman 1994) show. Institutional factors that enhance the lobbying power of local politicians are the size of of an electoral district and the number of seats allocated to it (Worthington and Dollery 1998) or the voting power of regions (Ansolabehere *et al.* 2002). Finally, channels of influence from lower to higher tiers of government should be easier when reinforced by partisanship. In Germany, for instance, it rather seems to be the partisan congruence between the national and the regional level (Kemmerling and Stephan 2002) that matters: In cities where the same partisan composition of government prevails as at the federal level, grant size is significantly higher than in other cities. Since there are many ways of modeling the political clout of a region, we select the following formulation of

Hypothesis 6: The higher the political clout of a region and, in particular, the higher the political congruence between the regional and the national governments, the higher is infrastructure investment in the region.

The second claim focuses on the preferences of national politicians rather than the resources of local politicians. The idea is that national politicians equalize marginal costs – that is, transfers to a region – with marginal benefits, predominantly in the form of higher electoral success. Assuming that central governments depend on local electoral support or money, national politicians will allocate funds to political strongholds (Cox and McCubbins 1986) or alternatively to those regions in which they can gain the most from additional spending (Dixit and Londregan 1998). Several studies (Levitt and Snyder 1995; Grossman 1994) found some evidence for the logic of partisan strongholds and incumbency bias (see below) in the regional distribution of federal outlays in the US. Correspondingly, we formulate

Hypothesis 7: Regional strongholds of the central government party receive more public investment than regions in which the central government party is weak.

The alternative and to some extent competing hypothesis is that central politicians are more interested in those regions in which additional spending has a disproportionate effect on the election outcome. The classic version of this argument is the one about swing voters for which there is ample evidence in US first-past-the-post elections (*e.g.* Jacobsen 1987). The simplest version of the swing-voter idea is equivalent to the closeness of the political race between the two largest parties, since the larger the distance of the major opposition party, the less likely it is that this party gains the constituency. Hence, central politicians lose interest in constituencies where they either dominate or have no chance of winning. One problem with the simple swing-voter hypothesis is that it does not fit all democratic systems alike. In multiparty or multidimensional settings, a median voter is less likely to exist, thereby increasing the number of swing-voters. It is therefore primarily an argument for the classic (majority) first-past-the-post electoral system, in which votes other than for the winning candidate are essentially lost. Nevertheless, the argument may be extended to other systems, for even in proportional systems higher electoral competition and more pliable voters should enhance parties' campaigning efforts (McGillivray 2004). Johansson (2003) finds corroborative evidence for a refined version of the swing-voter hypothesis in the Swedish case. There are also other factors that raise the marginal gains of central governments in regions. Crain and Oakley (1995) have found evidence that voter volatility and legislative stability are important predictors of the size of regional transfers. Castells and Solé-Ollé (2005) use several indicators of 'electoral productivity', *i.e.*, the marginal gains in form of additional seats from marginal increases in votes, in their relationship to public transport grants in Spain. We therefore formulate

Hypothesis 8: The larger the marginal gain in votes for the central government in a region, and the closer the political race, the larger is infrastructure investment in the region.

The swing voter idea has not remained uncontested, however. Cadot *et al.* (2006), for instance, predict an incumbency effect for infrastructure spending. The underlying idea is the margin of incumbency, that is, the lead of the incumbent political party over other parties. Those incumbent actors with a higher chance of reelection are expected to make greater efforts to receive infrastructure investment in their region. This hypothesis is formulated as

Hypothesis 9: The larger the regional vote share of the incumbent central government compared with the major political opposition party, the larger is infrastructure investment in the region.

Investment may be higher in 'swing states' and in regions with strong incumbents but lower in regions with intermediate levels of electoral competition.

One might think of Hypotheses 8 and 9 as competing, since a central government may care for either very tight electoral races or races where it is clearly ahead. In practice, however, one may also think of a non-linearity such that the central government holds both races in higher esteem than a race with a moderate level of competition.

We have now gathered all major complementary and in some cases competing hypotheses on the economic and political rationales for the distribution of infrastructure investment and can proceed to the measurement of their empirical relevance.

3. Data

3.1 Sources

In the following we briefly describe the data and their sources for each country.[3] The data for France are partly the same as described in Stephan (2000) and Cadot *et al.* (2006). They include 21 of the 22 French regions for the period 1978-1992.[4] All values have been converted into ECU at constant 1991

3 The level of regional aggregation corresponds to NUTS2 regions for France, Italy, and Spain and to NUTS1 regions for Germany.

4 Corsica was not included due to incomplete statistical information.

prices. For investment in transport infrastructure we are able to differentiate between roads, rail, and inland waterways. The infrastructure data for France are also described in Fritsch and Prud'homme (1994) and Fritsch (1995). Road infrastructure investment in France includes both public investment for all road categories and private investment for licensed motorways. The regional capital stocks of road infrastructure are determined from the regional investment series using the 'Perpetual Inventory Method' (PIM). The initial capital stock for 1975 for each region is determined in the following way. The aggregated transport infrastructure stocks in France as given by the Fédération Nationale des Travaux Publics (FNTP) are allocated proportionally to the individual regions in accordance with the investment shares of the individual regions. The calculated value is then used as the initial stock for the PIM. For the linear depreciation rate we assume a value of 2.5 percent.[5]

Regional transport infrastructure capital stocks are derived from investment data with the 'Perpetual Inventory Method'.

The measures for labor and regional value added data at market prices have been taken from the Eurostat 'New Cronos' data base (June 1999 edition). The values for 1979 and 1978 were extrapolated using GDP data for these years. The data relating to the regional stock of private capital for the period 1978-1991 have been provided by Professor Prud'Homme. A description of these data can be found in Prud'Homme (1996).[6]

For Germany we calculate regional road capital stocks separately for roads funded by federal states, districts and municipalities (*Landes-, Kreis-, und Gemeindestrassen*, district roads) on the one hand and roads financed by the federal government on the other (*Bundesstrassen*, federal roads). In both cases the PIM is applied based on investment series deflated with the GDP deflator and assuming annual depreciation rates of 0.8 percent for federal roads and 0.6 percent for district roads. These rates are chosen so as to minimize the difference between the sum of our regional road capital stocks and the nationwide figures of the stocks estimated for the government by the German Institute for Economic Research (DIW 2007). The initial regional capital stocks of road infrastructure for the West German federal states for the year 1970 are obtained from Bartholmai (1973). The information regarding investment made by the federal, state and local governments is taken from Statistisches Bundesamt (2005). It contains the road investment figures of the different bodies at the regional level.

As for the additional region-specific variables, the production function data originate from the regional accounts published by Statistisches Landesamt Baden-Württemberg. Value added is used as a measure for output. Private capital in period t is measured as the gross stock of fixed assets in all sectors at the end of year $t-1$ in constant prices of 2000. Labour is measured as the number of employees in all sectors at the level of the federal states. For the political data we use Brancati's (2007) constituency-level data set and own compilations.

For Italy the dependent variable is the public capital stock of roads taken from Picci (2002). We use data for 20 provinces from 1970 to 1998. Picci also uses the PIM to calculate his capital stock data. Data on private capital stocks come from the CRENoS Regio-IT data base (Paci and Pusceddu 2000; Paci and Saba 1997). This also holds for the other economic variables, which we extract for the years between 1960 and 1996. For the electoral variables we use Caramani's (2000) data base. This data set includes electoral results for all major parties in general elections between 1977 and 1996 at the regional level.[7] Retrieving electoral results for individual parties is not of great use, since the Italian

5 As a control for the capital stocks of road infrastructure obtained with this method, the sum over the individual regions was computed and compared with the aggregated value reported by FNTP. It turns out that the deviation between the sums of the regional stocks and the national stock is only between 1 and 2 percent.

6 The stocks for the year 1992 are computed with PIM using stocks of 1991 and adding regional gross investment in 1992 for all industries taken from the 'New Cronos' data base, assuming a linear depreciation rate of 10 percent.

7 For Italy the regional level of aggregation (20 provinces) does not match the 32 electoral districts. However, a problem of overlapping only exists for two constituencies of minor importance.

party system is notoriously unstable. Therefore we use the vote share of party families. This leads to seven families of which one reflects regional parties as in Caramani (2000).

For Spain we use data on transport infrastructure investment by the central and regional governments of 17 comunidades autónomas[8] during the period 1955-1998. The data on capital stock and infrastructure investment by government level and region come from the Fundación BBVA (Mas *et al.* 2003). We use investment in roads, which constitutes the largest part of overall spending. The stock is calculated using the PIM. Private capital stock data also come from the Fundación BBVA. The other economic variables are taken from the Regional Accounts of the National Institute of Statistics. For the political variables we again extract information from Caramani (2000). We extract the vote shares of the Spanish Workers' Party, the People's Party and the communists. The problem of regional parties anchored in only one or two regions (such as the Catalan or Bask parties) is addressed by creating a variable that lumps together the vote shares of all parties Caramani (2000) denominates as 'regional'.

3.2 Political proxy variables

The relevance of individual political factors depends on relationships between levels of government and on electoral systems.

Unlike most of the economic variables, the definitions of the political variables need careful explanation. This subsection shows for each of them how we operationalize our hypotheses on the political economy of transport infrastructure investment. Some of the hypotheses only make sense for some political systems. Notably, hypotheses on two-tiered systems are only useful for federal systems such as Germany and Spain.

As mentioned above, there is some debate in the literature on the political economy of regional transfers on whether politicians are disproportionately interested in swing constituencies (Dixit and Londregan 1998) or partisan strongholds (Cox and McCubbins 1986). We operationalize the latter as the regional vote share of the central government party.[9] Furthermore, we operationalize the idea of regional incumbency as the difference between the two largest parties in a region in national elections following Johansson (2003). Moreover, we operationalize the concept of electoral race by coding a dummy variable that equals one whenever this difference is very small, *i.e.*, less than 5 percentage points. This allows capturing nonlinear effects of the electoral race in cases where the race is really tight. Our threshold is arbitrary and alternative operationalizations are possible but we believe that not much is gained from more technical sophistication for our purpose. First, such methods may add substantive measurement error to the defined variables. Second, the underlying theory commonly assumes a one-dimensional policy space, which is unrealistic given the politics under investigation. Our version has the merit of being easily interpretable. More important is the theoretical caveat that swing voters should matter more in first-past-the-post voting systems and single-member districts. Thus we expect that the effect of swing voters and electoral tightness should be stronger in majoritarian systems such as France and the open-list system of proportional representation in Italy before 1993 (Golden and Picci 2008).[10]

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8 The choice of this level of aggregation best reflects actual decision-making power even though legal competencies differ strongly across Spanish provinces. It also makes the analysis comparable with that of the other three countries. We exclude the small regions Ceuta and Melilla as they are hardly comparable with the other Spanish regions.

9 For France 'Incumbent party' refers to either the Gaullists or the Socialists. For Germany it refers to the sum of vote shares of the coalition of the CDU-CSU and FDP before 1998 and to that of the SPD and Grüne thereafter. For Italy it is the Democrazia Cristiana for most of the period and for Spain it is the PSOE until 1996 and the People's Party thereafter.

10 We also compute complementary measures of the closeness of electoral competition in our robustness tests. One of these variables is electoral turnout, measured as the number of actual votes in relation to the size of the electorate. Many studies (Levitt and Snyder 1995; Castells and Solé-Ollé 2005) have used turnout as a proxy for the intensity of the electoral campaign and argue that it should be positively related to the size of regional investment. Alternatively, we could expect that the number of effective parties is inversely related to the size of regional investment. In this case the idea is that more

Finally, for multi-tiered political systems such as Spain and Germany, we use political information both at the central and the regional level. We compare the partisan constellation of central and regional governments to compute a measure of congruence between both levels (Kemmerling and Stephan 2002). For Spain we use a simpler congruence measure due to the lack of information on regional election outcomes. We code a dummy variable that equals one if the partisan composition of the regional and the central government coincide.

Table 1 summarizes our major political-economy variables, their operationalization and the expected sign of the relationship with public investment in road infrastructure. Following the discussion in Section 2.2, the first three variables capture broad normative goals in decision-making whereas the latter five focus on the political process and the electoral gains derived from investment in road infrastructure.

Table 1. Summary of major hypotheses and their operationalization

Hypothesis	Label	Operationalization	Expected sign
H2	Efficiency	y/g	+
H3	Redistribution	y/l	-
H4	Equity	g/s	-
H5	Left/regional parties	vote share of left or regional parties	+
H6	Political congruence (only federal systems)	for Germany: share of governmental party in regional elections for Spain: d=1 if same government on central and regional level, otherwise d=0	+
H7	Partisan strongholds	regional vote share of central government party in national election	+
H8	Electoral race	d=1 if difference of 2 largest parties <=5 percent, otherwise d=0	+
H9	Incumbency	difference in vote shares of 2 largest parties	+

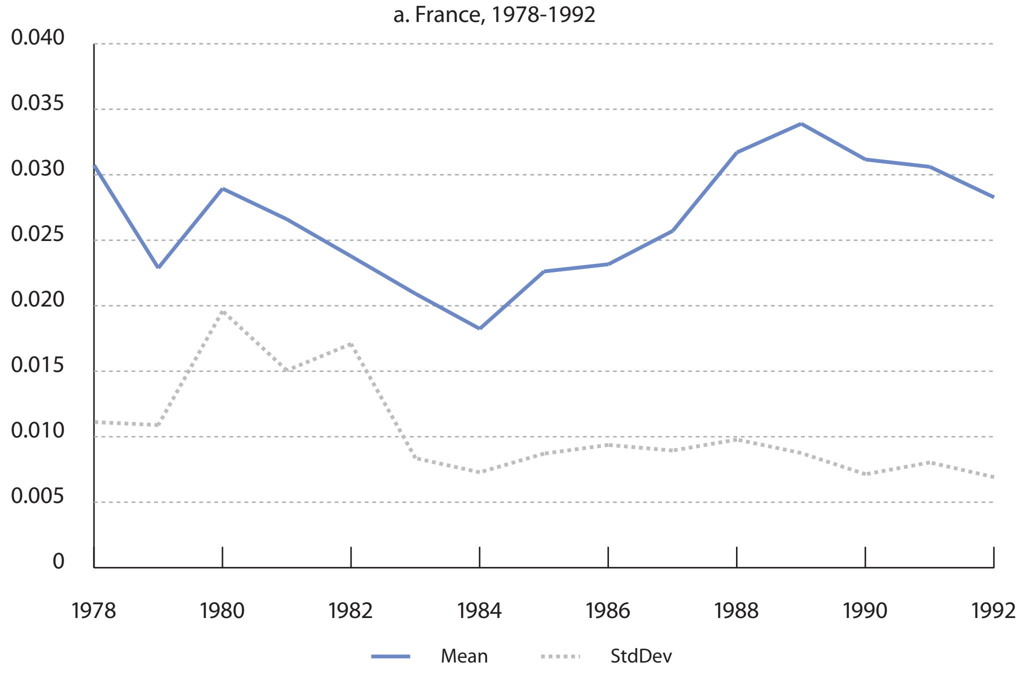
3.3 Descriptive statistics

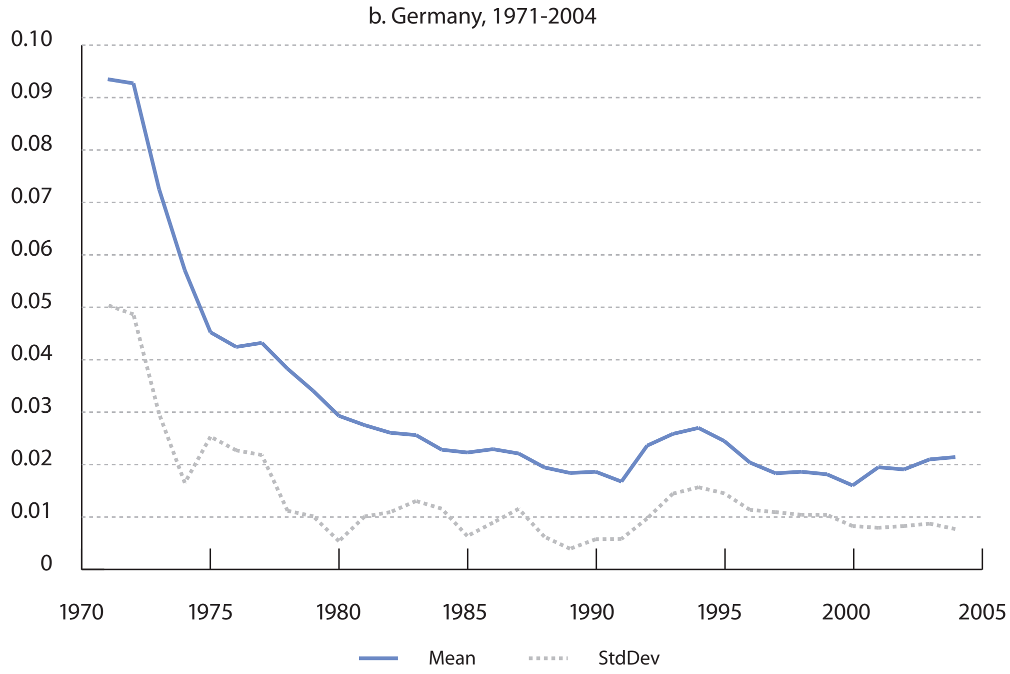
Figure 1 shows the mean and standard deviation of the growth rate of regional infrastructure stocks, the dependent variable of our policy equation. We find increasing growth rates of regional infrastructure stocks both in France and in Spain even though growth rates in Spain have decreased after their peak in the 1990s. In contrast, for Germany and Italy we note a decrease in the average growth rate of regional infrastructure stocks. The standard deviation does not decrease in the same proportion, implying an increasingly heterogenous growth pattern across regions. Further summary statistics of the dependent and independent variables for the different countries are presented in Tables A1 to A4 in the Annex.

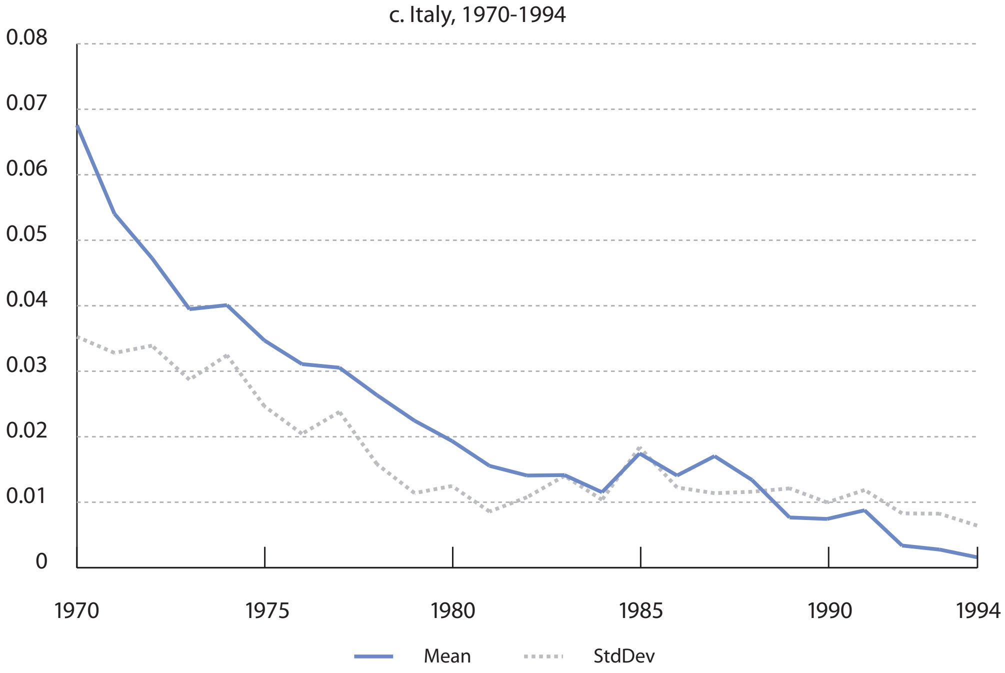
Average growth of regional infrastructure stocks decreased in Germany and Italy but increased in France and Spain.

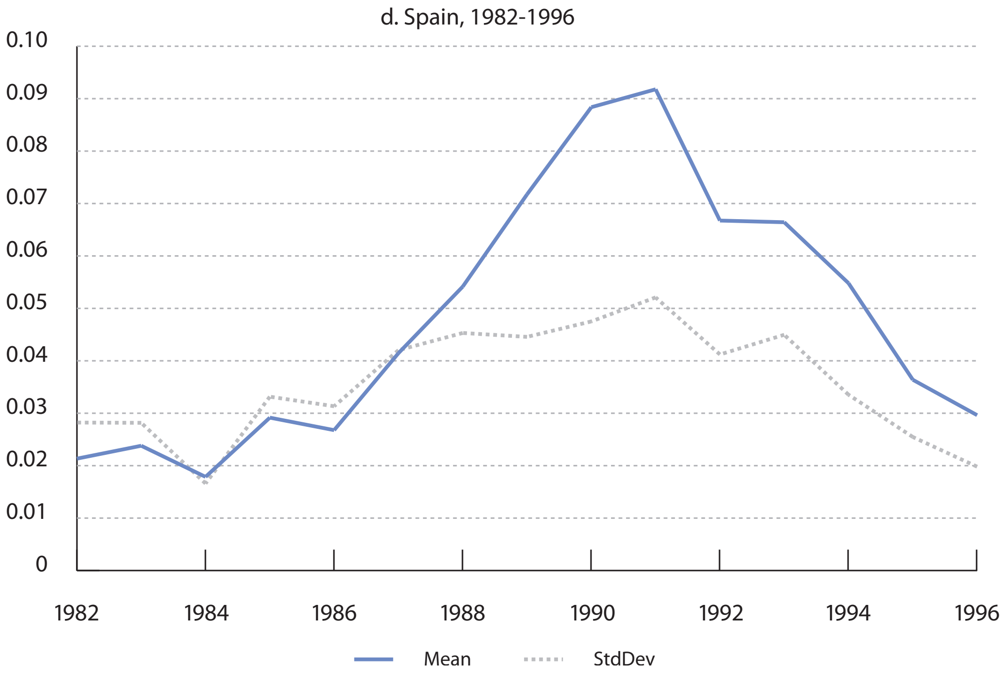
political parties make additional spending less effective for central government parties, since electoral gains are spread over several parties. The number of effective parties has also been used as an indicator for additional veto players, which make political changes in general more difficult (Tsebelis 2002). We follow Laakso and Taagepera (1979) by operationalizing the number of effective parties as one over the Herfindahl index of the vote share of parties.

Figure 1: Development of growth rates of regional transportation (road) infrastructure investment






c. Italy, 1970-1994
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1970
1975
1980
1985
1990
1994
Mean
StdDev


d. Spain, 1982-1996
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1982
1984
1986
1988
1990
1992
1994
1996
Mean
StdDev

4. Empirical estimation and results

4.1 Specification of the simultaneous equation model

Aschauer (1989b) has triggered a controversial debate about the contribution of public capital to growth using a simple production function framework with public capital as factor input to production. Several authors have argued that this approach could suffer from an endogeneity problem as there might be feedback effects from growth to infrastructure spending. Therefore a simultaneous-equation approach has been proposed where public infrastructure investment is endogenously and explicitly explained by several variables (Duffy-Deno and Eberts 1991; de Frutos and Pereira 1993; Kemmerling and Stephan 2002; Kawaguchi *et al.* 2005; Cadot *et al.* 2006). Following this line of reasoning, we specify a simultaneous equation model consisting of two equations – a production function and a policy equation. The two equations are linked through the production function by the definition of the current stock of infrastructure capital (in logs) as $\ln g_{it}=\ln(g_{i,t-1}+\Delta g_{it})$, where Δ is the first difference operator. Assuming a Cobb-Douglas functional form, the logarithmic regional production function can be written as:

$$(1) \qquad \ln y_{it}=\beta_0+\nu_i+\lambda_t+\beta_k \ln k_{it}+\beta_l \ln l_{it}+\beta_g \ln g_{it}+\varepsilon_{it},\ i=1,\ldots,N;t=1,\ldots,T$$

Regional output and transport infrastructure investment are jointly determined by the production function and the policy equation.

The GDP of region *i* at time *t* (y_{it}) depends on private capital (k_{it}), labor input (l_{it}), and public infrastructure (g_{it}). The production function is estimated in levels and region-specific effects ν_i as well as time-effects λ_t are included.

The policy equation describes the change in the regional road capital stock relative to the existing stock (*i.e.*, the growth rate of the stock).[11] To describe the politico-economic determinants of regional infrastructure stock changes we use the following stylized policy equation:

$$(2) \qquad \Delta\ln g_{it}=\alpha_0+\theta_t+\alpha_{eff}\frac{y_{it}}{g_{it}}+\alpha_{redistr}\frac{y_{it}}{l_{it}}+\alpha_{equi}\frac{g_{it}}{s_{it}}$$
$$+\alpha_{str}\,strong_{it}+\alpha_{inc}\,incumb_{it}+\alpha_{race}\,race_{it}+\alpha_{left}\,left_{it}$$
$$+\alpha_{reg}\,regional_{it}+\alpha_{congr}\,congruence_{it}+\nu_{it},\ i=1,\ldots,N;t=1,\ldots,T$$

The dependent variable of the policy equation is the growth of the infrastructure stock, $\Delta\ln g_{it}$ in region *i* at time *t*. The first three terms on the right-hand side of equation (2) describe the efficiency, redistribution, and equity criteria, respectively. The last terms correspond to the political variables discussed in the previous section. Note that y_{it} is treated as an endogenous variable in the policy equation, whereas $\Delta\ln g_{it}$ is treated as an endogenous variable in the production function.

As we aim to analyze the cross-regional allocation of investment (and not the intertemporal within-region allocation), we do not include region-specific dummies but only time-effects θ_t in the policy equation. These time-effects control for any common shocks at time *t* so that the remaining heterogeneity in investment captures differences across regions.

4.2 Econometric methodology

The endogeneity of the growth rate of regional road capital stocks in the production function is taken into account by using the non-linear GMM estimator proposed by Andrews (1991) whereby

11 Note that $inv_{it}/g_{it}=(g_{it}-g_{i,t-1})/g_{i,t-1}\approx\Delta\ln g_{it}$.

the exogenous variables of both equations are used as instruments. The GMM estimator provides consistent estimates of standard errors in the presence of heteroscedasticity and autocorrelation.[12] The results of specification tests on autocorrelation, heteroscedasticity and stationarity are discussed in Annex A1. They support the application of consistent estimators in general. When estimating simultaneous equations an issue that is even more important is the validity of instruments, *i.e.*, their non-correlation with the error term. In the context of the GMM estimation the validity of overidentifying moment restrictions can be tested as proposed by Hansen (1982).[13]

4.3 Estimation results

Table 2 shows the results of the non-linear GMM system estimation for each country.[14] Both equations are estimated with a good fit, though a large fraction of the fit is likely to be attributable to the region and time dummies and less so to the explanatory variables. The region- as well as the time-effects are significant in both equations for all countries. The choice of instruments in the GMM estimation is backed for all countries as the Hansen test does not reject the null hypothesis of valid instruments in any equation at the 5-percent significance level.

Regarding the results for the production function, we would *a priori* expect estimates of labor elasticity between 0.5 and 0.8 and of capital elasticity between 0.2 and 0.5. Furthermore, we would expect the labor- and capital elasticities to add up to one, implying constant returns to scale in the private inputs. The reported production function estimates in Table 2 are in line with these expectations only for Italy and France whereas the production function results for Germany and Spain appear to be less plausible with respect to the estimated labor elasticities, which are far below 0.5, in particular for Spain.

Transport infrastructure is found to foster output, except for Spain, with the elasticity ranging from 0.05 to 0.20.

Similarly, we find different estimates for the impact of transportation infrastructure on regional GDP. A very low and insignificant contribution is seen for Spain (0.02). France has a much higher and significant coefficient (0.14) and the estimates for Germany and Italy are 0.21 and 0.20, respectively. Hence, in three out of four countries we find that road infrastructure contributes to output. In light of most previous studies our estimates lie in a plausible range from 0.05 to 0.20.

The policy equation, however, displays more diverse estimates across countries. As for the three normative principles, we find that efficiency concerns matter of the growth rates of the infrastructure stock in all countries. In addition, the sign of the coefficient for the redistribution criterion is negative and significant as expected for three countries but insignificant for France. This is perhaps not surprising as interregional redistribution appears not to be a priority in France in contrast to federalist countries like Germany or Spain. The equity criterion shows a more ambiguous pattern. Here only France has a significant estimate with the expected negative sign whereas the effect is even positive for Italy. This implies that Italian regions with a good endowment of infrastructure receive more investment than those with a poor endowment. To some extent imprecise estimates or even implausible signs may stem from correlation between some of the explanatory variables (see Annex A1).

12 Using SAS V9.2 proc model we specify the GMM estimator using the Parzen kernel. Different kernel/bandwidth choices are tested but most results are unaffected by these choices.

13 The null hypothesis states that instruments and errors are uncorrelated. The test statistic is χ^2 - distributed with $r\text{–}s$ degrees of freedom, where r is the number of instruments multiplied with the number of equations and s is the number of parameters.

14 The results from simple OLS regressions turn out not to be very different from the GMM results in terms of parameter estimates, suggesting that endogeneity is not a serious concern in most of the estimations.

Table 2. Non-linear GMM system estimation results

	France		Germany		Italy		Spain	
Policy equation Dependent variable: Δ ln *g*	1978-1992		1970-2004		1970-1994		1982-1995	
Time effects	Included /1		Included /1		Included		Included	
Efficiency	0.0049	(11.97)	0.0005	(3.07)	0.0016	(3.59)	0.7682	(3.22)
Redistribution	-0.0001	-(0.84)	-0.0005	-(2.87)	-0.0011	-(5.27)	-0.0025	-(4.18)
Equity	-7.8559	-(2.16)	0.2294	(0.48)	1.9850	(3.03)	-0.0141	-(1.44)
Partisan strongholds	0.0168	(1.62)	-0.0279	-(1.72)	0.0883	(6.04)	0.0716	(2.05)
Incumbency	-0.0019	-(0.15)	0.0433	(4.19)	-0.0255	-(2.03)	-0.0556	-(1.76)
Electoral race	0.0024	(1.40)	0.0044	(2.64)	-0.0018	-(0.68)	-0.0117	-(2.02)
Left share	0.0217	(2.62)	-0.0206	-(1.21)	0.0413	(3.54)	0.0345	(1.06)
Regional parties share	–	–	–	–	0.0929	(6.25)	0.0120	(0.53)
Political congruence	–	–	0.0172	(2.57)	–	–	0.0018	(0.41)
R^2	0.5269		0.6924		0.4591		0.5000	
Production function Dependent variable: ln *y*								
Time effects	included		included		included		included	
Region effects	included		included		included		included	
log private capital	0.1948	(7.45)	0.0407	(2.09)	0.4253	(14.59)	0.2252	(2.96)
log labor	0.7287	(10.93)	0.3429	(11.60)	0.6865	(8.31)	0.2092	(2.18)
log road capital	0.1426	(3.72)	0.2064	(6.33)	0.2008	(5.39)	0.0182	(0.72)
R^2	0.999		0.9997		0.9989		0.9982	
N	315		439		500		255	
no. regions	21		16		20		17	
Hansen test /2	43.33		42.91		42.83		37.84	

Notes: t-values in parentheses.
/1 Dummy variables included in the policy equations of France (Île-de-France) and Germany (East German *Länder*).
/2 Hansen test is distributed χ^2 with (r-s) degrees of freedom.

Also the effects of the political variables vary across countries. In general, the political influences appear to be relatively moderate. Partisan strongholds do not seem to play a major role in France or Germany whereas in Italy and Spain regions where strongholds of the national government party are located indeed receive more investment than others. The coefficient of the difference between the two largest parties (incumbency effect) is only significant with the expected sign in the case of Germany. Similarly, the tightness of the electoral race shows an effect in Germany but has an unexpected negative impact in Spain. Furthermore, we find that left parties matter in France and Italy but not in Germany and Spain. Regional parties influence the distribution of public investment significantly in Italy but not in Spain. Finally, the congruence variable has the predicted effect on the distribution of investment in one of the two federalist countries, *i.e.*, Germany but not in Spain.

Taken together, the findings of our positive political variables reveal two interesting patterns. First, the ideological variables – left or regionalist votes – only play a role in a centralised system, arguably because in federalist systems these effects are either politically contained or dominant at the regional level. In contrast, partisan congruence does play a role in one of the two federalist systems (Germany). Second, the variables capturing electoral incentives show that – as expected – partisan strongholds (H7) and the electoral race (H8) are competing hypotheses, considering the signs of the coefficients for Germany, Italy and Spain. In addition, for Germany we find evidence of a complementary relationship between the tightness of the electoral race (H8) and incumbency (H9): Elections that are either very tight or very clear lead to a significant increase in infrastructure spending.

5. Conclusions

In this paper we have investigated the determinants and productivity effects of regional transportation infrastructure investment using a simultaneous equation approach. The analysis has been conducted for four major European economies: France, Germany, Italy, and Spain.

Three major findings of the study are worth being emphasized. First, the estimates confirm for three out of four countries that regional investment in road infrastructure has contributed to regional production. The estimated output elasticities between 10 and 20 percent lie in a plausible range and indicate that the economic contribution of infrastructure to regional development is not trivial at all. The insignificant estimate for Spain is in contrast to previous studies (*e.g.* Mas *et al.* 1996; Cantos *et al.* 2005), which use longer time series of the variables.

Second, we can establish that normative principles guide the distribution of investment to a large extent. In particular, we find that efficiency and redistribution criteria are relevant for the allocation of infrastructure investment across regions whereas the equity criterion is less important. These findings are also partly in contrast to previous work. For instance, Cadot *et al.* (2006) do not find that efficiency matters for the regional allocation of investment in France. However, their policy equation is differently specified and the period of investigation is shorter than in our case.

Efficiency and redistribution concerns drive regional infrastructure investment more than political factors.

Third, our findings show that political factors influence the regional distribution of infrastructure investment but are generally less important than anticipated. As we have elaborated in this paper, the results also support the view that political factors have a different impact depending on the political system at hand. For example, partisan strongholds and ideologic preferences matter to a greater extent for centralist political systems compared to federal ones. The effect of political congruence (same political affiliation of higher- and lower-tier governments) on the allocation of investment is supported at least for Germany. We also find evidence of a competing relationship between favouring partisan strongholds on the one hand, and favouring very tight or very clear electoral races on the other.

Data quality is an issue for the robustness of the results, econometric sophistication is not.

A few words on the limitations of our study are in place. First, according to our assessment the robustness of the results depends less on the sophistication of the applied econometric estimation methods (exemplified by the rather small differences between OLS and GMM estimates) than on the quality of the underlying data. The data for this study have been collected from several sources using different definitions, concepts, calculation methods, and so forth. This limits the comparability of figures across countries. However, the data should be consistent for regional comparisons within countries. Second, we are aware that in particular the political proxy variables are sometimes rather crude measures of the underlying mechanism formulated in the hypotheses. For instance, we have presumed a positive influence from electoral competition on infrastructure spending but this can only be proxied for by the outcome of the last election. Certainly, there might be tight political competition in a region, which is not reflected in the difference of vote shares between the two largest parties in the last election. Third, for two out of the four countries (France and Italy) we cannot distinguish at which level (regional or central government) road investment is administrated. Obviously we would expect a stronger political influence (*e.g.* from national election outcomes) in cases where the investment is under the control of the national government.

Overall, the approach presented here provides interesting insights into the determinants and productivity effects of regional transport infrastructure and may serve as an inspiration and starting point for future investigations into these topics.

Annex

A1. Specification tests and robustness checks

We have performed several specification and robustness checks regarding the econometric results. A first important issue is multicollinearity. The condition numbers are much higher than 100, which is seen as a critical value in Judge *et al.* (1985). Thus, imprecise estimates or even implausible signs of parameters might stem from the high correlation between some of the explanatory variables, which is even exaggerated in cases where the variables do not have much time variation and region-specific effects are included. However, there is no applicable solution to the multicollinearity issue.

A second issue is heteroscedasticity and auto-correlation in the residuals. The results of specification tests indicate that heteroscedasticity (Breusch-Pagan LM) and non-stationarity of residuals (Levin-Lin panel test)[15] are present both in the policy equation and the production function. Autocorrelation is also present in both equations according to the Godfrey LM test. Accordingly, the application of the non-linear GMM estimator with consistent estimation of the variance-covariance matrix of parameter estimates is justified.

Finally, the null hypothesis of a unit root in the residuals is tested for and can be rejected in almost all cases for both equations using the Levin-Lin test[16] (Levin *et al.* 2002). The only exception is Germany where due to the balancedness requirement of the Levin-Lin test we had to split the samples to only West German regions from 1970 to 2004 and all regions from 1991 to 2004 including the East German *Länder*. For the latter sample the test does not reject the null hypothesis of a unit root in ln*y* but the test based on the former sample with only West German *Länder* rejects it. We are not too much concerned about this outcome as the sample from 1991 to 2004 is a small part of the total sample and the power of the test may be limited given the relatively short time-series from 1991 to 2004. We have also performed an estimation where we allow for different estimates before and after the German reunification for key variables (structural break). The outcome is interesting and yields plausible results, and three of them are worth mentioning. First, the elasticity of output with respect to infrastructure capital is significantly lower after reunification compared to the years before. Second, the efficiency criterion becomes less significant after reunificaction, whereas both the redistribution and equity criteria gain significance, showing the expected negative sign. Third, the effect of political congruence becomes more important after reunification.

15 The idea for the stationarity test of the residuals is that, if any of the variables in the linear regression equation is non-stationary, this would also lead to non-stationarity of the residuals due to the definition of residuals as $\varepsilon = y - \Sigma\beta_i x_i$.

16 The Levin-Lin tests were performed without specifying a time trend and including two lags to account for autocorrelation of order two (expect for Germany, where a lag of one was specified).

A2. Descriptive summary statistics of the variables

Table A3. France (*n*=315)

Variable	Mean	Std Dev	Min	5th Percentile	Median	95th Percentile	Max
$\Delta \ln g$	0.0266	0.0117	0.0032	0.0096	0.0257	0.0471	0.0893
Efficiency	6.7776	1.4124	4.1439	4.4755	6.7055	9.7227	10.9323
Distribution	35.0550	5.0543	23.6208	27.3734	34.7811	42.8373	55.2802
Equity	0.0003	0.0001	0.0001	0.0001	0.0002	0.0005	0.0006
Strongholds	0.4735	0.0676	0.3005	0.3635	0.4724	0.6165	0.6233
Incumbency	0.0999	0.0624	0.0005	0.0042	0.0978	0.2116	0.2231
Electoral race	0.2762	0.4478	0.0000	0.0000	0.0000	1.0000	1.0000
Left	0.4939	0.0739	0.2822	0.3573	0.4943	0.6299	0.6415
$\ln y$	10.2558	0.6729	8.8873	9.4755	10.1792	11.3885	12.5248
$\ln k$	10.4171	0.7048	8.8781	9.5155	10.3532	11.7723	12.5375
$\ln l$	6.7090	0.5942	5.6017	5.9852	6.4977	7.6857	8.5389
$\ln g_{t-1}$	8.3371	0.6770	6.4943	7.4972	8.2962	9.5269	10.1984

Table A4. Germany (*n*=439)

Variable	Mean	Std Dev	Min	5th Percentile	Median	95th Percentile	Max
$\Delta \ln g$	0.0298	0.0245	-0.0037	0.0089	0.0231	0.0767	0.2213
Efficiency	5.1188	2.4311	2.5566	2.7446	4.2469	10.9511	12.1032
Distribution	46.7350	9.8070	24.2491	30.6071	46.8987	62.2887	74.6434
Equity	0.0029	0.0046	0.0001	0.0002	0.0006	0.0166	0.0213
Strongholds	0.4738	0.0881	0.2363	0.3131	0.4885	0.6160	0.6568
Incumbency	0.1062	0.0815	0.0000	0.0070	0.0955	0.2521	0.3333
Electoral race	0.3235	0.4683	0.0000	0.0000	0.0000	1.0000	1.0000
Left	0.4439	0.0806	0.2678	0.2936	0.4413	0.5874	0.6434
Congruence	0.4234	0.0973	0.1048	0.2277	0.4246	0.5882	0.6519
$\ln y$	11.2383	0.9673	9.1516	9.6959	11.1741	12.7983	13.0715
$\ln k$	12.8103	0.9596	10.8946	11.3233	12.7429	14.3866	14.6084
$\ln l$	7.4170	0.9029	5.8856	5.9410	7.3286	8.8798	9.0491
$\ln g_{t-1}$	9.6665	1.0927	7.2834	7.9073	9.7035	11.2912	11.4391

Table A5. Italy (n=500)

Variable	Mean	Std Dev	Min	5th Percentile	Median	95th Percentile	Max
$\Delta \ln g$	0.0225	0.0251	-0.0069	-0.0023	0.0156	0.0770	0.1436
Efficiency	4.4906	2.9407	0.9578	1.1698	3.5627	10.6820	14.1450
Distribution	46.0254	8.6157	24.2825	32.7750	45.4300	61.1102	69.5105
Equity	0.0018	0.0024	0.0001	0.0002	0.0007	0.0078	0.0135
Strongholds	0.2773	0.1410	0.0000	0.0523	0.3073	0.4884	0.5407
Incumbency	0.1305	0.0821	0.0016	0.0131	0.1233	0.3146	0.3627
Electoral race	0.1720	0.3778	0.0000	0.0000	0.0000	1.0000	1.0000
Left	0.3984	0.1195	0.0000	0.1893	0.4100	0.5773	0.6063
Regional parties	0.0450	0.1111	0.0000	0.0000	0.0005	0.3441	0.4980
$\ln y$	10.3938	1.0998	7.7470	8.1236	10.4088	11.8595	12.5048
$\ln k$	12.0140	0.9751	9.5125	10.0324	12.0723	13.3624	14.0462
$\ln l$	6.5824	1.0299	3.9627	4.4161	6.5201	7.9306	8.3082
$\ln g_{t-1}$	9.0740	0.6525	7.2465	7.7457	9.1976	9.8550	10.2246

Table A6. Spain (n=255)

Variable	Mean	Std Dev	Min	5th Percentile	Median	95th Percentile	Max
$\Delta \ln g$	0.0480	0.0431	-0.0186	-0.0094	0.0385	0.1415	0.2072
Efficiency	1.5775	0.9920	0.3356	0.5602	1.2989	3.8287	4.7869
Distribution	30.7125	5.4250	15.1243	21.3953	30.5139	39.3054	42.7330
Equity	0.2388	0.3384	0.0147	0.0239	0.0967	1.3300	1.6265
Strongholds	0.3945	0.1103	0.0183	0.1470	0.4018	0.5416	0.6070
Incumbency	0.1284	0.0988	0.0014	0.0141	0.1101	0.3252	0.3875
Electoral race	0.2941	0.4565	0.0000	0.0000	0.0000	1.0000	1.0000
Left	0.4759	0.0911	0.2428	0.3133	0.4704	0.6388	0.6691
Regional parties	0.0781	0.1483	0.0000	0.0000	0.0000	0.4928	0.6000
Congruence	0.6275	0.4844	0.0000	0.0000	1.0000	1.0000	1.0000
$\ln y$	16.5236	0.9087	14.5997	14.9980	16.4343	18.0740	18.2571
$\ln k$	16.0945	0.8350	14.1620	14.5537	16.0288	17.3941	17.8424
$\ln l$	6.2078	0.8857	4.3621	4.5031	6.1134	7.5546	7.7433
$\ln g_{t-1}$	13.8876	0.8111	12.0718	12.3517	13.9654	15.0901	15.5591

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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.*

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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:

$$(1) \quad y_{i,t} = \alpha_i + \beta \ln GDP\,0_{i,t} + \gamma Inf_{i,t} + \delta x_{i,t} + \zeta SpillInf_{i,t} + \varphi Spillx_{i,t} + \kappa \ln Nay_{i,t} + \varepsilon_{i,t}$$

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

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

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

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

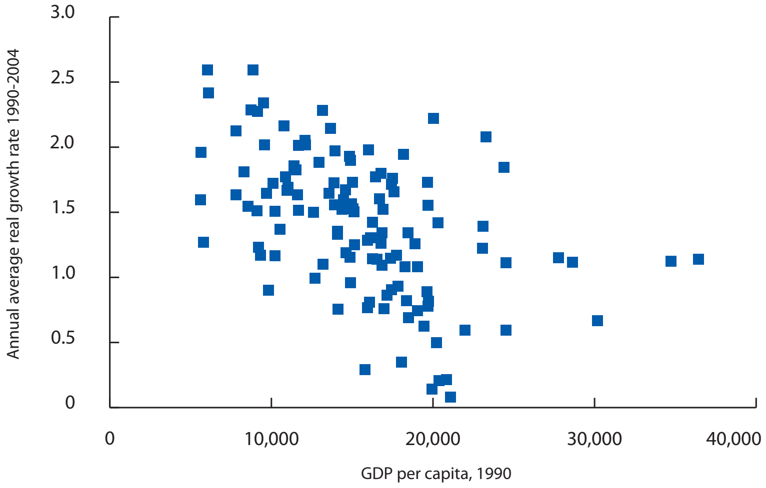
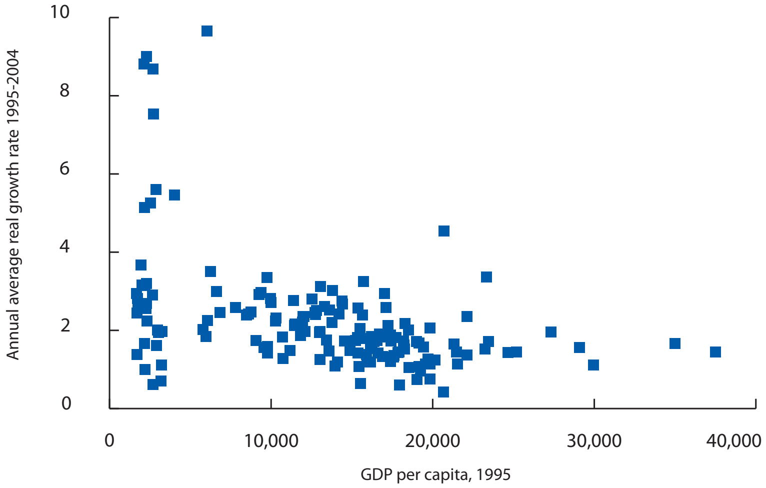


Figure 1b. EU-25: Initial GDP conditions and regional growth rate, 1995-2004



Source: Eurostat Regio database; own calculations

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

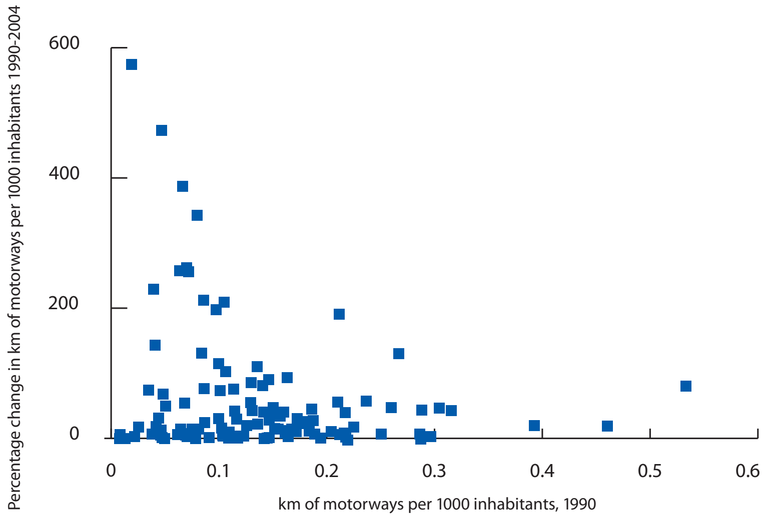
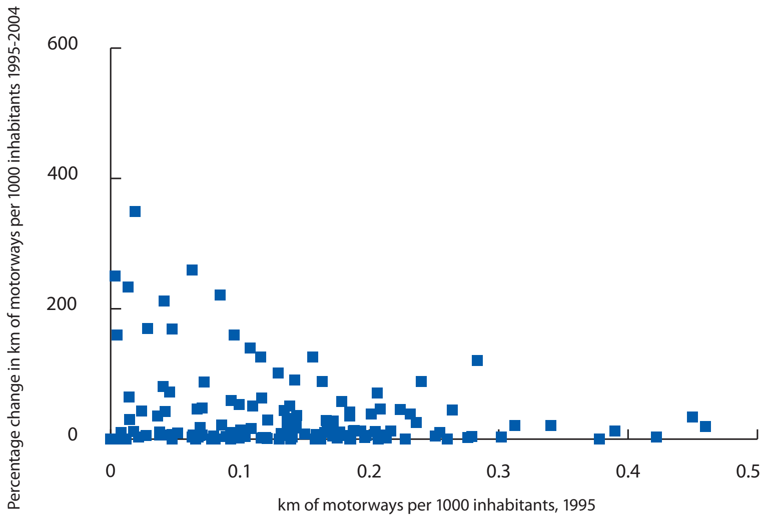


Figure 2b. EU-25: Endowment and change in motorways per thousand inhabitants, 1995-2004



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

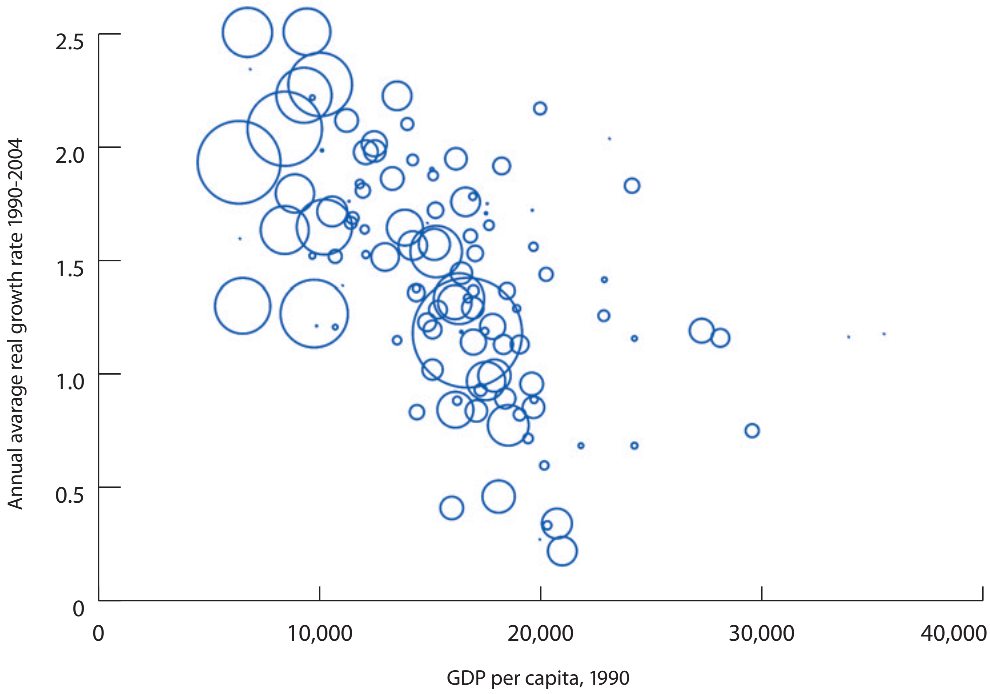
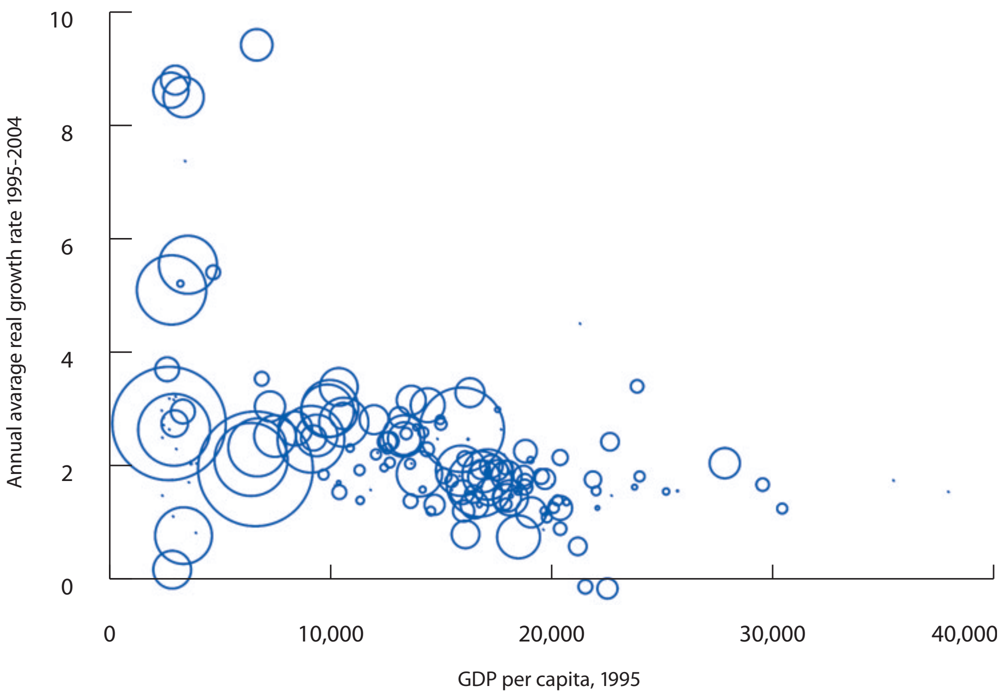


Figure3b. EU-25: Initial GDP conditions, regional growth and infrastructure development, 1995-2004



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.

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.

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

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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ABSTRACT

This paper deals with the effects of cross-border transport infrastructure in the presence of agglomeration economies. *Cross-border infrastructure is more likely to increase than to decrease inequalities between and within regions, and has not helped regional convergence in Europe. Under-investment due to spillovers, coordination failures, and the inadequacy of networks originally designed for national markets provide a role for supranational institutions. Hub-and-spoke networks tend to increase urban primacy while cross-border transport connections tend to reduce it. Improvements in transport and communication allow firms to separate innovation, management and production, increasing efficiency and urban interdependence.*

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Agglomeration and cross-border infrastructure

1. Introduction

Diego Puga

Economists have traditionally explained spatial differences in production, employment and income through differences in underlying characteristics. These characteristics include differences in natural endowments, as well as differences in the endowments of other factors that can only be changed slowly – the amount of capital accumulated over time, or the skills acquired by the workforce – and differences in the technology available at different locations. Such differences have much to explain when one compares regions and countries that are far away or have very different development levels. They also have relatively straightforward implications for cross-border infrastructure improvements: By facilitating trade, improvements in transport and communication across regions and countries will lead to increasing specialization in activities in which regions have a comparative advantage. Such specialization will typically generate aggregate gains in all regions involved, even if within each region there are both winners and losers from this process.

Comparative advantage considerations are not the main determinants of differences in production structures and patterns of trade across locations that are geographically close and similar in terms of underlying characteristics. Recent work in economic geography indicates that, in such a context, a key part of what makes a location particularly attractive for certain activities is the combination of localized increasing returns and how easy it is to access customers and suppliers from that location. This implies that regions with similar underlying characteristics can end up looking very different. The role of cross-border infrastructure in this context is also much more complex.

In this paper we begin in Section 2 by reviewing the literature that has often been called new economic geography, which tries to explain broad patterns of agglomeration extending across substantial parts of a region or even crossing regional boundaries. This literature puts a strong emphasis on transport costs and how they affect regional inequalities in production, employment, and income. We review the role of cross-border projects according to this work and also discuss the empirical evidence on their impact, drawing from a broad range of studies, especially for Europe. These studies include papers that are closely related to the new economic geography and others that are not, studies based on aggregate data as well as others using geographically detailed data on specific projects.

In Section 3 we turn to agglomerations at lower geographical levels, particularly those that operate at the level of individual cities. We study the role of transport infrastructure in either increasing the benefits or reducing the costs of large cities, how it affects the concentration of urban population in a country's largest city, and its role in facilitating the spatial separation of the various activities of firms and the growing interdependence of cities.

Throughout the paper we take a broad view of cross-border infrastructure, taking this to mean infrastructure that crosses the administrative boundaries of regions or countries, and therefore serves mostly to facilitate movement of goods and people across regions rather than within regions. A specific type of cross-border project is that which crosses national boundaries or the boundaries of regional jurisdictions with significant power to design and finance their own transport and communication infrastructure. These have distinguishing features that we also discuss. However, much of the paper deals with connections across regional borders more generally. We also discuss when the effects of cross-border projects are similar to local transport and commuting projects and when they are different.

2. Agglomeration, cross-border infrastructure, and regional inequalities

The new economic geography builds on two basic elements. First, large markets are disproportionately attractive for firms producing differentiated products under scale economies. Second, large markets are large partly because many firms and consumers choose to locate in them. The combination of market access and mobility creates a 'snowball' effect whereby a large market attracts more firms and people who will work for those firms, and the demand for intermediates by these firms and the demand for final goods by their workers make the market even larger, which in turn attracts even more firms and workers.

Let us look at these two key elements of new economic geography models, market access and mobility, in more detail. We will then explore their implications for cross-border infrastructure.

2.1 Market access

Large markets are disproportionately attractive for firms producing under increasing returns to scale because of the 'home market effect'.

Large markets are disproportionately attractive for firms producing with increasing returns to scale because, in imperfectly competitive industries where differentiated products are subject to transport costs, each firm typically has a larger market share close to its home location than far away. Consequently, firms with a larger home market have larger sales. With scale economies, larger sales allow firms to exploit economies of scale further, lowering their costs and increasing their profits. This in turn encourages existing firms to expand and attracts new firms into this market. As a result, if there were two regions in a relatively isolated country and one of them accounted for 60 percent of demand, it would produce more than 60 percent of the part of output that is characterised by scale economies. This is the 'home market effect' (Krugman 1980).

Defining the relevant size of demand in a market is straightforward in the benchmark theoretical model with only two regions: It is enough to look at demand from consumers, firms and government in the market itself. Furthermore, Head *et al.* (2002) show that, in the two-region context, the home market effect holds not only in static but also in dynamic terms: An increase in the share of demand that a market holds causes an even greater increase in its share of output characterised by scale economies. In reality, however, countries have many regions and are rarely isolated. As Head and Mayer (2004) point out, reformulating the home market effect in a multi-region, multi-country framework is not straightforward. The main difficulty is that, when there are more than two regions, the relevant size of demand in a market must combine demand from consumers, firms and government in the market itself with a measure of accessibility of consumers, firms and government in every other market. This is where cross-border infrastructure becomes key.

Behrens *et al.* (2004) extend Krugman's (1980) theoretical model to many regions allowing not only for differences in the size of demand in different regions but also for differences in the quality of transport links connecting them. They show that the attractiveness of a region for firms is a combination of three elements: Market size (attracting firms towards high-expenditure countries), accessibility (attracting firms towards countries that are centrally located or have good transport connections), and competition (driving firms away from markets easily served by many competitors). This raises three important issues for home market effects.

First, high-quality transport connections and a central geographic position are a crucial part of what makes demand for firms located in a particular region large, allowing the region to attract a disproportionate share of tradable sectors producing with increasing returns to scale (henceforth 'industry'). Thus, it is more appropriate to think of this force of attraction as a 'market-access' as opposed to a pure 'home market' effect. This turns out to be very important empirically. Davis and Weinstein (1996), focusing exclusively on local demand, find little support for the hypothesis that a larger share of demand is associated with a disproportionate share of sectors characterised by scale economies. However, Davis and Weinstein (2003), using the same data for OECD countries but measuring the size of demand with a combination of local demand and accessibility, find very strong support for the hypothesis that a larger share of demand is associated with a disproportionate share of sectors characterised by scale economies. This underlines the importance of cross-border transport infrastructure as a determinant of location.

Second – and despite this finding, Behrens *et al*. (2004) show that a larger market and better accessibility do not always translate into more industry. In particular, a region with substantial local demand and good accessibility may be cast under a 'hub shadow' if it is located very close to another region with even greater demand and better accessibility. As a result, it may end up with less industry than a region with smaller demand or worse accessibility that is not as close to the dominant region and, hence is less exposed to competition from firms located there.

Third, when one moves away from the two-region abstraction to a multi-region world, the dynamic version of the home market effect no longer holds: An increase in demand in a region or a transport project that improves accessibility will not always cause a more than proportionate increase in industry and may even lead to a fall in the share of industry in the region. This will be the case when the dominant effect from increased accessibility is fiercer competition from firms located elsewhere.

Improving accessibility might fail to raise the share of industry in a region due to the 'hub shadow' and fiercer competition from outside.

2.2 Mobility

Starting from the premise that there are market size or market access effects, the new economic geography departs from earlier approaches by noting that market size itself should not be taken as exogenously given. Krugman (1991) makes this point by introducing labour mobility in the model of Krugman (1980). This apparently simple change opens the possibility of a snowball effect where even small differences in market size or market access quickly lead to substantial changes in production patterns and income.

Krugman's (1991) model, like that in Krugman (1980), considers two sectors, one producing under increasing returns and monopolistic competition, the other one producing under constant returns and perfect competition.[1] Crucially, workers in the increasing-returns sector are mobile across regions.[2] To highlight how the interaction between market access and mobility can open up large differences in production structures and income even across regions that are *a priori* very similar, the model assumes that regions are identical in every respect, including their endowment of immobile factors.

Given that regions are assumed to be *a priori* identical, it is natural to consider a benchmark situation where they have identical production structures. If one firm then decides to relocate, how does this affect the profitability of firms in the destination region? The arrival of an extra firm puts additional pressure on the product and labour markets, reducing profits and encouraging the newly arrived firm

1 Krugman's (1991) model relies on many special assumptions. However, subsequent work (see, for example, Ottaviano *et al.* 2002) has found its main conclusions to be robust.

2 Workers are, however, not mobile across sectors. Allowing for inter-sectoral worker mobility does not substantially change the results, as long as there is some immobile factor (*e.g.*, land). All that adding inter-sectoral mobility does is to strengthen the propensity of the increasing-returns sector to agglomerate by making labour supply to this sector more elastic (Puga 1998).

to go back. If there was no migration, this would keep regions identical in the absence of exogenous differences in endowments or technology. Migration can change this because the arrival of an extra firm means that more goods can be bought locally without incurring cross-border transportation. This, combined with the upward pressure on wages caused by the firm's arrival, encourages some workers to migrate towards the region to which the firm relocates. The arrival of migrants in turn causes an increase in local demand and at the same time eases pressure in the labour market. The increase in local demand, by virtue of a market size effect, may encourage other firms to relocate, which would lead to further migration, and thus a further increase in demand, and so on.

Whether or not such a chain reaction takes place depends crucially on how costly it is to transport goods across regions. When transport costs are very high, firms sell almost exclusively in their own location and all that matters then is exogenous differences in local demand. Without such differences there is no reason why sectors with increasing returns to scale should concentrate in a few locations.

As transport costs fall, it becomes easier for firms to sell in other regions. Because firms have a larger share of sales in their own market, a larger home market allows firms to exploit economies of scale further, placing them in a favourable position relative to firms with a smaller home market. The key difference introduced by worker mobility is that even tiny initial differences are enough to get a cumulative process started. Once trade costs are sufficiently low, just a few extra firms and the additional workers they bring along are enough to create a market size effect that will attract more firms and workers and amplify differences further.

When firms and workers are mobile, falling transport costs tend to spur agglomeration, increasing regional inequalities.

A first implication of models of this type for the effects of cross-border transport infrastructure connecting different regions is that, in evaluating such projects, it is important to consider their effects on the geographical distribution of economic activities. A second implication is that, in the presence of agglomeration effects, projects that result in small changes in transport costs can sometimes have large consequences. It may be tempting to see this as a further justification for using transport infrastructure improvements to reduce regional inequalities. However, a third implication of such models is that reductions in transport costs have a natural tendency to increase rather than reduce regional inequalities.

Introducing localized knowledge spillovers and growth in this type of model raises an important additional consideration: Policies targeted at reducing the regional inequalities generated and amplified by agglomeration come with efficiency losses (Martin 1999). Furthermore, for regions that lose industry as a consequence of increasing agglomeration in other areas, static losses from firm relocation are compensated, at least partly, by greater aggregate growth and efficiency (Martin and Ottaviano 1999).

Agglomeration in the model by Krugman (1991) relies on the assumption that when firms relocate towards a region, they are able to attract more workers on the basis of higher wages and better access to a broad range of goods, thereby increasing local demand and encouraging further relocation. In the United States, migration is indeed the main adjustment mechanism to changes in regional fortunes (Blanchard and Katz 1992). In Europe, however, the adjustment takes place mostly through labour-market participation decisions (Decressin and Fatàs 1995).

Does this imply that when, as in Europe, there is limited interregional migration, production structures are determined mostly by traditional comparative advantage considerations? It does not because there are other sources of agglomeration economies that do not rely on labour mobility.

A key alternative source of agglomeration operates through mobile demand for intermediates by firms rather than through mobile demand for final goods by consumers.[3] Venables (1996) and Krugman and Venables (1995) model this in a way that closely resembles Krugman's (1991) framework. In Krugman (1991), a relocation by a few firms increases demand in the destination region through the expenditure of workers attracted from other regions. In Krugman and Venables (1995) there is no interregional mobility, so workers must be drawn from other sectors instead, and the higher demand comes from the expenditure on intermediates by the newly arrived firms. In addition to this demand linkage, in Krugman and Venables (1995) there is a cost linkage because firms in a region with a larger industrial base can purchase a larger share of their intermediates free of interregional transport costs.

Despite the many similarities between the frameworks of Krugman (1991) and Krugman and Venables (1995), their different assumptions about labour mobility have crucial implications for the consequences of cross-border transport improvements. Puga (1999) explores these differences using a framework in which both interregional migration and input-output linkages may drive agglomeration.[4] Limited labour mobility weakens the propensity of sectors with increasing returns to agglomerate but tends to create wider regional income disparities. It also complicates the relationship between transport improvements and agglomeration.

Wages tend to increase in areas attracting firm relocations. Yet firms often do not necessarily move to low wage areas, because in doing so they would forego the benefits of proximity to suppliers of intermediate goods and to their customers. If workers move in response to the wage differences opened by agglomeration, this amplifies differences in market size further and encourages more agglomeration but it also mitigates income differences across areas. It should be no surprise, therefore, that the United States has both greater concentration of economic activity and smaller income differences across areas than Europe where worker mobility is much lower (Puga 1999).

When workers are immobile, falling transport costs first lead to agglomeration, too, but firms might eventually spread out.

Another, perhaps more surprising implication of limited labour mobility is that transport improvements are not necessarily associated with growing concentrations of industry. Clearly, when transport costs are very large, firms avoid shipping their output by spreading out production. A firm's location is then mostly determined by local access to immobile demand, such as demand from farmers and resource-based activities. For intermediate values of transport costs, it becomes feasible to supply markets from distance, and places with a nascent advantage in terms of market size are able to build on it and attract a growing share of industry from other places. Thus, as is also the case with labour mobility, reductions in transport costs initially increase the geographic concentration of production. However, further transport cost reductions, when there is limited worker mobility, may lead industry to spread out to take advantage of lower wages in regions with fewer firms.

It may be tempting to see this as an indication that, due to low interregional labour mobility, European integration and improvements in transport infrastructure will cause regional convergence both in terms of real wages and of production structures. However, the ability of poorer regions to catch up in this context relies on very large reductions in transport costs, on similar endowments in terms of skills, and on a flexible response of interregional wage differentials to changes in the location of production. Regarding transport cost levels, Head and Mayer (2004) estimate the model

3 In Section 3 we discuss alternative motives for agglomeration at smaller geographical scales such as cities or neighbourhoods.
4 The framework also allows agglomeration to cause differences in wages across regions, which is important to understand the relationship between transport costs and regional inequalities.

by Puga (1999) for various sectors using European and North-American data and suggest that most sectors are in the part of parameter space where reductions in transport costs will induce more rather than less agglomeration. Regarding interregional wage differentials, Puga (1999) suggests that the combination of minimal interregional migration with wage setting at the national sector level may help understand the rise in income inequalities between European regions within each country over the last 20 years at the same time as inequalities between countries have fallen. If agglomeration is not reflected in wage differences, it may be reflected instead in differences in unemployment rates. Since clusters of activity may extend across several administrative units, this can result in clusters of high and low unemployment extending across regional and even national borders, as documented by Overman and Puga (2002).

2.3 Transport and the evolution of regional inequalities

The cumulative causation that is at the core of new economic geography models, whereby additional demand attracts more production, which in turn creates even more demand, implies that modest changes in transport costs can sometimes have large effects. Casual readers of this literature may conclude from this that there is even greater rationale than traditionally thought for using transport infrastructure investment as a key instrument to reduce regional inequalities. However, if anything, these models suggest the contrary. Whether there is strong labour mobility (as in the United States), or whether there is weak mobility, large differences in skills, and constrained flexibility of wage differentials across regions within each country (as in Europe), reductions in transport costs will tend to increase, not decrease, regional inequalities.

When immobility combines with wage inflexibility, infrastructure improvements favour regions with better initial conditions.

Clearly, cross-border infrastructure projects connecting lagging regions with key markets make it easier for firms in those lagging regions to reach new customers. However, as stressed by Puga (2002), roads and rail lines have lanes and tracks going both ways. Thus, improvements in cross-border communication also make firms in lagging regions subject to stronger competition from firms in more developed areas. New economic geography models indicate that, when there is a combination of weak interregional migration and institutional constraints on wage differences across locations, the latter effect is likely to dominate and, hence improvements in communication encourage firm location in regions with better initial conditions.

The above conclusion has particularly important implications for Europe. Rodríguez-Pose and Fratesi (2004) study the allocation of the European Structural Funds across different spending categories and find that investment in transport infrastructure has not been accompanied by investment of comparable magnitude targeted, for instance, at improving workforce skills or research and innovation. While regional policies have grown from about one tenth to over one third of the EU budget, their focus has become increasingly biased towards infrastructure, especially transport networks. The majority of the European Structural Funds is spent on promoting the development and structural adjustment of regions whose development is lagging behind – called 'Objective 1' regions, mostly those with a GDP per capita below 75 percent of the EU average. About one half of Structural Funds expenditure in Objective 1 regions during the period 1994–1999 was allocated to investment in infrastructure, transport, and the environment – a proportion that rises to 70 percent in the case of Spanish regions, and to 90 percent in that of Portuguese regions. Such improvements in transport connections alone are unlikely to trigger the takeoff of lagging regions.

A first indication that vast spending in infrastructure is not helping poor regions to catch up is the fact that income convergence across European regions came to a halt in the late 1970s (see, amongst others, Marcet 1994; de la Fuente and Vives 1995; Neven and Gouyette 1995; and López-Bazo *et al.* 1999). In recent years, if anything, regional income inequalities have increased, especially inequalities within individual countries (Esteban 1999, Rodríguez-Pose 1999, Duro 2004, Rodríguez-Pose and Fratesi 2004). Overman and Puga (2002) show that regional inequalities have also increased in terms of unemployment. Regions with high or low unemployment in the mid 1980s have seen little change, while regions with intermediate unemployment have moved towards more extreme values. During this process, regions have experienced similar outcomes to their neighbours, a process largely driven by similar changes in labour demand, partly due to agglomerations that extend across regional and national boundaries.

One could still argue that perhaps there are underlying forces pushing for regional divergence, and that investment in transport and communication infrastructure prevents even stronger divergence. However, the evidence indicates that even this more optimistic view of the effects of recent infrastructure spending on regional inequalities is not justified.

The claim that transport infrastructure investment prevented an even stronger rise in inequalities is not justified.

A first approach to empirically studying the effects of transport infrastructure on the economy is to use aggregate regional data to estimate an aggregate production function. The underlying motivation is the view of transport infrastructure as an input into the production process. Early exercises of this sort (Aschauer 1989) found implausibly large returns to government capital. Part of the problem with these early estimates is that they, to a large extent, capture common time trends: In the United States and other industrialized countries the rate of public investment in infrastructure and the rate of productivity growth were both unusually large in the 1950s and 1960s. Subsequent studies tackle this by using regional data and find much smaller returns (Garcia-Milà and McGuire 1992). There is an additional potential endogeneity problem with these studies, common in productivity estimations, because inputs are correlated with unobservable region-specific productivity shocks. One way to tackle this problem is to use regional panel data with region-specific fixed effects. Using this approach, Holtz-Eakin (1994) and Garcia-Milà, *et al.* (1996) find minuscule or even zero output effects from public investment. Fernald (1999) differentiates between industries that are vehicle-intensive and those that are not to further address the endogeneity problem and once again finds very small effects, at least for additional improvements. As he notes (p. 619), “the interstate system was highly productive, but a second one would not be.”

A related literature studies the effects of transport and communication infrastructure more specifically on regional inequalities by regressing regional growth rates on initial income and various regional characteristics, including regional infrastructure investment. Using this approach and detailed data on the allocation of the European Structural Funds across regions and investment categories, Rodríguez-Pose and Fratesi (2004) show that regions that have benefited from greater investment in infrastructure, whether individually targeted at the region or cross-border in nature, have not fared better in terms of income growth and convergence.

Recent empirical studies, using very geographically detailed data on actual and planned road improvements, provide further support for the idea that recent infrastructure investment in Europe is not helping convergence. Combes and Lafourcade (2005) carefully measure the evolution of transport costs in France over the 20-year period 1978–1998. They find that total transport costs (in real euros per kilometre) declined by 38.5 percent over this period. Surprisingly, improvements in infrastructure accounted for only 3.2 percentage points, with the bulk of the cost reduction due to lower tyre and truck maintenance costs, improved fuel economy, efficiency gains from logistics, and deregulation in the transport industry.

While infrastructure improvements played only a minor role in lowering average transport costs in France since the late 1970s, they mattered for relative changes. This is yet another reason why infrastructure improvements may have much smaller effects than expected: If the bulk of the change in transport costs is driven by other considerations common to all connections, relative accessibility will not change much. Combes and Lafourcade (2007) use the detailed transport data in Combes and Lafourcade (2005) to structurally estimate a new economic geography model for France. They conclude that relative accessibility and the agglomeration processes at the core of the new economic geography can account for much of the distribution of firms across France. Teixeira (2006) applies the same methodology to study the effects of transport infrastructure investment in Portugal in 1985–1998, which represented 1.9 percent of GDP over this period. He compares the actual size of sectors at different locations in 1985 with the size predicted by the model under the assumption of transport costs equivalent to their 1998 level. The model result is greater geographic concentration of activity than was actually observed in 1985 but less than the actual concentration in 1998. He concludes that road improvements not only failed to reduce spatial concentration but in fact increased it, a process which was amplified by economic growth. However, he also suggests that further improvements could take Portugal far enough that they would be associated with the final dispersion phase predicted by certain new economic geography models during an integration process. Garcia-Milà and Montalvo (2007) compare new business locations close to major Spanish roads that were improved in 1980–2000 with locations close to major roads that were not improved (but that *a priori* were equally likely to have been improved, on the basis of observable characteristics). They find that road improvements had no significant effect on new business location decisions.

Infrastructure investment in Europe has greatly improved core-periphery links but exacerbated differences in relative accessibility.

Part of the reason why there have not been greater effects from the vast improvements in infrastructure in Europe over the last decades may be that relative rather than absolute accessibility drives location decisions. As the European Commission notes, "[i]n transport policy, cohesion countries stand to gain in absolute terms from trans-European networks but not necessarily in relative terms" (Commission of the European Communities 1996, p. 8). Gutiérrez and Urbano (1996) study the changes in accessibility (measured as a GDP-weighted sum of travel times to network nodes) that result from the implementation of the trans-European road network. They show that, while most European regions gain better access to the main activity centres and lagging regions experience some of the largest changes in absolute terms, the gap in relative accessibility between the areas with the best and the worst initial accessibility increases as a result of the network. Similar conclusions emerge from an analysis of high-speed rail. Vickerman *et al.* (1999) show that, while there will be large changes in accessibility throughout Europe as a result of new high-speed rail lines, large and centrally-located European cities will gain the most accessibility in relative terms.

Behind this relative advantage of more central locations is the 'hub effect' (Krugman 1993; Puga and Venables 1997). When major cities get connected through roads or high-speed rail lines, cities located more centrally get better access to nearly everywhere whereas in more peripheral locations the improvement is felt mostly in the access to nearby locations. This increases demand in larger and more central locations relative to peripheral ones, and through a market size or market access effect encourages relocation towards those locations that already had an initial advantage. In the case of high-speed rail this hub effect is amplified by the strong nodal aspect of the network: High-speed rail lines have few stops and this greatly increases differences in relative accessibility between locations where the train stops and those where it does not. A consequence of this may be that, paradoxically, the main effect of cross-border infrastructure is on intraregional rather than interregional differences in production. Looking at the case of Spain using detailed spatial data, Holl (2004a) finds that indeed new production establishments are significantly more likely to locate in the immediate proximity of a major road. Holl (2004b) reaches a similar conclusion for Portugal.

2.4 Peculiarities of cross-border infrastructure

The above analysis refers to cross-border communication infrastructure defined as infrastructure connecting different regions – as opposed to infrastructure facilitating internal distribution and commuting. We have seen that, unlike improvements in local infrastructure (bound to help the region carrying out the improvements), cross-border projects linking different regions have more ambiguous effects in the sense that they may harm rather than help the investing peripheral regions (Martin and Rogers 1995).

Nevertheless, the distinction between the two types of projects is not as clear as it may seem. For instance, Venables and Gasiorek (1999) calibrate a new economic geography model with data for European regions in order to evaluate the impact of several road projects financed by the Cohesion Fund. Their analysis shows that sometimes infrastructure built in a single region has strong effects elsewhere. This is the case of the completion of the M-40 ring road around Madrid. Since it acts as a central link for Spain's radial motorway network, it has strong spillover effects throughout Spain and Portugal. On the other hand, the new Tagus crossing in Lisbon improves mainly local transport and its effects are highly concentrated in the Lisbon region.

Thus, the defining characteristic of cross-border communication infrastructure projects – as opposed to local projects – is not that investment is split among several regions, but that it mainly affects the cost of moving goods and people across regions rather than within regions.

In the EU national borders make within-country trade six times larger than international trade.

National transport and communication networks were often designed with a view to facilitating trade within a country. For example, travelling within France from Toulouse to Bordeaux (210 km apart measured as the crow flies) takes just over two hours by either road or train. Travelling from Toulouse to Barcelona (260 km apart) takes four hours by road and six hours by train despite there being no customs or passport controls. A large literature documents significant border effects – discontinuities in trade as one crosses the border. McCallum (1995) estimates that in 1988 the average Canadian province traded twenty-two times more with another Canadian province than with an American state of equal size and distance. Anderson and van Wincoop (2003) show that the border effect is much lower once the average multilateral trade barriers faced by both countries are taken into account. They estimate that the border can explain Canadian inter-province trade being six times as high as trade between Canadian provinces and US states. Since the United States has a much larger economy than Canada,[5] it experiences a much smaller border effect with US interstate trade being only 25 percent higher than US-state–Canadian-province trade. In the European Union, the border effect makes within-country trade six times larger than international trade for a comparable distance and country size, according to Chen (2004).

The measured border effect may be so high because even in the closed economy, activity is not distributed evenly across the territory but gets less dense near the border. Firms respond to networks designed for the national market by agglomerating within countries in clusters that rarely extend close to, let alone across, national borders. As a result, even if trade barriers are eliminated and transport networks adapted to facilitate international shipments, an important border effect will remain as long as earlier patterns of agglomeration persist. Hillberry and Hummels (2003), using data on actual distances of shipments within the US, find a substantial amount of the border effect to be driven by the fact that sectors do not spread out within countries proportionately to population.

5 Since the US economy is eight times larger than the Canadian economy, an increase in trade barriers raises the price of a smaller fraction of goods in the United States (where more goods are produced domestically) than in Canada.

Another defining characteristic of cross-border infrastructure is that it crosses political boundaries. Since its effects spill over beyond the boundaries of the region or regions where the infrastructure is built (and thus beyond the political constituency of the corresponding government), there is a natural tendency for individual governments to under-invest in cross-border infrastructure.

In addition, because cross-border infrastructure typically extends over a number of regions, this also raises coordination problems since a connection built or improved by one government up to the border will be of little use if the project does not continue on the other side – a problem that will be aggravated if the project has particularly asymmetric effects.

Rodríguez-Pose and Fratesi (2004) study the effectiveness of both cross-regional and intraregional transport projects financed with structural funds in promoting growth in Objective 1 regions. They find that more investment on either cross-regional or intraregional projects is not correlated with higher growth. However, since few border regions are classified Objective 1 regions, this is best interpreted as evidence of the ineffectiveness of the large infrastructure investment of the structural funds rather than as evidence of the relative effectiveness of cross-border and national infrastructure investment.

Cross-border infrastructure can address the inadequacy of national networks but lack of coordination and under-investment need tackling.

Taken together, the small effects from the vast improvements in infrastructure in Europe over the last decades and the three features discussed above – networks designed for the national market becoming inadequate with growing integration, under-investment due to spillovers, and coordination failures – suggest that it may be best for supra-national institutions to concentrate on cross-border infrastructure where they have a distinct role that national governments cannot play. Regarding the adaptation of transport networks to cross-border trade, this will be particularly effective when there are clusters with potential input-output linkages at different sides of the border. Hanson (1996) finds evidence of these cross-border clusters following trade liberalization between the United States and Mexico. Local employment has grown more in those border areas that have more agglomeration of industries with strong buyer-supplier relationships. Regarding spillovers and coordination failures, the role of supra-national institutions will be particularly important when the distribution of the investment that must be made at each side of the border differs substantially from the distribution of expected benefits.

3. Infrastructure improvements and growing urban interdependence

3.1 Transport and the urban trade-off

The previous section studied the relationship between communication infrastructure and agglomerations over large geographical areas, such as those that extend across substantial parts of a region or even cross regional boundaries. We now turn to agglomerations at smaller geographical levels, particularly those that operate at the level of individual cities.

Firms and workers are much more productive in large cities than in other locations. It is also in large cities where the vast majority of substantial innovations emerge. The productivity advantages of cities and urban clusters with a high density of firms and workers have been known for a long time. The first influential modern study, by Sveikauskas (1975), regressed log output per worker in a cross-section of city-industries on log city population and found that a doubling of population increases output per worker by about 6 percent.

Urban agglomerations are more productive than other places.

A problem raised by this and other early estimates of the magnitude of agglomeration economies is that higher output per worker may not be so much a consequence of a higher local employment but its cause, *i.e.*, if a location has an underlying productive advantage it will tend to attract more firms and workers. Ciccone and Hall (1996) were the first to tackle this issue, by instrumenting for local employment. Their main finding is that reverse causality on this matter is only a minor issue. This conclusion was confirmed by much of the subsequent literature (Combes *et al.* 2007). Another issue is that output per worker may not be the best measure of productivity. The literature has addressed this by using a wide variety of productivity measures: Estimated total factor productivity, wages, and proxies like local rates of firm creation and employment growth (see Rosenthal and Strange 2004 for a discussion). The current consensus is that a doubling of city size increases productivity by between 3 and 8 percent for a large range of city sizes.

Despite the broad agreement on the magnitude of agglomeration economies at the urban level, the literature has been far less successful at distinguishing between its possible sources. There is a large theoretical literature that builds three broad classes of mechanisms to explain the existence of urban agglomeration economies (Duranton and Puga 2004). First, a larger market allows for a more efficient sharing of indivisible facilities (*e.g.*, local infrastructure), a variety of intermediate input suppliers, or a pool of workers with similar skills. Second, a larger market also allows for a better matching between employers and employees, buyers and suppliers, or business partners. This better matching can take the form of improved chances of finding a suitable match, a higher quality of matches, or a combination of both. Finally, a larger market can also facilitate learning, for instance promoting the development and widespread adoption of new technologies and business practices.

Distinguishing between these mechanisms in practice has proven difficult, although there has been recent progress (see Rosenthal and Strange 2004 for a review). Most of these mechanisms operate over very small distances and are thus not particularly sensitive to long-distance transport infrastructure (Rosenthal and Strange 2001; Henderson, 2003a). An important exception is agglomeration in order to share a variety of intermediate suppliers. Overman and Puga (2008) show that spending a large fraction of costs on intermediate inputs alone does not make a sector more likely to agglomerate. Firms agglomerate to share a variety of intermediate suppliers only if the suppliers of a sector's key intermediates are themselves agglomerated. In this case final producers tend to cluster within reasonable distance of their intermediate suppliers and long-distance infrastructure allows the benefits of such an agglomeration to be reaped further away.

While there are clear advantages to having a larger population and more employment in specific activities in a city, there are also disadvantages. Larger cities have more expensive residential and commercial land and involve lengthier average commutes. Following from the work of Henderson (1974), models of systems of cities characterize city size as the result of a trade-off between the benefits of agglomeration economies on the one hand and congestion costs on the other. The relationship between city size and the net urban benefits resulting from aggregating agglomeration and congestion costs is thus typically concave, with net benefits first increasing and then decreasing with city size.

From a policy perspective, there is a tendency to focus on promoting the benefits, in particular through cluster policies. However, the case for such cluster policies is weak (see Duranton 2008 for a thorough discussion). The existence of both benefits and costs to greater clustering implies that, unless there is a clear reason to believe that the decisions of private agents will deliver suboptimal clustering, many cluster policies may be, if not harmful, at least wasteful. Of course, there are typically inefficiencies associated with agglomeration economies. However, the inefficiencies created by different agglomeration mechanisms and the policies required to address them are quite distinct. And when such policies are in place, the danger of capture by interest groups is great.

Addressing urban congestion costs is more effective than cluster policies.

Addressing urban congestion costs, while also complex is plagued by fewer problems and can also be more effective. There are also greater public checks on such policies, since bad transport or housing policies are more easily perceived by a city's population. This would in principle point to transport infrastructure for commuting as a way to improve the trade-off between agglomeration and congestion costs delivered by cities. However, interregional transport infrastructure also plays an important role because it is often widely used for commuting. When a highway connecting two cities is built or improved, people commuting between the suburbs and the centre of each city account for much of the traffic in the first 15 to 20 kilometres at either end of the highway. As a result, highways affect the housing choices of people living in a city by facilitating commuting. Baum-Snow (2007) shows that an additional highway crossing an average US city doubles the number of people relocating from the city centre to the suburbs.

Reductions in commuting and local transport costs following the construction or improvement of highways also make a city more attractive relative to other locations. Recent empirical work finds that, as a result, highways have a positive and significant effect on urban population growth. Duranton and Turner (2008) address the issue of reverse causation – faster growth possibly leading to more roads – by instrumenting US roads with the 1947 interstate plan.[6] They find that a 10 percent increase in roads increases a city's population and employment by an extra 2 percent over the following 20 years. Addressing the reverse causality problem thereby increases the estimated effect of roads on city growth by a factor of five. This indicates that road building is endogenous to urban growth, but with more roads being built in cities with slow growth than in cities with fast growth. Duranton and Turner (2008) show that there were more roads built between 1980 and 1990 in cities experiencing a negative population shock during the previous decade. These new roads built in response to a local downturn tend to have much smaller effects on urban growth than the average new road.

3.2 Transport, trade, and urban primacy

Various types of transport infrastructure differ in their effects on urban concentration. We have already discussed the hub effect created by radial transport networks. This implies that transport networks that connect different regions with radial links through a hub city (typically the capital or the largest city) will tend to increase concentration in that city. In an urban context this will tend to increase urban primacy, *i.e.*, the share of a country's urban population that is in its largest city. Henderson (2003b) documents that many countries have excessive urban primacy. This means that the largest city has grown to a point at which additional agglomeration creates more congestion costs than benefits. However, Henderson (2003b) also finds several countries with suboptimal primacy in 1990 – mostly European countries, such as Belgium, Netherlands, Switzerland, and West Germany. He estimates optimal urban primacy by using cross-country data to calculate the relationship between a quadratic function of urban primacy and productivity growth, after controlling for other determinants of growth and allowing for variations with country size. He then shows that deviations from optimal primacy reduce economic growth substantially. Henderson (2002) documents an additional cost: Excessive primacy not only implies very large commuting and

6 The argument is that highways in the 1947 interstate plan were designed to interconnect major US cities and to connect them with Canada and Mexico, not to improve local transportation. Therefore, they are a possible cause but not a consequence of suburbanization or population growth in particular cities. This is the same instrumentation strategy as that used by Baum-Snow (2007) to study the role of roads in suburbanization, although in the latter case addressing reverse causality makes little difference to the results.

housing costs in the biggest city but strains the whole urban system by diverting resources from other cities to contain congestion and environmental costs in the biggest city.

Cross-border infrastructure can reduce excessive urban primacy.

While transport infrastructure that connects national trade through a hub city favours primacy, cross-border infrastructure that facilitates trade with the outside world will tend to reduce primacy. Krugman and Livas Elizondo (1996) develop a model that shows this effect, motivated by the case of Mexico. In a closed economy accessing demand is equivalent to accessing the local market, which is often concentrated in the main city. Opening up to international trade, whether it is through tariff reductions or improved cross-border infrastructure, increases the importance of the international market relative to the national market. When access to the international market does not take place mainly through the largest city (as would be the case if it had to go through its port), this reduces urban primacy. Ades and Glaeser (1995) document that, in practice, countries more open to international trade tend to have less primacy. Hanson (1997) looks at the case of Mexico empirically and finds that bilateral trade liberalization with the United States has shifted Mexican industry away from Mexico City and towards states with good access to the US market. This is reflected in interregional wage differentials, which after integration are less related to distance from Mexico City and more related to distance from the border.

3.3 The growing interdependence of cities

Urban economists have long debated whether specialized or diverse cities are more conducive to growth (Glaeser *et al.* 1992; Henderson *et al.* 1995; Combes 2000). Duranton and Puga (2001) argue that both diversity and specialization are important but at different stages of a product's life cycle. Cities that are narrowly specialized in a few sectors create greater economies of agglomeration, thus a firm's productivity increases with proximity to similar firms. At the same time a diverse mix of activities makes cities more likely to grow, particularly in new sectors.

There is a tendency to think of clusters of similar firms as the best environment for innovation. Recent studies of innovation and technology adoption show instead that diverse metropolises encourage the development of new products and processes. Feldman and Audretsch (1999) find that local diversity has a strong positive effect – and narrow specialisation a negative one – on the development of new products reported by trade journals in the United States. Technology adoption is also facilitated by local diversity. For example, the adoption of computer-controlled machinery for cutting metals has been much faster at locations where there is a coexistence of firms (ranging from furnace manufacturers to aircraft producers) with similar technical needs, but not directly competing with each other (Harrison *et al.* 1996; Kelley and Helper 1999; No 2003). In the model developed by Duranton and Puga (2001), an entrepreneur with a new business project may not know all the details of the product to be made, which components to use and where to source them, which workers to hire, and how to finance the venture. Being close to different firms in different sectors makes it easier to experiment with several possibilities in the same location. Thus diverse cities facilitate learning and experimentation, important at early stages.

For firms in more standardized or mature industries, however, urban specialization is more important. These firms typically benefit less from the flexibility that urban diversity affords, and by locating in a specialized environment they can better reap the benefits of urban agglomeration economies. For example, automobile producers can substantially lower their costs by sharing suppliers of car parts with other producers, and garment manufacturers benefit from thick labour markets that facilitate the movement of workers across factories as the whims of fashion increase demand for some producers while simultaneously lowering demand for others (Rosenthal and Strange 2001; Overman and Puga 2008).

Studies of firm location indicate that new production establishments choose to locate disproportionately in more diverse cities (Lainé and Rieu 1999; Holl 2004b). However, over time many of these establishments relocate away from diverse cities towards more specialized environments (Duranton and Puga 2001). The pattern is particularly strong for firms for which innovating and being close to similar firms are particularly important (such as electronics producers). When such relocations take place, establishments tend to move to locations that are more specialized but still easily accessible from their previous location. In other cases exploiting the advantages of diversity early in a product's life cycle and the advantages of specialization later on does not involve relocation of a production facility but relocation of production across two facilities. For instance, Fujita and Ishii (1998) document that the major Japanese electronic firms produce prototypes in trial plants that are located in metropolitan areas, which are known to be particularly diversified. At the same time their mass-production plants are almost always located in more specialised cities. As Duranton and Puga (2001) put it, for manufacturing and services, unlike for agriculture, 'sowing' and 'reaping' can take place in different locations. A 'balanced' urban system is not one where all cities are similarly specialized or diversified but one where both diversified and specialized cities co-exist.

Transport infrastructure helps achieve a balanced urban system with specialized and diversified cities.

Such a balanced urban system is greatly facilitated by good transport connections across cities. It also has important implications for where more local infrastructure projects are developed. Since this growing urban interdependence manifests itself in plant relocations away from large diverse cities, governments may be tempted to take resources for infrastructure investment away from them. This would kill the goose that lays the golden eggs, since such relocations to smaller specialized cities are just a later part of a life-cycle of firms to whom large diverse cities helped give birth.

There is a second dimension of urban interdependence highlighted by Duranton and Puga (2005), for which transport and communication infrastructure matters even more as it may actually be the driving force. Just as product development and mass production increasingly take place at different locations, so do management and production activities. Half a century ago the difficulties associated with managing businesses from far away made most firms keep their headquarters and management offices close to their factories.

The extra cost of coordinating and monitoring firms with facilities at multiple locations relative to integrated firms has decreased dramatically following key technological developments in transport and communication technologies as well as new management practices (Chandler 1977, Kim 1999). The cost of transporting goods, people and ideas has declined dramatically over the last century. For instance, maritime freight in 1990 was only one third as costly as in 1920, revenue per passenger-mile in air-travel in 1990 was one sixth of what it was in 1930, and the cost of a three-minute telephone conversation between New York and London fell by 98.7 percent between 1930 and 1990 (Jones 1997).

Such falls in transport and communication costs have greatly facilitated managing production from a distance. As a result, many firms have spatially separated their management and production activities, searching for the best possible conditions for each. For headquarters this means locations with other headquarters where they can, for example, share legal services or advertising agencies; for production facilities, it means places with other production plants. Headquarters are usually in bigger cities, because professional services tend to exhibit greater economies of agglomeration, are less land-intensive and employ highly educated employees willing to pay for big-city amenities. The ensuing increase in land prices prompts production establishments to relocate to smaller, more specialized towns and cities.

In addition to modelling this process, Duranton and Puga (2005) illustrate it with data from the United States. In 1950 the ratio of managers to production workers was similar across cities of different sizes. By 1990, however, cities with between 75 and 250 thousand people had 20 percent fewer managers per production worker than the national average whereas cities with between 1.5 and 5 million people had 20 percent more managers per production worker. Cities larger than 5 million people were 50 percent above the national average. A similar trend can be seen in other countries such as France and Germany (Bade *et al.* 2003). Aarland *et al.* (2007) use establishment-level data for the United States to study the determinants of the spatial separation between management and production. They find that good accessibility between central administration offices and production plants is crucial. Of the firms that separate management and production at least partially, 75 percent locate their stand-alone central administrative office within the same county as one of their production facilities. Those that do not operate in this way tend to be firms with production plants that are particularly dispersed or located in small cities, and prefer to have their central administrative office in a large city from which there is good access to its different plants.

R&D and management tend to locate in big diversified cities, large-scale production in specialized cities.

Overall, cities are becoming increasingly interdependent places. Firms split innovation and early production from more mature manufacturing, or management facilities from production plants. Good transport and communication infrastructure is an essential element that makes it possible for firms to find the optimal environment for each activity. Whereas we have paid particular attention to roads throughout this paper, in this case other types of transport and communication infrastructure are key. High-speed rail, while rarely used to transport goods, greatly facilitates visits by managers to production plants within the same country. In France it has been suggested that the construction of the Paris-Lyon high-speed rail line led to the relocation of headquarters from Lyon to Paris while in Spain there are concerns that the Madrid-Barcelona high-speed rail line may reinforce the process of headquarter relocation towards the capital (Puga 2002; Vives 2001). Internationally, non-stop air travel is a crucial determinant of the location of headquarters (Bel and Fageda 2008).

4. Conclusions

Recent work in economic geography and urban economics highlights the importance of agglomeration economies as a determinant of where firms and people locate. In the presence of agglomeration economies, productivity increases with the size of an activity in a location. This is both good news and bad news for places with poor initial conditions. It is good news because it means that a firm's location is not as constrained by physical geography and natural endowments as traditional theories based on comparative advantage imply. A place with poor endowments can nevertheless sustain a large concentration of activity with most firms staying because they prefer to be where the other firms and consumers are. It is also bad news because the circle created by market access and mobility causes great persistence. Once some places are sufficiently far ahead it is very difficult for lagging areas to catch up.

Cross-border infrastructure projects connecting lagging regions with key markets make it easier for firms in lagging regions to reach new customers but also expose them to fiercer competition from firms in more developed areas. Whether there is strong labour mobility (as in the United States) or whether there is weak mobility, large differences in skills, and constraints on wage differentials across regions within each country (as in Europe), improvements in transport infrastructure connecting regions are more likely to increase than to decrease regional inequalities. Nonetheless, they have an important role in facilitating increased efficiency and growth – partly as a result precisely of spatial concentration – and wider gains from trade.

Supra-national institutions should help overcome cross-border coordination failures and under-investment.

Cross-border projects can have large effects that extend well beyond the boundaries of the national or regional administration designing and funding them. They require coordination to ensure there is no underinvestment and to prevent coordination failures. They are also important to replace infrastructure designed with the national market in mind with one more adequate for an integrated world with growing trade flows. All this creates an important role for supra-national institutions.

Agglomeration is also important at smaller spatial scales and is the main justification for the very existence of cities. Transport infrastructure can increase certain benefits of large cities. In particular, it can reduce the costs associated with them. An excessive concentration of a country's urban population can be costly. Different types of transport infrastructure have very different effects on such concentration. Hub-and-spoke networks tend to increase urban primacy while cross-border transport connections facilitating international trade tend to reduce it. Transport and communication infrastructure plays a key role in allowing firms to separate innovation and early production from more mature manufacturing, or management facilities from production plants. This process, which has advanced rapidly in developed countries, increases efficiency and urban interdependence. The most relevant bits of infrastructure in this respect include high-speed rail, airports with frequent non-stop flights, and communication technologies.

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ABSTRACT

We examine the economic implications of infrastructure investment policies that try to improve economic conditions in Russia's peripheral regions. *Our analysis of firm-level industrial data for 1989 and 2004 highlights a 'death of distance' in industrial location, with increasing concentration of new firms in regions with good market access. We assess the geographic determinants of growth econometrically and identify market size and proximity to Moscow and regional infrastructure as important drivers of productivity for new and for privately-owned firms. Simulations show that the benefits of infrastructure improvements are highest in the country's capital region where economic activity is already concentrated. Policies that divert public investment towards peripheral regions run the risk of slowing down national economic growth.*

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Death of distance? Economic implications of infrastructure improvement in Russia


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The transport system is a restraining factor for regional development. If we had roads - motor roads, railways – major deposits of mineral resources would have been under development. No roads – no development. People who sometimes have to travel to a neighbouring region via Moscow are experiencing great difficulties. Today we are going to finally agree upon the parameters and key targets of the Federal Transport System Development Program for 2010-2015. I am referring to the largest investment program that has ever been approved by the Russian Government… The financing under the programme in question will exceed 13 trillion rubles. 4.7 trillion rubles of them will be provided from the federal budget. Over 17,000 kilometres of federal, regional and local motor roads, over 100 airport runways will be constructed. The total annual throughput capacity of sea ports will increase by over 400 million tons of cargo. Over 3,000 kilometres of new railways will be commissioned.

Vladimir Putin, Russian Prime Minister, May 20, 2008, Sochi

1. Background and motivation

'Connective infrastructure' has been widely used to physically integrate regions within countries. By reducing the costs imposed by distance, policymakers believe that investment in connective infrastructure can reduce development gaps between peripheral and leading regions of their countries. In principle, infrastructure investment that connects peripheral areas to markets should improve both consumer welfare and productive efficiency. But has it stimulated growth in peripheral regions? And as countries relax regulations on where firms can locate production as they become globally integrated, is this investment favouring spatial equity at odds with overall national economic prospects? We examine these questions for Russia, a country that is wrestling with the legacy of institutions that were historically set up to ensure internal convergence through investment supporting spatial balance in the distribution of people and jobs across the national territory.

Lessons from the Russian example can provide insights for Central and Eastern European countries facing similar challenges of balancing spatial equity and national economic efficiency. In this study we focus on the potential consequences of road-infrastructure improvements, which are high on the current economic-policy agenda in Russia. A related analytical consideration is that we can use information on road conditions to develop indicators of market access, thus making it possible to empirically test hypotheses from the new economic geography literature.[1]

Our empirical assessment of the questions raised above is based on employing data at the firm level, which come from the Russian Enterprise Registry Longitudinal Database, a database of all large and medium-sized and many small industrial enterprises covering mining, manufacturing, and utilities. Cross sections of these firms are available from 1985-2004.[2] We geo-reference each firm down to the third level of Russian administrative units – *raions* – thereby making these data usable for spatial

1 One of the key insights from this literature is that spatial concentration of economic activity increases with improvements in infrastructure links between peripheral and leading regions. This is because firms are attracted to locations with high market potential and low production costs.

2 The data include basic indicators on all enterprises (such as employment, output, capital, and location) and product data at the ten-digit level for most enterprises.

analysis.[3] The most appealing feature of this geo-referenced dataset is that we can observe the spatial distribution of firms in two different economic environments – pre-transition, when central planners decided where firms should be located and what they should produce; and post-transition, when private entrepreneurs had more say in locating firms in places where they could maximize return on investment.

This distinction allows us to test our first hypothesis that firms are likely to locate closer to markets as countries liberalize their economic policies. Evidence for China and India tends to support this hypothesis.[4] For Russia there is evidence that Soviet location policies concerned with spatial equity not only ignored transportation costs but also did not account for the costs associated with the country's cold climate. Gaddy (2008) argues that by being placed in some of Russia's coldest and most remote regions, many manufacturing enterprises were not competitive and, hence, were less attractive for foreign investment.

Remoteness from markets impinges on productivity and has firms produce a larger-than-optimal number of products.

Our second hypothesis is that remoteness from markets has impinged on firm productivity. To examine the cost of remoteness, we identify econometrically if geographic factors such as market access, proximity to Moscow, access to railroads and ports, and winter temperatures are systematically associated with differences in productivity. An added cost of remoteness is that firms are likely to adapt by producing a larger number of heterogeneous products at any given location in order to insure themselves against supply-chain and logistic breakdowns.

However, the origins of this peculiarity are not distance related but politically motivated. In Soviet times, ministers wanted control over production and vertically integrated their ministries by building intermediate-goods enterprises outside of their assigned line of production. One of our interests is in examining if vertical integration at the level of the production unit led to productivity losses from limited specialization. All else being equal, one would expect to see a larger number of unrelated products made by firms in peripheral regions.

To implement this analysis, we develop a measure of market access based on the classic gravity model commonly used in the analysis of trade between regions and countries. Interaction between two places is proportional to the size of the two places as measured by population, employment or some other index of social or economic activity, and inversely proportional to distance – physical or economic – between them. In addition, we use a Geographic Information System (GIS) to develop spatially detailed variables on natural and economic geography.

Our main findings from this analysis are as follows. First, there has been a clear shift in industry location towards places with good market access. Indeed, our data show that between 1989 and 2004, 70 percent of the national increase in firms happens in regions which are above the 80^{th} percentile of market access, in contrast to only 4 percent for regions below the 20^{th} percentile. Second, market access has a positive and significant impact on productivity – this effect is particularly strong for private firms (relative to publicly-owned ones), new firms (relative to older ones), and for manufacturing firms (compared with mining firms). We also find that producing a larger number of unrelated products is harmful for productivity.

3 In our classification, *raions* include so-called *gorsovets*. There are approximately 2400 *raions/gorsovets* in Russia.

4 In China, after the implementation of an open-door policy in 1978, foreign firms preferred to locate in cities such as Shanghai and Shenzen with large industrial bases and historical foreign investment presence (Head and Ries 1996). In India, once industrial regulations were relaxed, private investment tended to favour existing industrial clusters and metropolitan centers with access to the coast (Lall and Chakravorty 2005).

What are the implications of these findings for the spatial allocation of infrastructure improvements? The results from the empirical exercise are used to simulate where improving transport infrastructure will produce the highest gains in productivity. By improving infrastructure endowments across regions by the same magnitude, we find that the returns in terms of productivity gains are the highest in the Central region around Moscow, the country's leading region. On the other hand, transport improvements produce lower returns in peripheral regions – particularly in the Far Eastern region. Thus, infrastructure by itself will not be adequate to bring about economic convergence across regions, and spatially equitable infrastructure policies may be accompanied by a trade-off with national economic performance.

The rest of this paper is organized as follows: Section 2 discusses the development of the market-access measure and related geographic variables. Section 3 discusses the spatial evolution of economic activity in Russia. Section 4 provides the estimation strategy and discusses the geographic determinants of productivity differences. Section 5 provides a policy simulation to examine the economic consequences of alternate spatial configurations of transport improvements. Section 6 concludes.

2. Indicators of market access

2.1 Selection of the measure

Market accessibility is a function of natural geography and the transportation system.

Access to markets is a function of geographic heterogeneity and space, and is also a function of the quality and speed of infrastructure connections. In this sense, 'accessibility' is both a function of natural geography and an outcome of the transportation system, both of which determine the locational advantage of a region relative to all regions. To assess the degree of accessibility of markets and population agglomerations, economists and economic geographers have formulated indicators of relative accessibility according to which locations can be ranked. These indicators of accessibility measure the benefits households and firms in a region enjoy both from the infrastructure they have access to and the travel costs imposed by the exogenous geographic conditions they face. As such, they are a measure of relative potential accessibility of markets or agglomerations.[5]

An early and well-known formulation of such an indicator is the Harris (1954) market-potential equation, widely used in regional economics. Using distance data for the US and the value of retail sales per US county, Harris found that the market potential of any location could be described by:

(1) $$MP_i = \sum_{j=1}^{R} \left(\frac{M_j}{D_{ij}}\right)$$

where MP_i is the market potential of location *i*, M_j is the demand by location *j* for goods from location *i*, and D_{ij} is the distance between locations *i* and *j*. The formulation thus provides an indication of the general proximity of a location to total demand, and was found to accurately predict the relative spatial distribution of the size of markets in US counties studied by Harris.

Since that time, many measures of relative market accessibility have been formulated, including those that can be defined to reflect both within-region transport infrastructure and infrastructure outside the region but affecting it. Simple indicators of relative intraregional transport infrastructure

5 In this study, we use market accessibility and market potential interchangeably.

are, for example, total length of motorways, number of railway stations (Biehl 1986 and 1991) or travel time to the nearest nodes of interregional networks (Lutter *et al.* 1993). More complex indicators take into account the connectivity of transport networks by distinguishing between the network itself (*i.e.*, nodes and links) and 'opportunities' represented by large markets that can be reached by the network (Bökemann 1982). In more general terms, accessibility is a construct of two functions, one representing the opportunities or markets to be reached, and the other representing the effort, distance, time or – more specifically in economic terms – the cost of reaching them:

(2) $$A_i = \sum_j g(W_j)\, f(c_{ij})$$

Market accessibility is the accumulated total of economic activity in all regions weighted by the cost of getting to each region.

where A_i is the accessibility of region *i*, W_j is the activity to be reached in region *j*, and c_{ij} is the generalized cost of reaching region *j* from region *i*. The functions g(W_j) and f(c_{ij}) are called the *activity functions* and *impedance functions*, respectively. They are associated multiplicatively (*i.e.*, they are weights to each other) and are both necessary elements of 'accessibility'. A_i is the accumulated total of the activities reachable at *j* weighted by the cost of getting from *i* to *j*. Furthermore, the formulation captures a gravity model of economic potential building on Newton's law of gravitation, which specifies that the attraction of a distant body is equal to its mass weighted by a decreasing function of distance. Here the attractors are the economic activities or opportunities in regions *j* and the distance term is the impedance c_{ij}. The interpretation is thus the greater the number of attractive destinations in regions *j*, and the more accessible regions *j* are from region *i*, the greater is the accessibility of region *i*.

The activity function may be linear or non-linear, but empirical sensitivity testing in the literature tends to favour a non-linear function as better capturing actual spatial economic distributions: Specifically, a negative exponential function is used, in which a large *β* parameter indicates that nearby destinations are given greater weight than remote ones:

(3) $$A_i = \sum_j W_j \exp(-\beta c_{ij})$$

2.2 Construction of potential accessibility indices for Russia

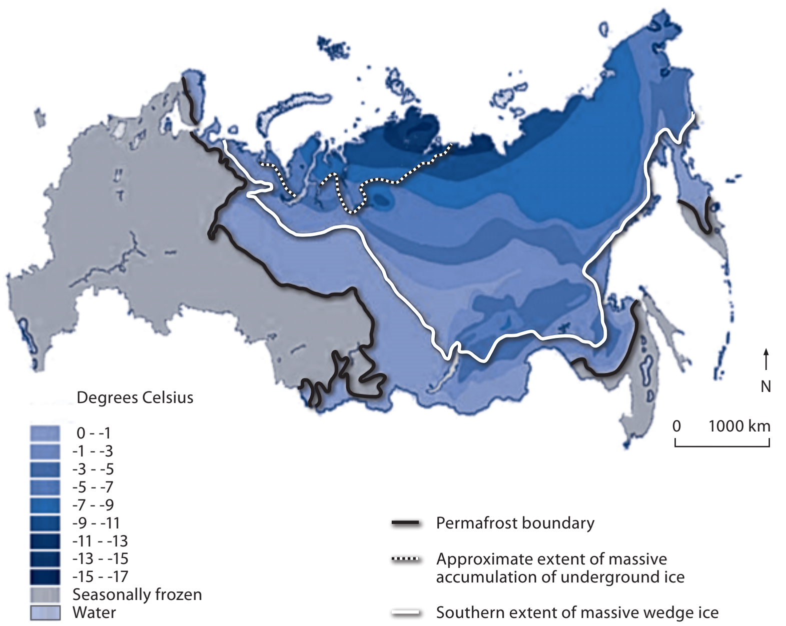
Level of analysis. Measures of accessibility are calculated for all Russian *raions* for three time periods (1989, 1995 and 2002) using Equation (3) above. In Russia, *raions* (*i.e.*, 'districts'), constitute the third level of administrative districts, one below the level of regions (*oblasts*). There are approximately 2400 *raions* (including so-called *gorsovets*) across all of Russia, and overall they have changed little since 1989, providing for spatial continuity over time.

Calculating accessibility in the GIS. Aggregate *raion* population, obtained from the 1989 and 2002 Russian censuses and from government statistical data for 1995 (Gosudarstvennyi 1995; Tsentralnaya 1996), is used as the measure of 'attractiveness' in the accessibility calculations (*i.e.*, for the *W* term in Equation (3) above).[6] Figure 1 shows the distribution of inhabitants by *raion* along with a map of permafrost temperatures – showing that Soviet planning left many people in very cold places.

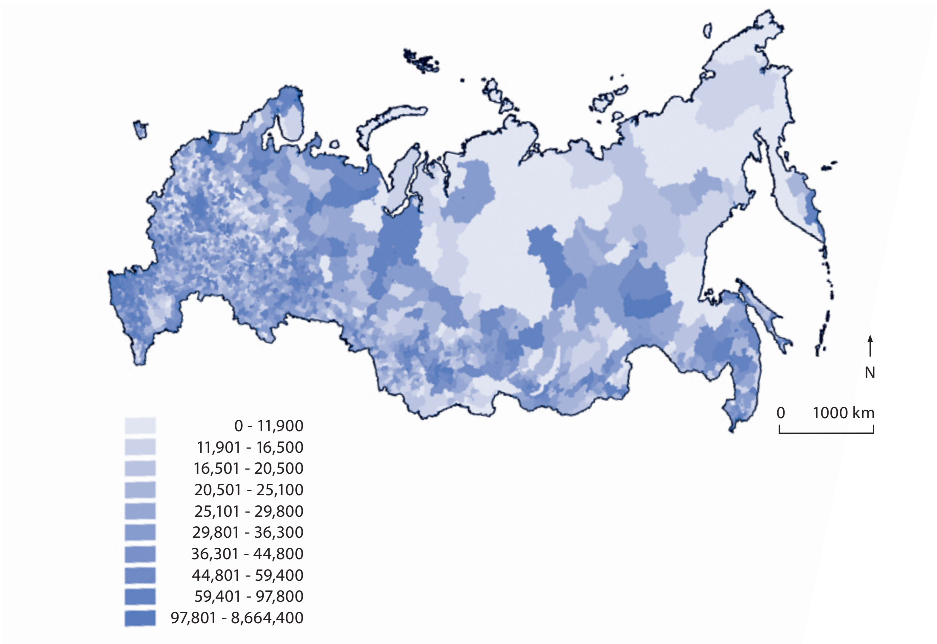
6 We use population as a proxy for market size as we do not have data on GDP or income at the *raion* level.

Figure 1. Russian climate and population distribution

Temperature of permafrost



Population per *raion*, 1996



Source: Permafrost map: National Snow and Ice Data Center (2008); population map: Own calculations based on Gosudarstvennyi (1995) and Tsentralnaya (1996)

For the impedance function *c* in Equation (3), travel time through road networks, weighted by variation in road type and quality, and by topographic variation, is calculated using a GIS and methods outlined in Farrow and Nelson (2001).[7] Using high-quality Russian road data (from the ADC WorldMap Roads data layers in GIS vector format) and a digital elevation model for Russia, it becomes possible to calculate travel times between any two locations. Information on road availability and quality is preferred to measures of straight-line or 'Euclidean' distance because it is a better reflection of the likely routes and travel times by which goods and people move in Russia. As the distribution of roads in Russia is not spatially uniform or complete, goods are moved from more remote regions (such as in the northeast) to the large urban markets in the west through road networks that tend to be located in the southern half of the country. Thus, travel routes to markets are likely to be much longer in practice than what Euclidean distances would suggest.

Actual travel routes to markets are longer than those suggested by Euclidean distances.

Figure 2 shows the road network used for the travel-time estimations. It illustrates that Russia has a sparse transport network. As a result, many shipping routes are not direct but involve more circuitous routes across larger primary and secondary roads that are selected to minimize travel costs and travel times to the final destination. The GIS travel-time algorithm selects a travel route in the same way as shippers in Russia choose their shipping routes: By finding the 'least-cost path' (or 'shortest-path-first' route, following Dijkstra 1959). That is, the GIS algorithm considers all possible routes through the road network that could be taken from one destination to another, and then selects the path that minimizes travel time. The calculation considers variations in road quality and topographic slope for each segment of the road network.

Figure 2. Russian road network

Source: VMAP0 (2008)

Calculating final accessibility. To compute the final accessibility measures for each *raion*, data on the population of each *raion* are taken from the censuses and used in Equation (3) as the *W* term.[8]

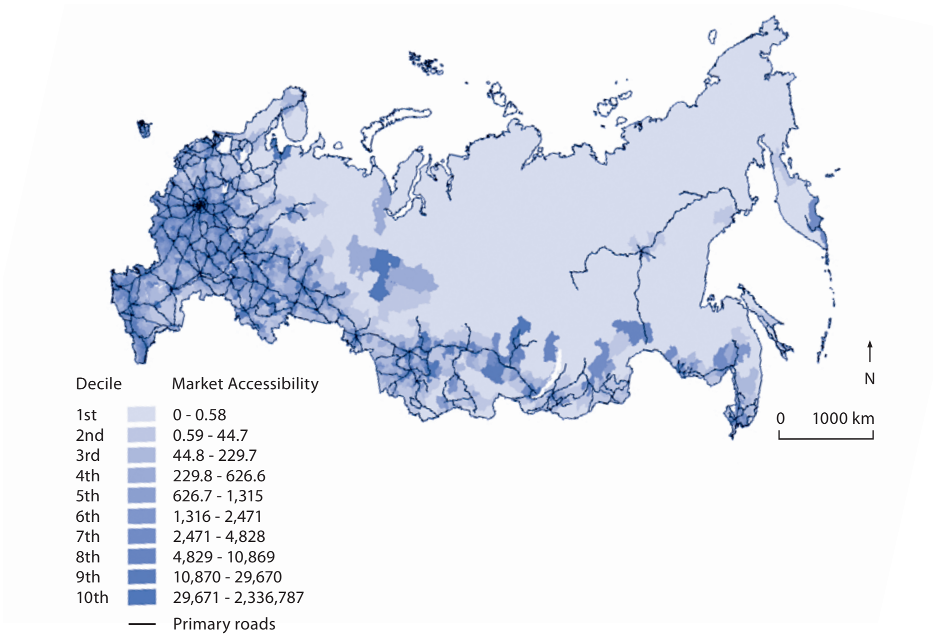
7 Schürmann and Talaat (2000) and Spiekermann and Wegener (2007) provide an in-depth discussion of the algorithms behind these calculations.

8 In addition to Russian *raions*, our measure of *W* includes population data for administrative districts of countries geographically bordering Russia to control for 'edge effects' in the accessibility calculations. These include district-level populations for Kazakhstan, Georgia, Azerbaijan, Armenia, Ukraine, Belarus, Latvia, and Estonia; 2003 NUTS3 population values for Finland; and 2002 population values for Chinese counties. Thus, it is not surprising that the raions on the southern border of Russia close to China have high 'potential' accessibility because there are 100 million people just south of them in China, even though we include a two-hour border crossing delay on all road segments crossing the border.

The travel times calculated by the GIS (as described above) are used as the impedance term *c* entering the calculation of relative accessibility for each *raion*. As market accessibility is a theoretical notion, there is no general agreement on the choice of the parameter values in Equation (3) (Deichmann 1997). The choice of parameters for β is ultimately an empirical decision. We calculate accessibility using five different values of the β parameter in the equation: 0.1, 0.25, 0.5, 1, and 1.5. The larger the β value, the greater weight is given to nearby destinations in the negative exponential distance-decay function. The results reported here use a β value of 0.5, which provides for the best empirical productivity-accessibility link. Figure 3 shows the resulting market access across Russia's regions.

The choice of the distance-decay parameter is an empirical decision.

Figure 3. Potential market access across Russian regions



Source: Own calculations of market access

Notes: The calculation method follows Schürmann and and Talaat (2000) and Wilson (1967). The β value is 0.5, the α value is 0.1, and *W* corresponds to 2002 population per *raion*. The impedance function is travel times through road networks considering variation in road type/travel speed with negative exponential distance decay as a function of spatial access to population. The accessibility calculation takes populations in bordering countries into account, assuming border-crossing time to be equal to two hours.

3. Spatial transformation: Firms move closer to markets

Using the market access measure discussed above, we group Russia's territory into deciles of market access at the *raion* level and summarize other natural and economic geography variables (Table 1). What is striking is that over 50 percent of Russia's land is 'unconnected' in the sense of falling into the bottom decile of market access; and that part is penalized by every imaginable geographic indicator: 50 percent of the land in that decile is under permanent frost, winter temperatures are -21 degrees Celsius, and it takes more than 27 hours to reach Moscow, 54 hours to the Trans-Siberian railroad and 35 hours to a port. All these indicators improve as one gets closer to areas with good market access.

Table 1. Russia's natural and economic geography

Market-access deciles in 2002	Land area, share of national total, percent	Winter temperature, in degrees Celsius	Share of area under perma-frost	Travel time to Moscow, hours	Travel time to Trans-Siberian railway, hours	Travel time to a port, hours	Travel time to a coal deposit, hours
1 (low)	52.6	-21.2	50.3	27.9	53.9	34.5	16.0
2	15.1	-15.4	16.7	22.6	16.3	30.0	12.1
3	8.7	-13.6	11.8	21.1	9.1	26.8	7.7
4	6.4	-12.4	8.6	18.5	8.5	26.0	9.4
5	5.0	-11.2	6.8	15.8	7.8	22.1	6.5
6	2.8	-10.5	5.1	14.7	5.7	21.3	7.2
7	3.2	-9.9	5.1	15.1	6.3	20.5	6.5
8	2.5	-8.5	4.3	14.6	9.2	18.2	7.1
9	1.8	-9.2	4.0	15.2	8.2	19.8	6.2
10 (high)	1.9	-8.9	4.5	12.3	7.4	18.3	7.8
Average/ Total	**100.0**	**-12.1**	**11.7**	**17.8**	**13.2**	**23.8**	**8.7**

Note: Winter temperature data are from the WorldClim global climate layers. Travel times to Moscow, the Trans-Siberian railroad, and a coal deposit (from the USGS MRDS) are computed using the same algorithm as the accessibility calculation. Travel time to a port is from the World Bank's internal database.

When Russia moved to a market-based economy, many firms left remote areas and new firms entered in places close to large markets.

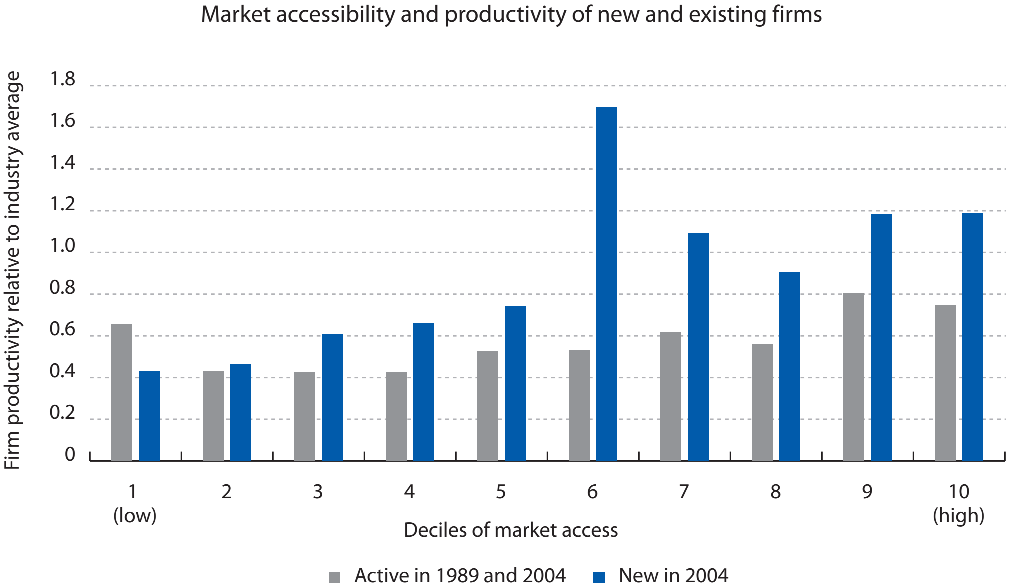
Table 2 shows that once Russia moved from a centrally-planned to a market-based economy, many firms left unconnected places and new firms entered in places physically closer to markets. Using firm-level data, we find that between 1989 and 2004, there were 266 more firms in the two lowest deciles of market access compared to about 4450 in regions in the top-two deciles. Put another way, 70 percent of the national increase in firms has happened in regions that are above the 80^{th} percentile of market access although these regions were host to just 47 percent of all firms in 1989. And only 4 percent of the national increase in firms has taken place in regions in the two bottom deciles – clearly below the share of firms these regions were hosting in 1989 (7 percent).

Table 2. Number of firms by market-access deciles in 2002

Market-access deciles in 2002	Average market access measures in 2002	Number of firms in 1989 (a)	Number of firms in 2004 (b)	Change in number of firms (b-a)
1 (low)	8.0	383	577	194
2	17.2	705	777	72
3	24.9	896	928	32
4	32.7	888	980	92
5	43.3	1075	1209	134
6	57.4	1151	1344	193
7	77.1	1430	1815	385
8	109.9	1706	2485	779
9	183.7	2127	3446	1319
10 (high)	811.7	5136	8253	3117
Average/total	**136.6**	**15497**	**21814**	**6317**

Figure 4 shows that new firms have not only located closer to markets but that they also have higher productivity. Clearly, economic distances are shrinking as firms move physically closer to markets.

Figure 4. New firms are entering closer to markets, with higher productivity



Finally, Tables 3 and 4 describe how firm entry and exit are correlated with market access. Table 3 shows that new firms are more productive than old firms (established before 1989), and firms become less productive compared with their concurrent rival firms. The last two columns of Table 4 show that firms in areas with high market access have higher survival rates than firms in low-market-access areas. Combining these facts, we conclude that Russian firm productivity growth and corresponding national economic growth would benefit more from promoting entrepreneurship and new firm creation particularly in high-market-access areas than from subsidizing old and unproductive firms.

National economic growth would benefit more from new firm creation than from subsidizing old and unproductive firms.

Table 3. Productivity of entering and exiting firms

Firm entry and exit	Firm productivity relative to industrial average at 2-digit NACE level		
	1989	2001	2004
Active in 1989 but exited before 2004	0.99	0.63	
Active in 1989 and 2004	1.02	1.06	0.68
New and active in 2001 but exited before 2004		0.90	
New and active in 2001 and 2004		1.18	0.79
New and active in 2004			1.38

Table 4. **Firm entry and exit by market-access deciles**

Market-access deciles in 2002	Number of firms					Survival rate of firms in 1989	Survival rate of new firms in 2001
	Active in 1989, but exited before 2004 (a)	Active in 1989 and 2004 (b)	New and active in 2001, but exited before 2004 (c)	New and active in 2001 and 2004 (d)	New and active in 2004	b/(a+b), percent	d/(c+d), percent
1 (low)	239	99	123	174	334	29.3	58.6
2	440	179	185	257	427	28.9	58.1
3	548	232	214	278	486	29.7	56.5
4	467	329	213	267	442	41.3	55.6
5	600	342	241	340	543	36.3	58.5
6	599	425	258	405	516	41.5	61.1
7	700	564	321	539	736	44.6	62.7
8	783	692	407	758	1034	46.9	65.1
9	976	827	477	1053	1493	45.9	68.8
10 (high)	2051	2202	1075	2177	3497	51.8	66.9
Total	**7403**	**5891**	**3514**	**6248**	**9508**	**44.3**	**64.0**

We are measuring the productivity gains from proximity to markets and access to transport infrastructure.

To sum up, the maps and descriptive statistics indicate that economic activity is moving closer to markets following transition and that this move is associated with improved economic performance. Our main interest is in measuring the gains in productivity due to proximity to markets and access to network infrastructure, and in thereby assessing the costs in terms of lost productivity due to central-planning decisions of spreading economic activity across the Russian territory.

4. Geographic determinants of productivity differences

In this section, we discuss the econometric analysis to examine the drivers of productivity at the firm level. The underlying economic model is that firms try to maximize their profits by optimizing and adjusting their production systems to the local environments in which they are operating. Local market conditions both on the supply and the demand sides, access to external markets, and natural environments, in particular winter temperature in Russia, influence firm behaviour and performance. We examine what kinds of location-specific endowments influence firm performance, specifically productivity.

We first measure firm productivity as Solow residuals from a simple Cobb-Douglas production function. The firm-level production function is estimated by regressing the value of production on the average number of employees and the book value of fixed assets (capital stock) separately for 19 two-digit NACE industries. The nominal values in each year are converted to 2001 prices using implicit deflators, which are disaggregated for about 150 industry sectors.[9]

4.1 Too many products?

Before analyzing the spatial determinants of productivity, we explore an important factor that we believe is likely to influence productivity – that is, vertical integration or the number of product lines that a firm engages in. Why is this important in Russia? Because in Soviet times, ministers

9 Implicit deflators are calculated by taking the change in nominal value of production of the sector divided by the real change (what Rosstat calls the index of growth in production), using sectoral growth numbers produced by Rosstat.

wanted control over production and vertically integrated their ministries by building intermediate goods enterprises outside of their assigned line of production. Following privatization, Russian oligarchs have also used vertical integration to their advantage as they want to ensure that there are no hold-ups in production in markets with few buyers and sellers (Guriyev and Rachinsky 2005).[10] Even though this approach helps firms adapt to local conditions and internalize various binding constraints, it is likely to introduce inefficiencies in resource allocation, thereby hurting productivity. These history-related inefficiencies are explicitly taken into account as an additional supply-side variable in the analysis of firm productivity below. Yet as the number of product lines of a firm and its productivity are likely to be at least partly driven by the same determinants (notably natural geography and infrastructure endowments), the number of product lines cannot enter the productivity regressions directly due to potential multicollinearity problems. Rather, the empirical strategy consists in estimating the determinants of the number of product lines in an auxiliary regression and in using the residuals, which capture the non-spatial component of vertical integration, in the main productivity regressions presented in Sub-section 4.2.

Political control of production and the need to avoid supply-chain hold-ups led to 'excessive diversification'.

For a start, it is useful to understand the structure of the firm data. Typically, an establishment is defined as each part of a firm that has a different physical location – and all production in one physical location is considered as one establishment. However, in Russia and other parts of the former Soviet Union, firms usually located all their production in one geographical location. These single-location firms were often quite large and comprised several production units, similar to multi-establishment firms in market economies such as the United States (Brown and Brown 1999).

In many countries, individual establishments have become more specialized over time whereas firms have diversified. In Russia, however, even establishments are becoming more diverse. Comparing production structures in the United States and in Russia, Brown and Brown (1999) show that 88 percent of Russian establishments were producing multiple products in 1997, accounting for 97 percent of total industrial output. In contrast, only 30 percent of the US establishments were multi-product, with 66 percent of total output in 1982.

To examine if vertical integration has a spatial dimension, we econometrically analyze the effects of geographic conditions on the number of product lines by firm.

(4) $\text{Number of product lines}_{ij} = f\,(\text{MP}_j, \textit{Aggre}_j, \textit{travel time}_j, \textit{winter temperature}_j)$

The number of product lines of firm *i* in *raion j* is regressed on the *raion's* market potential (MP_j), agglomeration economies ($Aggre_j$), access to external markets ($travel\ time_j$), and natural constraints ($winter\ temperature_j$). Our measure of market accessibility developed in Section 2 accounts for market 'demand' for a firm's products. It directly tests the propositions in the new economic geography literature that regions with larger market demand attract a disproportionate share of economic activity (Krugman 1991).

The variable $Aggre_j$ measures agglomeration economies as the number of firms in the region (*raion* in this case). The co-location of firms generates positive externalities that enhance productivity of all firms in the region. These externalities can occur within a given industry and between inter-related industries (Marshall 1890), but also across diverse industries in the same region (Jacobs 1969). Within the same industry, these benefits include sharing of sector-specific inputs, skilled labour, knowledge, intra-industry linkages, and opportunities for efficient subcontracting. Across industries, externalities include innovation and knowledge sharing. In a review of agglomeration

10 For example, they report that all major Russian oil companies are vertically integrated; most steelmakers own sources of coal and ore; and some companies own ports, fleets of railroad cars and even rail tracks.

measures, Henderson (2003) shows that the number of firms in a region performs better than other empirical measures.[11]

Vertical integration at the firm level is a response to the constraints imposed by remoteness.

The results from the product-line estimations are provided in Table 5. We find that in part, vertical integration at the firm level is a response to the constraints imposed by remoteness: The number of product lines (across industrial sectors) increases as firms are further away from markets (using market access as well as distances to Moscow and a port) and when they are in cold places (low winter temperatures).

Table 5. Determinants of the number of product lines

	(1)	(2)
Dependent variable	Number of firm product lines, 2004	Number of firm product lines, 2004
Estimation method	GMM	OLS
Sample	Total	Total
Ln(market access, 2002	-0.096***	-0.066**
	(0.034)	*(0.034)*
Ln(total number of firms in *raion*, 2004)	0.114***	0.049
	(0.037)	*(0.036)*
Ln(winter temperature)	0.333***	0.348***
	(0.072)	*(0.085)*
Ln(travel time to Trans-Siberian railway)	-0.015	-0.007
	(0.018)	*(0.015)*
Ln(travel time to Moscow)	0.112***	0.129***
	(0.023)	*(0.025)*
Ln(travel time to a port)	0.072*	0.102***
	(0.038)	*(0.038)*
Industry-group dummies	Yes	Yes
Constant	Yes	Yes
Observations	19,555	19,555
R^2	..	0.094

Notes: Robust standard errors in paretheses. *, ** and *** denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The estimation implements the OLS and the two-step efficient Generalized Method of Moments (GMM) estimator. Robust standard errors are in parentheses, and the observations are assumed to be independent across *raions* (no clustering) but not necessarily independent within *raions.* The instruments used in the GMM estimations are *raion*-level ln(market potential in 1995), ln(total number of firms in *raion*, 1989), ln(travel time to Trans-Siberian railway, 1989), ln(travel time to Moscow, 1989), ln(Euclidean distance to Trans-Siberian railway), ln(Euclidean distance to Moscow), a dummy for state capital city, share of arable lands, a dummy for permafrost region, ln(annual temperature), ln(annual precipitation), ln(average elevation), ln(standard deviation of elevation), ln(winter temperature), and industry-group dummies for firms.

11 While in principle, market potential and agglomeration benefits represent two separate mechanisms that influence firm behaviour and performance (demand and supply, respectively), empirical applications may encounter considerable correlation between these measures. We find that the correlation between market potential and the number of firms in a *raion* is 0.7, which is high but less than 0.9, which is the rule of thumb criterion where multi-collinearity may be considered harmful. In the empirical application, due to multi-collinearity one of the coefficient estimates will become insignificant.

4.2 Effects of remoteness on productivity

Now we examine the cost of remoteness on firm-level multi-factor productivity (MFP) directly by regressing total factor productivity on the first- and second-nature geographic variables described above and the residual of the product-line regression as a proxy for the non-spatial component of vertical integration.

$$\text{(5)} \qquad \text{Firm productivity} = f\left(\begin{array}{l} MP_j, Aggre_j, \textit{travel time}_j, \textit{winter temperature}_j, \\ \text{residual of Eq. (4)} \end{array} \right)$$

This estimation makes it possible to examine how remoteness impinges on productivity of Russian firms. One issue that needs to be addressed is the correlation of unobserved regional attributes with explanatory variables used in the analysis. These regional attributes influence the distribution of local market conditions and, more importantly, the location and quality of transport infrastructure. More favourable geo-climates would have attracted more people, leading to infrastructure development in their regions. This would lead to an upward bias in estimates using Ordinary Least Squares (OLS) estimators. However, in the Soviet Union, decisions to pursue spatial equity in infrastructure location may have reduced the development potential for regions with natural advantages. Here OLS estimators are likely to be downward biased. To address this problem, we estimate the model using the Generalized Method of Moments (GMM). The instruments used are historical and geo-climatic conditions.

Both a 10-percent increase in market potential and a 10-percent decrease in travel times would boost productivity by 0.8 percent.

The results and methodological details are reported in Table 6. The main findings based on the results reported in column 1 are that market access and agglomeration economies have positive effects on productivity, vertical integration and harsh geography (low winter temperatures and long distances to markets and ports) have negative effects. Consider, for example, the coefficient of 0.076 for market access in column 1. This would imply that a doubling of market access would increase firm productivity by 7.6 percent. And the coefficient of -0.08 for travel time to Moscow would imply that firm level productivity would increase by 0.8 percent for a 10 percent reduction in travel times. This could either be achieved by firms moving closer to Moscow or transport improvements that reduce the cost of Russia's large distances.

Table 6. Determinants of firm productivity (MFP), by firm characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)
Estimation method	GMM	OLS	GMM	GMM	GMM	GMM
Sample	Total	Total	Private firms	Public firms	Firms established before 2001	New firms after 2001
Ln(market access, 2002)	0.076***	0.044**	0.102***	0.005	0.023	0.128***
	(0.021)	*(0.021)*	*(0.024)*	*(0.030)*	*(0.021)*	*(0.030)*
Ln(total number of firms in *raion*, 2004)	0.044*	0.096***	0.011	0.133***	0.075***	-0.001
	(0.025)	*(0.023)*	*(0.028)*	*(0.035)*	*(0.025)*	*(0.035)*
Number of firm product lines, 2-digit NACE, 2004	-0.049***	-0.049***	-0.039***	-0.070***	-0.034***	-0.058***
	(0.005)	*(0.005)*	*(0.005)*	*(0.014)*	*(0.005)*	*(0.012)*
Ln(winter temperature)	-0.910***	-0.570***	-1.131***	-0.275**	-0.934***	-0.696***
	(0.124)	*(0.112)*	*(0.153)*	*(0.118)*	*(0.141)*	*(0.135)*
Ln(travel time to Trans-Siberian railway)	-0.032**	-0.014	-0.032**	-0.038**	-0.034***	-0.036*
	(0.013)	*(0.012)*	*(0.015)*	*(0.018)*	*(0.013)*	*(0.019)*
Ln(travel time to Moscow)	-0.080***	-0.056***	-0.091***	-0.028	-0.097***	-0.063***
	(0.014)	*(0.015)*	*(0.015)*	*(0.018)*	*(0.014)*	*(0.018)*
Ln(travel time to a port)	-0.226***	-0.135***	-0.247***	-0.177***	-0.211***	-0.226***
	(0.032)	*(0.020)*	*(0.033)*	*(0.054)*	*(0.035)*	*(0.040)*
Industry-group dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,902	14,902	11,845	3,057	9,027	5,875
R^2	..	0.076				

Notes: Robust standard errors in paretheses. *, ** and *** denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The variable 'number of firm product lines' corresponds to the residuals of the GMM estimation of the product-line equation (see Equation (4) and Table 5). The instruments used in the GMM estimations are the same as those used in the product-line estimation reported in Table 5.

The main difference in the results for public-sector firms (column 4) is that in contrast to the results for private firms (column 3) their performance is not sensitive to market access or proximity to Moscow. However, they value proximity to ports and railroads, and they are also hurt by being located in cold places, albeit less so than private firms. Interestingly, for publicly-owned firms the number of heterogeneous products has a larger negative effect on firm productivity, and agglomeration economies at the *raion* level appear to have a stronger positive effect than for private firms. The results imply that the productivity of private firms is influenced more by market-demand conditions, whereas public-firm productivity is more linked to the supply-side factors such as agglomeration economies and vertical integration.

The productivity of private firms depends more on demand conditions while that of public firms hinges on supply conditions.

Columns 5 and 6 disaggregate the data based on when the firm started production. For firms in production before 2001, differences in access to markets are not associated with productivity differentials. In contrast, for firms that entered after 2001, proximity to markets is an important contributor to productivity.

Table 7 reports sector-specific regression results for mining, light manufacturing and heavy manufacturing. Let us first consider the results for light manufacturing (column 2). As expected, market access is valued by these firms – estimates suggest that productivity would be higher by 0.53 percent with every 10-percent increase in market access; and distance from Moscow, railroads and ports impinge on productivity. Also, firms in this sector value agglomeration economies – a doubling in the number of firms in the same *raion* is associated with a 5.7 percent increase in productivity. And for this sector, the number of products produced by the firm has a negative effect on productivity.

Now consider the results for heavy manufacturing in column 3. Firms in this sector are not sensitive to regional differences in market access or the strength of local agglomeration.[12] However, productivity of these firms is adversely affected by adverse climate and distance to infrastructure networks (connecting external markets), as well as product heterogeneity at the firm level. In contrast, the results for mining firms suggest that economic geography does not appear to influence productivity – the positive coefficient of distance from Moscow might simply reflect the fact that natural resources are located far from Moscow.

12 This difference may come from different locations of major product markets: Local markets for light manufacturing goods and national or international markets for heavy manufacturing goods.

Table 7. Determinants of firm productivity (MFP), by industrial sector

	(1)	(2)	(3)
Dependent variable	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)	Ln(firm MFP, 2004)
Estimation method	GMM	GMM	GMM
Sample	Mining	Light manuf.	Heavy manuf.
Ln(market access, 2002)	0.080	0.053**	0.042
	(0.078)	*(0.023)*	*(0.032)*
Ln(total number of firms	0.030	0.057**	0.038
in the same *raion*, 2004)	*(0.077)*	*(0.028)*	*(0.036)*
Number of firm product	0.015	-0.046***	-0.058***
lines, 2-digit NACE, 2004	*(0.018)*	*(0.009)*	*(0.007)*
Ln(winter temperature)	-0.373	-0.624***	-1.143***
	(0.288)	*(0.110)*	*(0.218)*
Ln(travel time to Trans-	-0.018	-0.037***	-0.074***
Siberian railway)	*(0.031)*	*(0.014)*	*(0.019)*
Ln(travel time to Moscow)	0.189***	-0.075***	-0.128***
	(0.062)	*(0.015)*	*(0.021)*
Ln(travel time to a port)	-0.119	-0.227***	-0.246***
	(0.082)	*(0.036)*	*(0.044)*
Industry-group dummies	No	No	No
Constant	Yes	Yes	Yes
Observations	723	8,299	5,032

Notes: Robust standard errors in paretheses. *, ** and *** denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The number of firm product lines corresponds to the residuals of the GMM estimation of the product-line equation (see Equation (4) and Table 5).

5. Identifying regional infrastructure priorities

Now let us return to the questions of infrastructure prioritization raised at the very beginning of this study. First, what are the implications of transport investment that improves market access of peripheral areas? And second, will this investment produce the highest economic benefits nationally – or are there trade-offs between peripheral and national growth? We use the results from the econometric analysis to simulate the impacts on firm productivity of market-access improvements across Russia's larger economic regions.

In these simulations, each region is given an exogenous increase in infrastructure endowment such as to increase market access by 10 percent and to reduce travel times to Moscow, the Trans-Siberian railroad, and a major port by 10 percent each. Given these regional infrastructure improvements, productivity growth of existing firms is computed and then aggregated to the national level. This is a conservative estimate of the impact of infrastructure improvements as some regions could also benefit from an increase in the number of firms and thereby benefit from higher agglomeration economies. However, to keep the analysis manageable, we only calculate direct effects on productivity.

Simulations suggest that the productivity-enhancing effect of improved transport infrastructure would be by far the strongest in Russia's capital region.

The projected firm productivity improvements of these simulations are reported in Table 8 alongside relevant regional indicators such as the number of firms, population, region area, and the average market-access value. The results are then normalized to the productivity effect in the Central region, which is set equal to 100. The projected improvements in firm productivity provide the magnitude of region-level benefits from the aforementioned infrastructure improvements. Two results are worth mentioning. First, the benefits of these improvements are likely to be the highest in the Central region (which includes Moscow), followed by the North-western region (including St. Petersburg) where the productivity effect would be half that in the Central region (first column). Similar effects, ranging from one-third to 44 percent of the benchmark, are observed for most of the remaining regions. However, two regions stand out for showing particularly low economic gains: Northern and East Siberian. Second, it appears that the projected firm-productivity improvements are closely related to the economic (rather than geographic) size of regions.

Table 8. Simulated impact on average firm productivity growth from improving transport connectivity in different economic regions

10-percent improvement of transport connectivity in the economic region of:	Projected average firm productivity growth, percent	Number of firms, 2004	Market access, 2002	Population, 2002	Area, square-kilometres
Central Black	0.267	1,471	106	6,285	158,515
North Caucasus	0.327	1,864	161	12,800	199,219
East Siberian	0.144	833	54	5,488	1,702,144
Far Eastern	0.502	1,404	36	5,818	6,887,041
North-western (incl. St. Petersburg)	0.525	1,733	101	8,957	311,728
Central (incl. Moscow)	**0.998**	**4,028**	**428**	**22,500**	**255,442**
Northern	0.134	738	44	3,268	857,748
Urals	0.317	2,156	98	11,500	558,028
Volga	0.401	2,647	93	15,400	613,472
West Siberian	0.369	2,481	62	10,200	3,193,654
Volga-Vyatka	0.383	2,460	90	10,800	514,699
Relative to Central, percent					
Central Black	26.7	36.5	24.8	27.9	62.1
North Caucasus	32.7	46.3	37.6	56.9	78.0
East Siberian	14.5	20.7	12.5	24.4	666.4
Far Eastern	50.2	34.9	8.3	25.9	2696.1
North-western (incl. St. Petersburg)	52.6	43.0	23.7	39.8	122.0
Central (incl. Moscow)	100.0	100.0	100.0	100.0	100.0
Northern	13.4	18.3	10.3	14.5	335.8
Urals	31.7	53.5	22.8	51.1	218.5
Volga	40.2	65.7	21.8	68.4	240.2
West Siberian	37.0	61.6	14.6	45.3	1250.2
Volga-Vyatka	38.4	61.1	21.0	48.0	201.5

Note: Technically, the improvement of transport connectivity in an economic region is simulated as a 10-percent increase in regional market access and into 10-percent decreases in regional travel times to the Trans-Siberian railway, Moscow, and the closest port, respectively.

There is a trade-off between connecting remote regions and boosting national economic growth.

This ranking of economic benefits has two implications. First, infrastructure investment by itself is unlikely to help growth in lagging regions and, hence, economic convergence. Second, if investment expenditure favouring spatial equity is at the expense of funding infrastructure in high-return regions such as the Central region, it is likely to impose a severe trade-off with respect to the objective of boosting national economic performance.

6. Conclusion

In this study, we have used firm-level data on Russian manufacturing to examine the cost of remoteness on economic productivity. By developing detailed geo-referenced indicators of market potential that account for transport infrastructure linking firms to markets, we have directly estimated the benefits that accrue to firms from locating close to dense economic regions. While central-planning decisions of distributing economic activities across space have historically impinged on productivity, new entrants are concentrating production units and locating closer to markets. This 'death of distance' has important productivity implications – our estimates suggest that a doubling of market access would increase firm productivity by 7.6 percent.

While entrepreneurs prefer to concentrate production, public policy in Russia is vconcerned with spatial equity. The World Bank's latest Country Economic Memorandum for Russia (World Bank 2008) shows that the growing concentration of economic activities is seen as a cause for concern. The Russian government created a Ministry for Regional Development in 2004, and a National Regional Strategy is being drafted to facilitate the adoption and coordination of policies in the area of regional and spatial development. However, the jury is still out on the extent to which the strategy should focus on supporting national growth *vis-à-vis* helping lagging regions. Our analysis provides empirical evidence to inform this discussion.

Entrepreneurs prefer to concentrate production while public policy in Russia is concerned with spatial equity.

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