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Infrastructure and Growth in Developing Countries: Recent Advances and Research Challenges

Stephane Straub (University of Edinburgh)

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School of Economics
University of Edinburgh
30 -31 Buccleuch Place
Edinburgh EH8 9JT
+44 (0)131 650 8361
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Abstract:

This paper presents a survey of recent research on the economics of infrastructure in developing countries. Energy, transport, telecommunications, water and sanitation are considered. The survey covers two main set of issues: the linkages between infrastructure and economic growth (at the economy-wide, regional and sectoral level) and the composition, sequencing and efficiency of alternative infrastructure investments, including the arbitrage between new investments and maintenance expenditures; OPEX and CAPEX, and public versus private investment. Following the introduction, section 2 discusses the theoretical foundations (growth theory and new economic geography). Section 3 assesses the analysis of 140 specifications from 64 recent empirical papers examining type of data used, level of aggregation, econometric techniques and nature of the sample and discusses both the macro-econometric and microeconometric contributions of these papers. Finally section 4 discusses directions for future research and suggests priorities in data development.

Infrastructure and Growth in Developing Countries: Recent Advances and Research Challenges

Stéphane Straub [1]

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I. Introduction

Writing the introduction to a survey on infrastructure and development sometimes feels like an impressionistic exercise, especially if it is mostly policy oriented. Indeed, one feels compelled to start by painting an overview of the state of infrastructure sectors in developing countries, in particular with respect to existing stocks, households and firms access to services, and past and present investment figures. However, one quickly realizes that on all these issues, at best only patchy information is available, ending up with a number of stylized facts that do not completely fit together, information holes that can't be filed, time series that stop ten years ago, etc. So while most practitioners and people living in developing countries know about chronic infrastructure deficiencies, and it is possible to appeal to statistics showing cruel deficiencies in sectors such as sanitation, water or electricity, there is no completely satisfying way to systematically document the state of infrastructure in and across many poor countries.

The world's number one provider of statistics on developing countries, the World Bank, has in its more than 60 years of functioning considered infrastructure as one of its top priorities. Indeed, between 1970 and 2005, infrastructure-related lending has oscillated between 1/3 and 2/3 of the Bank's total lending.[2] However, researchers of the subject acknowledge that the current state of statistical knowledge is less than satisfying.[3] Of course, this also implies strong limitations in the quality and relevance of empirical research that can be performed.

Based on this assessment, the objective of this paper is not to be an additional survey of the theoretical or empirical literature on the subject.[4] Instead, it starts from a literature review of recent contributions to highlight what works and what doesn't work when trying to understand the causal pathways between infrastructure investment and development outcomes, in order to draw conclusions along two dimensions: First, which type of research is more likely to be useful in the search for implementable policy recommendations and second, which type of data are needed to carry out such research.

More precisely, the discussion is organized around two main set of issues. First of all, it focuses on the linkages between infrastructure and economic growth on an economy wide, regional and sectoral basis. This is clearly where the bulk of contributions are found, with studies looking at the impact of infrastructure on a variety of indicators such as output level or output growth, productivity, etc., and also where a wide array of sometimes contradictory results is found. Some of the relevant questions are the relevance of infrastructure spending at different stages of development (e.g. for low and middle income developing countries, possibly taking into account other specific

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[2] Figures for 2005 indicate a total of IBRD/IDA lending of close to $8 billion. See World Bank (2006).
[3] See for example Estache and Fay (2007), Briceño-Garmendia and Klytchnikova (2006) and Briceño-Garmendia, Estache and Shafik (2004) for a more detailed discussion on the main holes in the infrastructure picture.
[4] Previous surveys include Munnel (1992), Gramlich (1994), Sturm et al. (1998), Romp and de Haan (2005) and Prud'homme (2005) among others.

initial conditions); the role of infrastructure in creating or closing the gap between poor and rich regions within and across countries, as well among urban and rural areas, etc.

Second, it addresses the issue of composition, sequencing and efficiency of alternative infrastructure investments. This includes aspects such as the arbitrage between new investments and maintenance expenditures, operational expenditure (OPEX) and capital expenditure (CAPEX), public versus private investment, as well as different infrastructure sub-sectors. The objective is to inform the discussion on aspects such as the contribution of different composition of infrastructure investment in terms of growth, the difference in performance of infrastructure industries where a specific sequencing of market based reforms (including privatization regulatory reforms and introduction of competition) has been implemented or, in those infrastructure industries that have remained regulated, what forms of regulation have been most successful, what regulatory mechanisms have yielded superior economic performance, whether those countries and infrastructure sectors that have unbundled and attempted to introduce competition produced greater benefits for these sectors and other sectors of the economy, etc. Note, however, that results on these topics have often not been explicitly integrated in the broader picture of infrastructure development in developing countries, so this paper will mostly highlight gaps and avenues for future research.

Regarding data and empirical work, a few main conclusions emerge. First, the macro-econometric approach, although it has been useful to strengthen the conviction that many aspects of infrastructure do indeed matter for development, has probably reached a limit and the type of policy lessons that practitioners are looking for are unlikely to be provided by such an approach. One area, though, where this type of data can provide additional knowledge is the analysis of how institutional, regulatory and political economy aspects affect the amount and quality of infrastructure services provided. Important efforts both to model the theoretical channels involved and to systematize the corresponding institutional and political data appear necessary.

Following recent development in theory, the area that seems more promising is the economic geography one. Its main strength is the ability to insert micro-level data in a global framework that accounts for the spatial, sectoral and macroeconomic linkages of investments in infrastructure. This literature, however, is still very new in terms of both its theoretical extensions to policy issues, the integration in the models of more realistic infrastructure proxies, and its empirical validation. The main challenges identified in the paper have to do with additional theoretical advances and with the development of the right econometric framework to test dynamic models characterized by threshold effects and multiple equilibria.

At the data level, the systematic development of infrastructure-related micro-level firm and household data is advocated. The objectives are differentiated according to the nature of sectors. For transport data, in particular road and railroad statistics, the paper argues that the aim should be regional (within country) data disaggregated at several levels of road quality / class, of the type already available for some countries such as China. For energy, telecommunications, water and sanitation on the other hand, it argues for the systematic collection of data in household- and firm-level surveys, with a view on upward aggregation to generate village- or district-level average access statistics. Additional data on quality, costs and institutional aspects should also be collected in this way. Finally, econometric issues linked to the use of this type of data are also discussed, one key aspect being the endogeneity of firms' technological choices.

In summary, this paper's recommendations converge to the combination of three main components at the macro-, micro- and economic geography level. A drive to strengthen collection of microeconomic data through both household and firm-level surveys, considering the need to take into account institutional constraints (ownership of surveys) and limitation in their current design, should support major theoretical and empirical efforts at the macro-level (especially with regards to the assessment of the impact of political, institutional and regulatory aspects on the delivery and efficiency of infrastructure services), and at the economic geography level.

Infrastructure is understood in this paper to include the following sectors: Energy, transport, telecommunications, water and sanitation. Although some of the material discussed bears on developed countries, the focus of the conclusion is on low and middle income transition and developing countries. The structure of the paper is as follows. Section 2 presents the theoretical foundations of the effect of infrastructure on growth and other development outcomes in the context of growth theory and of the new economic geography literature. It then discusses to what extent the literature reviewed provides answers to the two broad set of issues mentioned above. Section 3 reviews how these insights have been taken to the data. It starts with an overall assessment of the empirical literature based on the analysis of 140 specifications from 64 papers between 1989 and 2007, looking in details at the type of data used, the level of aggregation, the technique, the nature of the sample, etc. It then discusses macroeconometric contributions, looking at the questions addressed, the main methodological issues and the limitations of this approach. Next, it reviews studies including geographical insights. Microeconometric contributions are mentioned, and finally a review of lessons according to the two set of issues above is performed. Based on this, Section 4 spells out what appear to be the most promising directions for future research, highlighting key short to medium term working objectives. Suggestions of priorities in data development are presented.

II. Theory

The theoretical foundations of the effect of infrastructure on growth and more generally on development outcomes are mostly to be found in growth theory[5] and the new economic geography literature.

1. Growth Theory

A number of theoretical justifications for advocating policies fostering investment in infrastructure are found in the growth literature. Most of the channels discussed in this context can be represented in the following generic framework based on an aggregate production function:[6]

$$Q = A(\theta, K_I).F(K, L, G(K_I)), \qquad (1)$$

where Q is real aggregate output, K is the (non-infrastructure) aggregate capital stock, K_I the infrastructure capital stock, L aggregate hours worked by the labor force, and $A(.)$ is a standard productivity term, which we discuss below. Note that K_I enters the production function $F(.)$ through a function $G(K_I)$. As it stands, this formulation can accommodate infrastructure considered simply as an additional factor of production ($G(K_I)=K_I$), as is often done in the macro literature (Romp and de Haan, 2005). This assumes that the stock of infrastructure has pure public good attributes and produces services in a non-rival and non-excludable way.

However, there are reasons to allow for a different way to incorporate infrastructure in the production function. First, it is not always the case that infrastructure has pure public good attributes and in the last decades a growing part of infrastructure investment has been mediated through the market and has taken characteristics of standard private goods. Second, even when private operators are involved, the level of unit costs and prices of infrastructure services are often not strictly market determined[7], so including K_I as a factor in the production function would rely on the unrealistic assumption that firms are able to make informed decisions on the cost of the amount of infrastructure capital they use (Duggal, Saltzman and Klein, 1999).

Under this interpretation, infrastructure K_I enter the production function through the services provided by this type of capital ($G(K_I)=I(K_I)$), rather than simply as an additional factor of production as is often assumed in the literature. $I(K_I)$ is an intermediate inputs variable, and an increase in K_I lowers the cost of related intermediate inputs like transport, communications, etc., that enter firms' production

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[5] Standard general growth theory references are Aghion and Howitt (1998) and Barro and Sala-i-Martin (2004). Agénor (2004) and Agénor and Moreno-Dodson (2006) discuss and model several channels through which infrastructure may affect growth.

[6] Arguably, this is a very simple framework that obviates numerous relevant issues, such as problems of aggregation. See a more detailed discussion in Straub (2007) and Banerjee and Duflo (2005).

[7] The reasons include regulatory oversight of prices in certain sectors and more generally problems to determine the real costs and prices (Pritchett, 1996).

functions.[8] Hulten, Bennathan and Srinavasan (2003) call this a *market-mediated effect* of infrastructure. Whether introduced directly or as a source of specific services, $G(K_I)$ captures what I will call the "direct" effects of infrastructure.

Moreover, note that the formulation in (1) distinguishes between two sources of increases in the productivity parameter A: generic efficiency-enhancing externalities, represented by θ, and efficiency-enhancing externalities specifically linked to the accumulation of infrastructure capital. I refer to this effect as an "indirect" effect of infrastructure.

Note furthermore that this formulation does not make specific assumptions on the nature of returns to scale. Depending on the elasticity of infrastructure introduced as part of the *F(.)* function and on the strength of potential externalities, it may accommodate diminishing, constant or increasing returns. Whether the effects of infrastructure are strong enough to generate an endogenous growth process will be of considerable theoretical and empirical importance in terms of the potential impact of infrastructure, in particular when considering whether it acts simply as an additional capital accumulation device or has the potential to generate long term permanent growth effects.

Direct Channels

The direct channels from infrastructure capital, whether in its pure public good or intermediate inputs form, to growth first involve a simple productivity effect. Indeed, in a standard production function with factors being gross complements, an increase in the stock of infrastructure would raise the productivity of the other factors. As signaled above, whether the productivity-enhancing effects will result in a higher steady-state growth rate or not will depend on the assumptions made on aggregate returns to scale.[9] An extreme version of the direct effect of infrastructure corresponds to the case of strong complementarities. For example, by providing access to certain remote or uncommunicated areas, roads or bridges make private investment possible. Similarly, by giving entrepreneurs access to certain services such as electricity or telecommunications, investments in critical parts of infrastructure networks enable corresponding private investment. Note, however, that the way infrastructure investments are financed is obviously not neutral and that the risk of a crowding-out effect on private investment exists, especially if these investments are financed through taxation or borrowing on domestic financial markets.

Indirect Channels

More interesting, however, are potential indirect channels that reveal the possibility of growth effect of infrastructure investments above and beyond the simple factor accumulation effect. A (possibly non-exhaustive) list includes:

- *Maintenance and private capital durability.* A crucial aspect that has received relatively little attention in the literature although practitioners are well aware of

[8] See Fernald (1999) for an application to the impact of the road infrastructure in the US on specific industrial sectors.
[9] See Barro (1990) for a model displaying this channel in the context of an AK-type of dynamics.

its importance is maintenance of the existing infrastructure stock. Indeed, it is often argued that infrastructure policy is biased toward the realization of new investments at the detriment of the maintenance of the existing stock. Two main reasons for politicians having such a bias have been mentioned. Rioja (2003) posits that maintenance is tax-financed, while new investments rely on soft international loans, which are more palatable to politicians as long as they do not have too many strings attached. Alternatively, new investments may have higher "political visibility" and shorter "horizon" than maintenance, which only has gradual effects on the quality of the infrastructure stock (see for example Maskin and Tirole, 2007, and Dewatripont and Seabright, 2006). This lower-than-optimal level of maintenance has two consequences. First, it reduces the life-span of the existing stock of infrastructure itself. Rioja (1999) and Kalaitzidakis and Kalyvitis (2004) have modeled this phenomenon in the context of exogenous growth models. Second, it is well documented that it also implies higher operative costs and reduced duration of private capital, such as trucks operating on low-quality roads or machines connected to unstable voltage lines.

- *Adjustment costs.* A closely related aspect is signaled by Agénor and Moreno-Dodson (2006). Improvements in the stock of infrastructure capital are likely to reduce private capital adjustment costs, through at least two related channels. First, by lowering the logistic cost of such investments and second by allowing for the substitution of palliative private investments in devices such as electricity generators for more productive investments in machinery for example. Ample evidence from firm-level surveys such as investment climate assessments (ICAs) backs up this assumption (see evidence of this in Lee, Anas and Oh (1996) for Indonesia and Nigeria, Alby and Straub (2007) for Latin America, Reinikka and Svensson (2002) for Uganda among others). Improvements in the stocks of infrastructure, as they make the services more reliable, reduce firms' necessity to invest in substitutes in order to hedge against potential service interruptions, thereby freeing up resources for private productive investment. Reinikka and Svensson (2002) show that this may be aggravated by a selection effect, as the firms that actually invest in substituting devices are the bigger or more profitable ones, resulting in even larger investment shortfalls.

- *Labor productivity*. Another posited channel is the potential effect on labor productivity due to reductions in time wasted commuting to work and stress, as well as to the more efficient ways of organizing work time as a result of improved information and communication technology, learning by doing, etc…

- *Impact on human development*. Numerous microeconometric studies have documented that better infrastructure induces improvement in both health and education[10], which increase labor productivity both in the short term by making the existing stock of human capital more effective, and in the medium and long term by inducing additional investment in education.

- *Economies of scale and scope*. A few examples include better transport infrastructure that, by lowering transport costs, leads to economies of scale, better

[10] See for example Galiani et al. (2005) and Thomas and Strauss (1992).

inventory management and a different pattern of agglomeration (Hulten et al., 2003; Baldwin et al., 2004); changes in the pattern of specialization of agents and incentives to invest in innovation as the transport and communication infrastructure, and therefore access to market, change; network externalities; more efficient market clearing and enhanced competition as a result of improved information flows (see Jensen, 2007).

Most of the effects alluded to in the last bullet point, however, open to mechanisms best modeled within a spatial framework such as the new economic geography one. There are treated in detail in the following section.

2. Economic Geography

One striking feature of the literature reviewed so far is the fact that it completely overlooks one of infrastructure's main characteristics, namely its geographical dimension. Indeed, it is fairly obvious that infrastructure investment is by nature spatial, since it involves rival choices on the location of equipments that will serve limited geographical areas. This is true for example of roads, bridges, canals, airports and railroads for transport, pipes and sewerage networks for water and waste water treatment, base towers for telecommunication services, electricity or gas networks and connections for energy.

Second, infrastructure services are an input in both households' and firms' consumption and investment decisions. Variations in the availability and quality of infrastructure across space will therefore result in different economic agents' behavior depending on their location. Moreover, they will also crucially influence agents' location decisions, such as migration, establishment of new firms, investment of capital at different locations, etc.

This section summarizes the available body of knowledge on these issues. It first reviews what economic theory has to say on spatial dimensions of economic activity. Specifically, it starts by looking at the so-called "new economic geography", which started with the work of Masahisa Fujita, Paul Krugman, Anthony Venables and co-authors in the early 1990s and for which an early synthesis is Fujita, Krugman and Venables (1999) (hereinafter referred to as FKV). A following generation of models, for which an excellent synthesis is found in Baldwin et al (2003), blended the new economic geography framework with endogenous growth to analyze more specifically policy issues, including infrastructure. After briefly summarizing the main building blocks of these frameworks, I reflect on how they allow us to think about infrastructure issues and on their main shortcomings in that perspective.[11]

Finally, I mention another related literature, namely that on urban and regional economics, and in particular on the modeling of cities. Because along the process of development the nature of infrastructure needs is strongly shaped by issues such as rural-urban migration, the size of cities and the spatial distribution of economic activity, both between but also within cities that sometimes span large geographical areas, these contributions allow to a certain extent to open what has previously mostly

[11] Note that the variety and complexity of models reviewed makes it intractable to develop a common framework, such as the one in the previous section, in the context of this paper.

been modeled as a black box. Of course, there are many overlaps in recent research inspired by standard location theory and new economic geography, as can be seen for example in the Fujita and Thisse (2002) synthesis of these issues. The way I organize the present discussion is for analytical convenience only.

New Economic Geography and Public Policy

There are many excellent textbooks and surveys covering the main results of the "new economic geography" and the purpose of this survey is by no mean to replicate these, but instead to highlight the main features of these models that are relevant to meaningfully discuss infrastructure issues.[12]

The canonical new economic geography model has two regions, which may initially be symmetric in their endowments of the two factors of production (capital and labor), ruling out standard comparative advantages. There are two sectors of production, a traditional one (often alluded to as agriculture) producing a freely tradable good under constant returns to scale, and a modern (say, industrial) one characterized by imperfect competition and differentiated products. Finally, workers and capital may be characterized by different degrees of mobility between regions.[13] This literature further distinguish geographical aspects termed "first nature", such as natural conditions of the soil, proximity to coasts or rivers, weather conditions, from "second nature" attributes resulting from the non random location of firms and workers across space. Its objective is therefore to explain how such patterns of agglomeration may arise, above and beyond first nature attributes of different locations, and how they may be affected by policy interventions such as subsidies to firms or human capital accumulation, and the accumulation of infrastructure capital among others.

The main feature of economic geography models is that they consider this second nature dimension of economic activity to be the result of the interplay between agglomeration and dispersion forces.[14] Technically, agglomeration forces arise as the result of increasing returns that may be either internal or external to the firms in the industrial sector.[15] Internal increasing returns may be due to backward, demand linkages, often called the "market access effect" or "home market effect", that push firms to locate their activities in regions with bigger markets to be able to serve more consumers avoiding trade costs, or to forward, cost linkages that bid input prices down and again tend to attract firms to already crowded locations.

Agglomeration may also arise for reasons external to the firms, such as knowledge spillovers or labor market externalities linked to the greater availability and better training of workers, as already mentioned by Marshall in the 19th century.

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[12] See for example FKV (1999), Neary (2001), Baldwin et al. (2003), Ottaviano and Thisse (2004). Henderson, Shalizi and Venables (2001) discuss some of these issues specifically in a development perspective.
[13] See Puga (2001) for a discussion of the differences between models with and without migration. Empirically, migration is lower in the EU that in the US, which justifies alternative assumptions.
[14] Of course, different models display different combinations of (a subset of) these forces.
[15] See Rosenthal and Strange (2004) for a recent survey on the empirical evidence on these agglomeration forces. Ellison, Glaeser and Kerr (2007) find evidence for all the mechanisms discussed here.

These centripetal forces are potentially balanced by a number of dispersion forces again affecting both the supply and the demand side of relevant markets. These include first the fact that some factors, such as land and labor, are at least partially immobile so their prices might be bidden up as agglomeration goes on, an outcome that will generate an increasing tension for firms having to face fiercer competition in bigger agglomerations. Second, dispersed immobile labor implies that firms agglomerating at a given location neglect distant markets. Finally congestion also bids up the cost of living in large cities.[16]

The key point is that when agglomeration forces dominate dispersion forces, a shock to the initial distribution of workers and firms (for example migration by a worker or investment of some capital in a different location) will trigger a cumulative process of agglomeration and all industry and workers will move to one region. Conversely, if dispersion forces dominate, an initial symmetric distribution between two regions will be stable as any shock would be immediately reversed.

Transport costs are what determine the balance between agglomeration and dispersion. In most economic geography models, these are modeled simply as "iceberg" transport costs, i.e. by assuming that a fraction of the goods shipped melts down during transportation. Looking at the effects spelled out above, it appears that both agglomeration and dispersion forces diminish as trade costs decline. For example, the market access effect loses relevance as the differential cost of serving consumers at home or at the other location shrinks, but the wage effect linked to greater competition is also less relevant for firms, and so is the issue of forgoing distant markets. In most models, such as the core-periphery (CP) model of FKV, dispersion forces tend to dominate when transport costs are high, but they decline more rapidly than agglomeration forces when these costs are reduced (see Baldwin et al., 2003, for a more formal discussion). This gives rise to the well-know "tomahawk bifurcation" diagram of FKV, which shows that symmetric dispersed outcomes are stable at high transport costs, while a process of catastrophic agglomeration (in the sense that all firms and workers move to one region) happens below a certain level. Moreover, there is usually a middle range of values for which both dispersion and agglomeration are stable equilibria.[17] Which equilibrium prevails then comes down to historical initial conditions, specific exogenous shocks or policy interventions.

In the range of models discussed so far, the main outcome is the long-run geographical pattern of economic activity.[18] There are at least two reasons why such models are ill-equipped for regional policy analysis. First, shift in the spatial distribution of firms can at best be an intermediate objective for policy makers and the final objective is more likely to combine concerns for output growth and its distribution among the population. Moreover, in these frameworks, industry

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[16] Empirical evidence shows that the cost of living roughly doubles between a city of 100,000 and one of 5 million inhabitants, with wages following. Moreover, higher urban concentration appears to correspond to increased child mortality, higher pupil-teacher ratio and increased use of non-potable water among others (Henderson et al., 2001).

[17] Note that not all economic geography models display such catastrophic agglomeration process. For example, models with no or limited worker migration are more likely to give rise to intermediate outcomes (Puga, 2001).

[18] See Baldwin et al. (2003), chapters 2 to 6, for a number of models that display properties close to that of the canonical CP model.

agglomeration is always a win-lose situation. It is therefore clear that policy lessons on infrastructure require the growth dimension.

Starting with Martin and Ottaviano (1999), models blending economic geography with endogenous growth have been developed to address a number of policy issues.[19] These models rely generally on the existence of technological externalities between firms to overcome the tendency to diminishing returns. Furthermore, for geography to have a distinct impact on the long-term growth rate, these spillovers have to be of local nature[20], an assumption that is warranted by empirical evidence (e.g. Jaffe et al. 1993; Rosenthal and Strange, 2004). Note also that endogenous growth represents an additional agglomeration force, while knowledge spillovers are an additional dispersion force.

In the context of these models, Baldwin et al. (2003) put forward a number of conclusions on infrastructure policy. The main policy trade-off arising from a geography and growth model is a spatial equity-efficiency trade-off. Indeed, the static loss in the periphery resulting from industrial agglomeration may be compounded by faster growth overall, so there might be a global dynamic gain, and the overall effect on the periphery is no longer unambiguously bad. Obviously, this conclusion and the strength of the trade-offs discussed below will be affected by whether the degree of agglomeration in equilibrium is above or below the optimal level.[21]

The basic lessons are based on different consequences of this trade-off. First, infrastructure policies that facilitate transport between regions, for example the building or improvement of major road corridors, will increase both regional inequality and national growth. On the other hand, infrastructure policies that facilitate transport within poor regions will have the opposite effects of decreasing regional inequality but also slowing down national growth. These trade-offs will be even stronger if richer regions are characterized by a mix of (first) nature endowment and technological conditions that positively affect both the return from private and public capital (Puga, 2001).

As discussed in the introduction, the normative take on these issues depends strongly on the mix and the nature of objectives, growth and redistribution, sectoral and social groups targeting, that policy makers pursue. It also depends on the strength of redistribution instruments that they have at their disposal. In particular, in countries where taxation and redistribution faces greater institutional constraints, i.e. the shadow cost of public fund is higher, these trade-offs will be more acute.

Contrary to the case of transport costs, a win-win situation arises when considering public policies that facilitate the inter-regional diffusion of technology spillovers, as these decrease regional inequality while increasing national growth. This is not surprising since the local nature of these inter-firms externalities is precisely the ingredient that generates the spatial equity-efficiency trade-off in the models. Baldwin et al. (2003) consider policies aimed at facilitating all forms of telecommunications,

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[19] See Baldwin et al. (2003), chapter 7.
[20] Intuitively, if spillovers are global, any technological improvement benefits to all firms regardless of their location, so the spatial distribution of firms does not affect growth.
[21] Henderson (2003) shows that both cases are likely to prevail in a cross-section of cities.

increasing competition or fostering investment in human capital as potentially facilitating the trade in ideas and knowledge. However, as they acknowledge, it is not clear in practice whether we can disentangle the effects of transport or telecommunication policies on goods versus knowledge trade. In other words, policies aimed at a specific type of infrastructure may well facilitate both the transfer of goods, giving rise to the equity-efficiency trade-off mentioned above, and the transmission of ideas or knowledge spillovers, as they are often conveyed or mediated by the movements of persons. Moreover, whether better telecommunications increase or decrease the area over which spillovers materialize is still an open empirical question (Gaspar and Glaeser, 1996).

When the model is enriched to consider the existence of congestion costs, multiple equilibria arise, with in particular the possibility of the economy being in a good state with high growth, low spatial concentration and low inequality, or conversely in a bad state with low growth, high spatial concentration and high inequality. In that case, both policies that facilitate technological spillovers and those that improve infrastructure in the poor region have the potential to improve growth and reduce inequality.

At that stage, it is also interesting to note that new economic geography models help substantiate the claim that active infrastructure policy is a form of industrial policy. Indeed, different types of investments have effects on economic activity that go primarily through their impact on industrial specialization and (co-)agglomeration patterns.[22] In that sense, they might be a way to do industrial policy without having to make choices regarding potential winning sectors, instead relying on market dynamics.

Finally, a key aspect to this policy discussion is the fact that given the nature of the models at hand, very non-linear effects are to be expected. Because of the circular causality inducing agglomeration effects, policies will have very little effects until specific thresholds are reached and very strong effects beyond these. For example, convergence between a poor and a rich region will require that infrastructures in the poor region improve beyond a given level, while investment in roads facilitating trade between these regions may trigger strong divergence once it drives trade costs below a given level.

This generates a number of problems when trying to draw practical policy conclusions. If one accepts the basic logic of these models, identifying the right level of the thresholds may proved to be a daunting empirical task. If such thresholds indeed exist, but are hard to identify, large amount of resources may be spent with little results. Similarly, if these effects interact, so that for example policies have implications at the same time for inter- and intra-regional transport costs, policies may actually have effects opposite to those expected.

Moreover, the models' key ingredients relevant to infrastructure policy raise a number of deeper issues, which we address in what follows.

[22] Combes and Lafourcade (2005) indeed show that road infrastructure was only a minor contributor to the decline in transport costs in France between 1978 and 1998, but that it was the main force shaping the spatial distribution of these gains.

In the CP model and its extensions, infrastructure is at best an implicit determinant of transport costs, which themselves are modeled in a rather ad hoc way, i.e. as iceberg costs proportional to the value of trade. However, transportation is likely to entail significant fixed costs, so the assumption of proportionality is not empirically warranted.[23] This may not be a problem as long as one is interested by results in term of agglomeration for given transportation costs, but it seriously limits the potential scope of discussion of more detailed infrastructure issues.

Moreover, as discussed in Neary (2001), the CP model hardly allows for an appropriate modeling of transportation services considered as an economic sector per se, with its aspects of increasing returns, network externalities, etc.[24] Indeed, the transportation infrastructure has an effect on transport costs of other sectors that goes beyond a simple inverse linear relationship and is instead rooted in the industrial organization of the sector, its regulation, the different level of linkages with other sectors, etc.[25] Then, new investments in this type of infrastructure are likely to transform the structure of the sector and of the whole economy by affecting the pattern of input costs and availability, something that is not readily captured by standard economic geography models.

This is compounded by the fact that space is in general modeled in a rather sketchy way, consisting most of the time of two points, and in more sophisticated extensions of three points along a line, or of a continuous distribution of firms along either a line or a circle. This general criticism of economic geography model is especially worrying when one intends to use the theoretical framework to think about transport infrastructure, with the strong relevance of its geographic architecture.

Baldwin et al. (2003) improve on the traditional 2-points models by including into the model the parameterization of intra-regional transport costs, i.e. a measure of how costly it is to transport goods within regions. This allows for a distinction between traditional inter-regional transport costs, linked for example to the quality and availability of national roads, and local transport costs that can proxy for the quality and availability of more local aspect of infrastructure (local roads, bridges, etc.). Most of the policy conclusions discussed above rely on this framework.

The three-points-line framework may allow for conclusions relevant to some specific contexts where regional development is indeed close to such a pattern, such as Nepal (see Jacoby, 1999) or Papua New Guinea (Gibson and Rozelle, 2003), although the real issue in these cases seem to be one of access of remote points to the main roads rather than of development of the road itself. Alternatively, the “hub-and-spoke” framework has been explored by theory, with the result that better infrastructure may reinforce agglomeration in the hub, while exacerbating disparities with spoke regions (Puga, 2001).

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[23] Hummels (2007), Hummels and Skiba (2004), Combes and Lafourcade (2005).

[24] Rioja (2003), and Bougheas et al. (1999) also model infrastructure and transport cost in a general equilibrium framework, although not an economic geography one, but again their frameworks are restricted to a linear inverse relationship between these costs and the amount invested in building or maintaining transport networks.

[25] See for example Fernald (1999). Ellison, Glaeser and Kerr (2007) discuss the relationship between agglomeration and industrial coagglomeration patterns.

Finally, another question is how to consider other dimensions of infrastructure that arguably have crucial implications for some of the key elements of the model, such as electricity, which supply is crucial for firms' productivity, water, which is both an input for firms and a key consumption good for households, therefore having an impact among others on the cost-of-living dimension, and telecommunications. Regarding the latter, Baldwin et al. (2003) suggest that it may be proxied for by the degree of learning localization, in the sense that a better telecommunication infrastructure would allow spillovers between firms to span a larger geographical area. I return to the discussion of this aspect in the next section.

Urban Economics and the Role of Cities

While this is to some extent a distinct literature, the study of urbanization, cities and growth should also provide interesting elements to incorporate in a discussion on the role of infrastructure policies in the context of development.[26] Indeed, most of the development-induced processes of urbanization result in large pressure being put on local city infrastructure services. However, as stressed by Henderson (2005), formal models that endogenize transport costs and the spatial structure both across and within cities meaningfully by considering infrastructure investment are still needed.

One aspect on which relatively little theoretical insights are available is what happens in the process of development. Is it the case, as first conjectured by Jeffrey Williamson (1965), that low-income countries first experience a process of concentration, industrialization and regional divergence and then, as congestion becomes more important in the main cities, a reversed path of deconcentration and regional convergence, sustained by regional investment and development? How important to such a story is the presumption often found in economic geography models that market failures lead to too big cities, both because of standard agglomeration forces and of political economy arguments? Implicit here is the idea that infrastructure investment is at first lagging and follows rather than precedes development, but when a certain stage of is reached, investment in infrastructure outside the main cities could literally pave the way for the deconcentration of the economy. We discuss the available empirical evidence that seems to support these views in the next section.

This discussion has very important implications in terms of policy priorities. In particular, it indicates that it may be optimal to invest massively in city infrastructure at low-income levels while concentration happens, to avoid jeopardizing growth prospects, for example by limiting cities' capacity to attract investment (including from foreign sources). Additionally, given rapid rural-urban migration at that stage and the strong increase in urban concentration, such a policy is likely to have high welfare and poverty-mitigating payoffs. At some point, though, a shift toward measures aimed at connecting inner cities to their outside areas with large road and railroad corridors, telecommunications, etc., may be necessary to induce deconcentration.

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[26] See Henderson (2005) for a survey on Urbanization and growth, and Fujita and Thisse (2002) for a synthesis integrating this literature with the new economic geography models.

A number of additional issues arise in this context. First, determining the optimal concentration level and the right timing to shift resources from cities to outside areas is easier said than done. Moreover, infrastructure policies are not applied in a vacuum, so they need to be coordinated with other (possibly non-spatial) policies, like benefits to certain groups that are not evenly distributed across space and will therefore interact with spatial policies. Finally, this raises the larger question of whether there is a given remoteness threshold above which it is better to move people to jobs than move jobs to people.

3. Main Lessons from Theory

It is useful to briefly summarize how the insights from the growth theory and the economic geography literatures relate to the two sets of issues that we have highlighted in the introduction. Note also that while in most cases the original discussion is framed in terms of quantities of infrastructure, most of the discussion above can easily be reinterpreted in terms of quality in the sense that what matters is the level of services provided by given levels of infrastructure stocks.

Linkages between Infrastructure and Growth

Most of the channels highlighted in the context of growth theory sustain a link between infrastructure stocks (or their variations) and economic growth. This is of course the case of the direct productivity channel, which capture the impact of an increase in the quantity of infrastructure capital on the productivity of other factors.

Several of the potential indirect channels implied by growth theory also rely on the impact of more/better infrastructure on the productivity of other factors: private capital in the case of adjustment costs and some instances of economies of scale and scope, labor in the case of human development and labor productivity.

Issues such as the relevance of infrastructure spending at different stages of development or its role in facilitating convergence within or across countries are standard questions in the growth framework, but they also open to a number of problems such as the relevance of steady-state behavior versus transition dynamics, the optimal (dis)aggregation level, etc. We return to these problems when discussing empirical contributions.

The new economic geography framework is also mostly concerned with the link between infrastructure stocks and economic activity, although it explicitly adds an additional intermediate dimension, namely the spatial distribution of agents (firms and possibly labor) and assets. As such, it predicts a joint outcome in terms of growth and spatial inequality.

Composition, Sequencing and Efficiency of Alternative Investments

The theory bearing on these issues is far patchier, although not inexistent. The discussion can be grouped around three issues: 1) the composition of infrastructure investments (new investments vs. maintenance; operational vs. capital expenditures; private vs. public investment); 2) sequencing; 3) the relevance of different sub-sectors.

We discuss briefly the material related to point 1) below. On the other hand, we postpone the discussion of points 2) and 3) until the empirical section, as very few relevant theory exists on these topics. As for sequencing of reforms, is often referred to as an important issue in contexts where the strategy to generate infrastructure investments includes market based reforms such as privatization, introduction of competition and regulatory innovations. Some theoretical contributions have analyzed the link between ownership and efficiency.[27] However, so far their insights still have to be linked formally to the type of development outcomes of concern here. Similarly, growth model do not usually distinguish investments in different sub-sectors, defining instead "public capital" as a generic infrastructure good entering the production function. As for economic geography, it usually deals with transport infrastructure. As hinted in the discussion above, some dimensions included in the models can implicitly be related to other sectors, e.g. water and electricity to the cost-of-living aspects, the degree of localization of spillovers to telecommunications, etc. However, a more detailed integration of these aspects in the economic geography framework is still on the agenda.

Composition

As stressed when reviewing indirect channels in the growth framework, the new investment vs. maintenance debate has been addressed analytically in this context. It is not surprising that the conclusion of most models is that the balance between both types of expenditures is likely to depart from the optimal one. The weakness of these contributions, however, is that the reasons leading to this result (whether on the financing side or linked to the pork-barrel arguments) are generally assumed from the start rather than derived from more primitive aspects of the situation under study. An important topic for further theoretical research is therefore the potential to generate adequate incentives for politicians to revert the biases uncovered here.

As mentioned, this debate is also closely linked to the one on operational vs. capital expenditures. One reason for that is the fact that the OPEX/CAPEX balance is likely to be crucially influenced by the amount of relative maintenance expenditures. In essence, growth models imply that lower than optimal levels of maintenance expenditures will generate higher operational costs, both to run the infrastructure facilities and for private capital goods that rely on them. But again, they do not offer differentiated predictions according to initial conditions or sectors.

[27] See for example Riordan (1990), Shleifer and Vishny (1994), Schmidt (1996) and Martimort and Straub (2006).

III. Empirics

This section reviews the available empirical evidence on the link between infrastructure and development outcomes. Following the structure of the theoretical section, it does so by looking first at macro-level contributions, then turning to analyses that explicitly integrate a spatial dimension. Finally, it also provides an overview of micro-econometric studies touching upon the issue of infrastructure. The objective is to assess the suitability of the type of data used, the strengths and weaknesses of each technique, and the specific econometric issues that they raise, keeping always in mind the ultimate objective of deriving practical policy implications.

1. General Literature Review

In addition to reviewing these contributions, an overall assessment of the literature is intended based on the analysis of 140 specifications from 64 papers between 1989 and 2007, looking in details at the type of data used, the level of aggregation, the technique, the nature of the sample, etc. Of the 64 contribution reviewed, 43 (67%) were published in peer-reviewed outlets, while 21 (33%) were not.[28] Of course, this is not an exhaustive coverage of the relevant literature, which is probably at least ten times as large, and it cannot be claimed to be a random selection either. Before going on, we summarize a few general lessons from this analysis.

Table 1

Technique					
Prod fn	Cross-country	Cost function	Growth Accounting	Household survey data	Others*
69	29	13	4	7	18
49.3%	20.7%	9.3%	2.9%	5.0%	12.9%
Dependent variable					
Output	Growth	Productivity	Others**		
67	24	18	31		
47.9%	17.1%	12.9%	22.1%		
Independent variable					
Public capital expenditures	Physical indicators				
65	75				
46.4%	53.6%				

* Firm-level regressions, assets prices…
** Poverty, inequality, investment, asset prices…

In terms of techniques used, Table 1 shows that macro-econometric techniques have largely dominated the field. Among these, specifications based on the estimation of some version of a production function represent half of our sample, followed in

[28] Journals include the American Economic Review, the Journal of Monetary Economics, the Review of Economics and Statistics, the Journal of Development Economics, the Annals of Regional Science among others.

frequency by cross-country regressions (21%), cost function estimations (9%) and growth accounting techniques (3%). On the other hand, micro-level specifications using either household data or firm-level data sum up to approximately 18% of the total.

What is the global picture coming out of the research surveyed here? Overall, 63% of the specifications find a positive and significant link between infrastructure and some development outcome, while 31% find no significant effect and only 6% find a negative and significant relationship. Before discussing in more details the characteristics of these studies, two facts are worth noting.

First, contrary to what might be expected, there does not seem to be a bias towards publishing positive results, as the frequency of positive and significant results is actually lower in the sub-sample of published paper (58%). Of course, the possibility that this results from a selection bias when including papers in this review cannot be totally excluded, although no such explicit selection rule was used.

Second, the type of infrastructure proxies used by researchers interested in infrastructure has evolved in the last two decades. While most of the papers in the field at the end of the 1980s and beginning of the 1990s used some form of public capital figures (public investment), the limitations of this type of data, together with the growing availability of alternative infrastructure proxies such as physical indicators, has led to a move towards this second type of data. Indeed, while in the period 1989 to 1999 (65 specifications), the proportion of papers using public capital proxies is 72% against 28% using physical indicators, between 2000 and 2007 (75 specifications), the figures are reversed to only 24% using public capital data and 76% using some form of physical indicators.[29]

Looking now in more details, Table 2 shows the distribution of results from the studies under review depending on a number of characteristics. Historically, the literature has first been oriented to developed countries studies, mostly because this was where data were available and of better quality.[30] Where infrastructure problems are more acute and policy lessons more needed, however, is clearly in developing countries. This has led to a research drive to develop and use developing countries data. As a result, while in the period 1989-1999, only 29% of specifications were using specific developing countries data (and 20% mixed developed/developing samples), between 2000 and 2007, this figure went up to 47% (and 35% of mixed sample specifications).

Do results differ depending on the type of sample used? In our sample review, developing country data do lead to positive results slightly more often, but the difference is small (5%), while mixed sample are more often inconclusive, an outcome probably related to some fundamental heterogeneity across observational units (most of these studies use country-level data).

[29] The suitability and limitations of each type of data is discussed in more details in the next section.
[30] A large part of this literature corresponds to the US cross-state public capital literature.

Table 2 (number of specifications in parentheses)

	-1	0	1
Overall results (140)	5.7% (8)	31.4% (44)	62.9% (88)
Sample type			
Developed (47)	6.4%	31.9%	61.7%
Developing (54)	7.4%	25.9%	66.7%
Mixed (39)	2.6%	38.5%	59.0%
Dependent variable			
Output (67)	1.5%	44.8%	53.7%
Output growth (24)	16.7%	29.2%	54.2%
Productivity (18)	5.6%	27.8%	66.7%
Other * (31)	6.5%	6.5%	87.1%
Independent variable			
Public Capital (65)	10.8%	40.0%	49.2%
Physical Indicator (75)	1.3%	24.0%	74.7%
Public capital			
Aggregate (48)	12.5%	41.7%	45.8%
Transport (9)	11.1%	33.3%	55.6%
Telecom (4)	0.0%	0.0%	100.0%
Energy (1)	0.0%	0.0%	100.0%
Water (3)	0.0%	100.0%	0.0%
Physical indicators			
Electricity (20)	0.0%	30.0%	70.0%
Roads (27)	0.0%	18.5%	81.5%
Telecom (17)	0.0%	29.4%	70.6%
Water (2)	0.0%	0.0%	100.0%
Sanitation (2)	0.0%	50.0%	50.0%
Synthetic (6)	0.0%	16.7%	83.3%
Other (1)	100.0%	0.0%	0.0%
Theoretical framework			
Prod function (69)	2.9%	36.2%	60.9%
Cross-country reg (29)	13.8%	37.9%	48.3%
Cost function (13)	7.7%	15.4%	76.9%
Growth accounting (4)	0.0%	25.0%	75.0%
Other (Firm-level survey) (18)	5.6%	27.8%	66.7%
household survey data (7)	0.0%	0.0%	100.0%
Aggregation level			
Country (81)	4.9%	35.8%	59.3%
State / region / district (35)	5.7%	34.3%	60.0%
Industry (9)	11.1%	22.2%	66.7%
Firms /households (15)	6.7%	6.7%	86.7%

* Poverty, inequality, individual income, child height, asset or product prices, exports, investment, etc.

Different types of dependent variables have been used, the main ones being output, growth and productivity. Only about half of the analyses using either out put or output growth have produced conclusive positive results, while about two thirds of the studies trying to explain productivity have done so. Finally, studies using some alternative dependent variable (see table footnote) have been much more successful in proving a positive association between infrastructure and development outcomes.

An important question that has been addressed in the literature is to determine the more appropriate proxies for infrastructure. These have either been some measure of public capital (i.e. investment in infrastructure, generally from public sources although not exclusively) or physical indicators. The early literature using aggregate measures of public capital stocks has been unable to uncover a positive link between infrastructure and outcome variables in more than half of the cases. As mentioned above, the literature has gradually shifted to the use of physical indicators and this move has coincided with papers reporting more positive results.

There are at least two reasons why public capital figures are not very good proxies for infrastructure, or to put it differently, why infrastructure is not "public" capital.[31] First, a significant part of investment in infrastructure is made by the private sector. For example, in 7 Latin American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Mexico and Peru), private investment represented 16.4% of total investment in the period 1980-85, and 62.9% in 1996-2001 (Fay and Morrison, 2007). Because the trends in public versus private investment in sectors such as transportation, electricity or telecommunications have responded to a number of macroeconomic and institutional determinants, both at the national and international level, it should be obvious that measuring infrastructure stocks using only public investment figures introduces systematic measurement errors and renders most estimations unreliable.

An even more serious problem is that even if we could use total public and private investment in infrastructure sectors, there are serious reasons to think that stock figures computed from investment flows do not reflect effective infrastructure stocks and the level of services that they provide. The main reason for that is the fact that, especially in developing countries, the official costs of investments are often disconnected from their effective value, mostly because of governmental inefficiencies or institutional weaknesses (see Pritchett, 1996 for a more detailed discussion).

The second and related point already discussed in the theoretical section above is that infrastructure is often not a pure public good. In part because of its private sector origin, it is increasingly taking a private good nature and its services are being priced. The flow of services that accrue to private operators like firms is therefore more relevant than the stock of infrastructure capital, however well it is measured.

These shortcomings have to some extent been responsible for the trend towards physical indicators. However, to date physical infrastructure proxies suffer from three main problems. First, there are not systematically available across suitable geographical units and time. Second, the indicators currently used are often relatively bad proxies of the services they are supposed to capture. Third, the quality dimension of infrastructure services, which appears crucial to private operators, is almost completely absent from these indicators.

Finally, does the level of aggregation of data have an impact on the results? Although the trend is not overwhelming, it seems that results become more positive as we move towards a more disaggregated level. This is particularly clear when one looks at results from household-survey and firm-based survey based studies. In what follows,

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[31] The issue of the choice of indicators is discussed in more details in Straub (2007).

we discuss more specifically the macro-level literature, before turning to studies inspired by the new geographic literature and finally micro-econometric ones.

2. Macro-Level Empirical Studies

Issues and Conclusions

Of the 64 papers (140 specifications) included in the review, 48 papers (116 specifications) can be considered to be macro-econometric ones, i.e. either based on cross-country, cross-state or cross-region data. As discussed in Straub (2007), an inherent weakness of the macro-empirical literature has been the lack of clearly defined questions or issues to be tested. Following the taxonomy of relevant questions defined there, Table 3 shows that the overwhelming majority of the macro-level studies have limited themselves to comparing the elasticity of infrastructure capital and that of private capital. Moreover, a closer review of the papers shows that this is often a “default” option, in the sense that no real theoretical model motivates the empirical tests.

What types of results have come out of these exercises? A first generation of papers, including the well-known one by Aschauer (1989), produced very large estimates for the elasticity of infrastructure capital, between 0.20 and 0.40, mostly looking at public capital stocks in the context of US states.[32] Aschauer’s estimates imply marginal returns such that infrastructure investment pays for itself in approximately one year (Gramlich, 1994). More recent studies have also generated large estimates. For example, Duggall, Saltzman and Klein (1999) find an elasticity of 0.27, very similar to Aschauer’s. An often cited paper by Röllers and Waverman (2001), published in the American Economic Review, concludes, looking at OECD countries in the period 1970-1990, that a 1% increase in telecom penetration rate implies +0.045 % increase in GDP, which implies for example an additional compounded annual rate of 1.2% for Germany and that one third of the average OECD growth over these 20 years period can be attributed to telecom expansion. Similarly, Calderón and Servén (2004) state that if Latin American countries' infrastructure stocks were to catch up with the regional leader (Costa Rica), they would get additional growth of between 1.1 and 4% per year and would reduce their GINI coefficient by between 0.02 and 0.10.

Table 3

Questions tested (total number of specifications=116)	
Compare elasticity of infrastructure and private capital (108)	93.1%
Direct vs. indirect effects of infrastructure (8)	6.9%
Infrastructure-related vs. other externalities (7)	6.0%
Permanent vs. transitory effects (40)	34.5%
of which: cross-country (22)	19.0%
Others (18)	15.5%
Determination of optimal stock (6)	5.2%
Characterization of network effects (9)	7.8%
Effects of maintenance vs. new Investment (3)	2.6%

Note: see Straub (2007) for a discussion of the classification used here.

[32] Examples include Ford and Poret (1991), Munnel (1990) and Berndt and Hansson (1994) inter alia.

Such large estimates have often been considered as unrealistic and have triggered a large amount of subsequent research, looking at different samples or refining the techniques used.

As discussed in the theoretical section above, the fact that infrastructure-related capital can be both a public good, an input in the production of other intermediate inputs, and a productivity-shifting force raises a number of additional empirical questions. These include first the disentangling of direct (the first two channels above) versus indirect effects (the third channel), and within these indirect effects the characterization of the part responding strictly to infrastructure. As is apparent from table 3, a very limited amount of research has been devoted to these questions, mostly in the context of growth accounting studies. Notwithstanding the difficulties, already mentioned, involved in attributing a price to infrastructure capital to determine its share of output, Hulten and Schwab (2000) and Hulten et al. (2005) have developed a methodology to overcome that issue and find transport and energy infrastructure to account for an important part of TFP growth in India, while no such effect is found in the US case. Duggall et al. (1999, 2007) develop an alternative methodology based on 29 and 26 years of US data respectively. They find a large infrastructure elasticity, similar to that of Aschauer (1989), and conclude that the effect of infrastructure is partly dependent on the presence of other technologies. Replicating their methodology in the context of developing countries, however, would require data much beyond what is currently available.

An important conclusion of Duggall et al. (2007) is that public capital, through a combination of its direct and indirect effects, has the potential to generate increasing returns to scale at the aggregate level, thereby implying a permanent increase in the growth rate. Setting aside simple cross-country regressions that by nature imply the estimation of the long run growth rate, this issue, of particular policy relevance, has been little addressed in the literature. Canning (1999) and Canning and Pedroni (2004) use unit root and cointegration tests in the context of country level panel data as a way to assess long run effects. Additionally, these contributions highlight the fact that the issue of transitory versus permanent effects is closely linked to the question of identifying optimal infrastructure stocks. Indeed, Canning and Pedroni (2004) conclude that positive (resp. negative) long run effects are characteristic of an above-optimal (resp. below-optimal) infrastructure stock. Alternatively, Aschauer (2000) assess the optimality of US states infrastructure stocks by assuming a reference steady-state optimal output elasticity of 0.30. His conclusions, however, are subject to doubt both because this elasticity, in line with his previous results, appears very large and because he fails to account for the potential reverse causation between output and infrastructure.

More fundamentally, it appears that macro-level data on aggregate stocks of infrastructure, be it public capital figures or physical indicators, are by nature not adequate to capture the notion of optimality of infrastructure stocks. Indeed, the spatial nature of infrastructure implies that a given aggregate stock, for example a number of telephone connections or of kilometers of road, can be either optimal or grossly inadequate depending on the way it is distributed across geographical and individual units. We discuss this point further in the next section on the geographical empirical evidence, but an illustration of this is found in Cadot et al. (2005), who show, using French regional data, that infrastructure investment decisions are often politically driven and are therefore likely to depart from efficiency considerations.

Main Methodological Issues

The main problem that has plagued early studies and has been deemed responsible for the sometimes unrealistic results displayed is the potential endogeneity of infrastructure indicators. Such endogeneity has three main origins.[33] First, measurement error problems have already been discussed above and the main conclusion is that they seriously weaken the case for using public capital figures as proxy for infrastructure.

The second issue is that of potential unobserved effects or omitted variables. Unobserved effects arise if specific geographical units, countries or regions, have characteristics that lead them both to have higher performance (growth, productivity, etc.) and to invest more in infrastructure and if these aspects are unobserved to the econometrician. In most cases, it is plausible that some of these unobserved effects are time invariant, so the issue may be addressed with fixed effects estimation techniques in the context of panel data. Holtz-Eakin (1994) and Garcia-Milà et al. (1996) revisit the evidence on US states and find that once fixed effects are accounted for, no significant effect of public capital remains. Table 4 indeed shows that panel data specifications incorporating fixed effects do find negative or inconclusive results much more often.

Table 4

	Results		
	-1	**0**	**1**
Fixed effects			
No (41)	2.4%	22.0%	75.6%
Yes (47)	8.5%	40.4%	51.1%

It may also the case that omitted factors are time varying ones, in which case instrumental variables are needed. Straub (2007) discusses how instrumental variables may be constructed using data about policy in neighboring countries or state.

Finally, perhaps the more serious problem is that of reverse causation, and indeed it is often argued that the large estimates obtained by early papers were due to the neglect of this issue. This has mainly been addressed by using lagged values of the independent variables as instruments, a less than perfect solution in the context of the relatively small samples that characterize infrastructure studies. Romp and de Haan (2005) survey the macro-econometric literature and indicate that when reverse causation considerations were taken into account, the magnitude of estimates was approximately reduced to one third of Aschauer’s initial estimates, an indication of the importance of the issue. Cost function studies have also been used in an attempt to go around this problem, but they are in principle more suited to industry-level data and long panel because of their very data-demanding nature (see discussion in Romp and de Haan, 2005).

[33] See Wooldridge (2002) for more details.

Policy Implications

To close this section, it is important to form an overall assessment of the contribution of the macro-level empirical literature. Three main conclusions emerge. First, this literature has been plagued by numerous methodological issues that have often clouded the robustness of the conclusions, and despite numerous efforts to overcome endogeneity problems, it is not clear that it has succeeded. Pande and Udry (2006) illustrate clearly, in the context of another literature, namely the macro-level empirical literature on the link between institutional quality and development, some of the limitations of aggregate data. One aspect that is relevant to infrastructure proxies is the fact that, as long as the variables used to capture some dimension of infrastructure are in fact aggregates of different underlying aspects with separate causal relationship with the outcome of interest, the aggregate estimated effect will depend on the arbitrary weights used to define the right-hand side proxy. This is especially relevant for public capital proxy, but may also affect physical indicators as long as they are defined in a way that make them distinct from the real flow of services that households or firms receive. For example, Torero and von Braun (2006) show that rural households in Bangladesh use telephony for a large number of reasons, including business issues, land transaction, family/friend relationships, remittances, emergency news, etc., each of which may connect through different pathways to economic activity. Aggregating all of these into a simple indicator such as the number of telephone connections may give rise to the problem discussed above.

Second, even when studies have been technically sound, they have suffered from inescapable limitations due to the nature of data. Infrastructure capital stocks are inadequate proxies to the growing private nature of infrastructure services, while physical indicators are still too coarse to really capture the flow of services to households and firms, and optimal stocks are unlikely to be ever identifiable at the aggregation level of regions or countries.

Moreover, as discussed extensively in Straub (2007), key aspects that influence the efficiency of infrastructure sectors, such as the nature of the regulatory framework, the identity of operators and the nature of the political economy process that drives investments, have been almost completely ignored by this literature. While the inclusion of such data will not solve the methodological problems discussed above when trying to explain development outcomes, they could be used more systematically to analyze how the overall provision of infrastructure investments and the quality of services is affected by different aspects of the institutional environment, the sequencing and overall composition of reforms, etc.[34]

This leads to the third conclusion, namely the one questioning the policy relevance of the macro-level approach. Indeed, with the existing body of accumulated knowledge, the problem is not that we do not have significant evidence of a link between infrastructure and development outcomes, but rather that most of it is useless in a policy perspective. For example a diagnostic of insufficient aggregate transportation

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[34] For related contributions, see among others Cubbin and Stern (2005), Dal Bo and Rossi (2007), Dewatripont and Seabright (2005), Estache and Rossi (2005), Guasch, Laffont and Straub (2003, 2006), Henisz and Zelner (2004), Laffont (2005), Maskin and Tirole (2006), Rauch (1995) Robinson and Torvik (2005), Wallsten (2001) and World Bank (2004).

infrastructure in a given country might be warranted, but it leaves open the question of the exact types and location of investments, new freeways or rural roads, bridges, railways, maintenance versus new investment, etc., that should be prioritized.

Faced with these limitations, two routes appear attractive. The traditional one is to come back to microeconometric empirical assessments of specific projects or instances of infrastructure development. A more recent approach is to explicitly incorporate the lessons from the new economic geography literature in the empirical exercise. We review attempts along this line in the next section before looking at more traditional microeconometric studies.

3. Empirical Economic Geographic Studies

Empirical evidence on the role of infrastructure in the context of the economic geography frameworks mentioned above can be organized in three strands. First of all, I review generic evidence on the theoretical mechanisms underlying these models, namely agglomeration forces, transport costs and the volume of trade.

In a nutshell, two crucial steps need to be integrated to incorporate spatial insights into the discussion of the development impact of infrastructure policies. First of all, the nature of the link between infrastructure and transport costs need to be made explicit, so that we can estimate the impact of new investment, maintenance or upgrading of existing networks on these costs. Second, we need to be able to estimate how changes in transport costs will affect trade and agglomeration of firms and workers, and ultimately what their effect on a number of outcomes such as growth or income distribution will be.

I then turn to papers looking at the relationship between infrastructure and development outcomes by linking the two steps outlined above. I review them in two groups. Those that implicitly incorporate geography by testing the effect of infrastructure on the spatial variations of some variable of interest, generally prices of land, houses or labor, and those that explicitly introduce geographical variables in the analysis.

Generic Evidence

As stated when discussing theory, most of the discussion of infrastructure in the context of new economic geography models is based on the assumption that investments in transport infrastructure reduce trade costs and facilitate trade. This first raises the issue of how to measure transport costs.

Measuring Transport Costs with a View on Infrastructure Policy

Traditional methods have focused on simple proxies such as distance, ad valorem shares of trade values (predominantly the cif/fob ratio, which compares the cost-insurance-freight value of a good at the point of entry into the importing country to the free-on-board value at the point of shipment for exportation), or real freight expenditures.

First of all, as summarized in Henderson, Shalizi and Venables (2001), transport costs in many developing region of the world are far from negligible. For example, the costs measured by the cif/fob ratio can rise to 30 to 40% for remote landlocked countries. The impact on trade is also very important. Using distance as a proxy for transport costs, these authors report that doubling costs reduces trade volume by 80% and that the median landlocked country has 60% trade less than the median coastal country, a finding partly due to the fact that land transport is approximately seven times more costly than sea transport.

Using a gravity model of trade with either transport costs or cif/fob ratios, Limao & Venables (2001) show that, on top of distance, infrastructure matters strongly. Indeed, in such a model distance alone explains approximately 10% of transport costs, while including infrastructure variables increases the pseudo-R^2 to 50%. More precisely, improving a country's infrastructure stock from the median to the top 25th percentile would reduce the cif/fob ratio from 1.28 to 1.11, a change equivalent to the country getting 2,358km closer to all its trading partners. Conversely, deterioration from the median to the 75th percentile would increase the cif/fob ratio from 1.28 to 1.40, an increase equivalent to getting 2,016km further away from all trading partners. Similarly, Bougheas et al. (1999) estimate a gravity model of trade applied to EU countries, using both the stock of public capital and the length of the motorway network, and show that infrastructure is a significant determinant of trade volumes.

Similar evidence is found for African countries in Limao & Venables (2001), who estimate that intra-African transport costs are higher (136%) and trade volumes are lower (6%) than predicted by a standard gravity model, much of this corresponding to poor infrastructure (e.g. 59% of the total for costs) and the very high cost of distance. Moreover, an interesting element in that paper is the recognition of non-linear effects in the case where transit countries with very poor infrastructure virtually "kill" trade.

There is however an issue with the quality of transport costs proxies, which seriously limits the inferences that one can draw regarding the impact of specific infrastructure development policies.[35] First of all, cif/fob measures appear to do a relatively bad job at explaining the link between distance and transport costs. Moreover, by construction, they are limited to inter-country trade and do not allow for intra-country data, a serious problem when the objective is to assess the impact of regional infrastructure policy for example. As for distance, the main problem is that usual measures do not allow for the decomposition of the sources of variations in transport costs resulting from changes in the environment such as new investment in infrastructure, technological or regulatory changes. Indeed, Combes and Lafourcade (2005), after developing a more sophisticated measure, which I detail below, show that while simple time or distance measures do relatively well in a cross-section setting, they very imperfectly capture variations in transport costs in a time-series perspective, a particularly preoccupying feature when it comes to policy evaluations.

Using GIS data on the French road sector, as well as distance and time aspects of traffic conditions, transport technology and market structure of the transport industry,

[35] See Combes and Lafourcade (2005) for a more detailed discussion of the criteria that good transport cost measures should satisfy.

they develop a measure of Generalized Transport Costs (GTC) that satisfies a number of desirable requirements, and in particular allows for the decomposition of the variations of these costs into a number of components including infrastructure, fuel price, technology and regulation. The striking conclusion is that while the deregulation of the road transport industry was the main driver of the reduction in GTC, explaining 57% of the decrease against only 8% for infrastructure, the spatial distribution of this variation in costs was mostly mediated by infrastructure developments that allowed for the targeting of specific regions.[36]

Agglomeration Patterns and Outcomes

A related issue is the pattern of geographic industrial concentration, which I identified as an intermediate objective in the theoretical discussion. Ellison and Glaeser (1999) test an array of factors explaining industrial concentration in the US, among which a number of proxy for the quality of infrastructure services: prices of electricity and proxies for transport costs. Both of these appear to have a significant impact on firms' location decisions. Using coagglomeration patterns to disentangle further between the different theoretical mechanisms that may drive agglomeration, Ellison, Glaeser and Kerr (2007) find support for transport costs savings secured by locating near consumers and suppliers, for labor market externalities and for knowledge spillovers.

Additionally, some authors have provided evidence of the dynamics of agglomeration, dispersion and re-agglomeration that may occur at the industrial level and of the role of pioneer firms in that process (Kim, 1995; Dumais, Ellison and Glaeser, 2002; Hanson, 1996). Dumais et al. (2002) provide the most sophisticated such analysis. In particular, they link geographic concentration and the changes thereof to firms' life cycle, distinguishing between the effect of new firms' birth, expansion or contraction of existing firms, plant closures, and plants switching between industries. They conclude that mobility is rife, both among concentrated and non-concentrated industries, a fact that they interpret as proof of concentration being an equilibrium outcome determined by industry characteristics. They also conclude that firms' births tend to reduce concentration, while closures increase it.

How do these (co)agglomeration patterns relate to growth and income distribution? Overall, apart some suggestive aggregate evidence[37], there is no definitive evidence on the link between agglomeration and growth. The first issue here is whether there is an excessive or suboptimal degree of agglomeration. As signaled in the theoretical discussion, models allow for both outcomes so this is ultimately an empirical matter. Related evidence is found in urban empirical analysis. Using cross-country data on city concentration, Henderson (1999) finds that there is a best degree of urban concentration (also called primacy) that maximizes productivity growth by balancing benefits (local knowledge spillovers) and costs (congestion, cost of life in mega-cities).[38] His estimations indicate that one standard deviation from the best value costs

[36] Of course, such conclusion might not be directly transposable to a developing country context, in the sense that deregulation may fail to have an impact in a context in which the network is underdeveloped, although further research on this aspect is still due.
[37] See for example the introduction in Baldwin and Martin (2004).
[38] According to this paper, over-concentrated countries include Argentina, Chile, Algeria, Mexico, Peru and Thailand.

1.41% a year in terms of growth.[39] As for the process of concentration-deconcentration that may arise in the process of development, suggestive evidence from Brazil and Korea supports the Williamson (1965) view. Indeed, after an initial historical phase of concentration that led to the rapid growth of megalopolis like Seoul and Sao Paulo, industry appeared to move first to suburban areas and nearby satellite cities (say, those located at less than 60km or 1 hour of travel) in search for lower wages and land rents. This then created problems of pollution, saturation of infrastructure, aggravated by bad land use planning in areas that did not have the adequate administrative capacity to face such rapid population growth. In a second phase, activity then moved further out to hinterland and rural areas, a process sometimes facilitated by infrastructure investment.

Empirical Evidence in a Spatial Framework

Having discussed the building blocks, we now turn now to analyses that explicitly test the impact of infrastructure policy on development outcomes by integrating the various aspects. We divide them in two groups, depending on whether they explicitly include spatial variables or not.

Models Implicitly Including a Spatial Dimension

Haughwout (2000 and 2002) provide a methodology to indirectly account for the spatial implications of public capital investment when testing its effect on productivity. These papers propose spatial models that look at the effect of public capital on house prices, employment and wages, as a way to incorporate geographic mobility effects. Applying a compensating variations method and using US state and city level infrastructure and household data on house prices and wages to elicit geographic mobility impact, Haughwout (2002) shows that in general the marginal effect of infrastructure is positive but low. Infrastructure investments mainly benefit households, much less so firms, and the aggregate willingness to pay is less than the cost.

Jacoby (2001) represents an example of an application of this method in a developing country context. The paper uses household survey and plot value data to examine the distributional consequences of rural roads in Nepal, a country characterized for most farmers by long and costly travel to reach the main road that leads to market centers. It concludes that enabling better access to market does provide important average benefits, a 10% increase in travel time to market reduces the value of land by 2.2%, but that these benefits are only imperfectly targeted, therefore being “more like a tide that lifts all boats rather than a highly effective means of reducing income inequality”.

Models Explicitly Including Spatial Variables

Accessibility studies are an additional building block towards economic outcomes.
An accessibility indicator aims at measuring, for households and firms at each location in a given geographic area, the opportunities available at other locations in terms of employment opportunities or market potential. It does so by inversely

[39] Note that this does not impede the fact that urbanization may not generate any growth benefits, as has been the case in many African countries for example.

weighting the sum of some destinations' indicator (GDP or employment for example), by a proxy of the cost involved in reaching them. Obviously, following our discussion above, the better the cost measure (ideally some type of GTC), the more significant the accessibility index.

A number of contributions exist for Europe (see Combes and Lafourcade, 2005, and Spiekermann and Neubauer, 2002, for a methodological survey), and the use of GTC-like measures allow for an analysis of the role of different components, infrastructure, technology, market structure, on the changes in the level and spatial distribution of accessibility over time.

These accessibility indicators have been included in empirical analysis of firm-level productivity, together with standard determinants such as human capital, technology and regulatory measures, as well as additional "first and second nature" proxies signaled by the new economic geography literature. Examples for developing countries include Deichman, Fay, Koo and Lall (2002) for Southern Mexico, Lall, Funderburg and Yepes (2004) for Brazil, Lall, Shalizi and Deichman (2004) for India, and Deichmann, Kaiser, Lall and Shalizi (2005) for Indonesia. All these studies find that accessibility is a major determinant of firm productivity. For example, Deichmann et al. (2002) assess that a 10% improvement in market access would increase labor productivity by 6%, this effect being stronger for smaller firms. Starting from a gravity model of trade including road distances and road quality between 83 African mainland capital and cities of more than 500,000 habitants, Buys, Deichman and Wheeler (2006) set out to estimate the potential gains in trade volumes that would result from a major upgrading of the continental road network. They conclude that a road network upgrading costing less than $50 billion would generate trade gains of more than $250 billion over 15 years.

While these studies are clearly a step in the right direction, a major problem arises from the fact that the data used in the analysis are in all cases cross-section samples of firms. In effect, the conclusion mentioned above amounts to derive a dynamic prediction (a 10% improvement would generate 6% productivity gains) from a static indicator.

Leaving aside for the moment the difficulty inherent in figuring out the type of infrastructure investment that would generate this 10% improvement in market access, note that such a jump from static estimators to dynamic policy conclusion is in effect negating the very logic on which economic geography models are built. These models tell us that firms location decision are affected by transport costs, so firms may have decided their location in the past based on (previous) developments of the network. If that is true, the resulting estimations might be biased for several reasons.

First, the result of the static model generates estimators for a number of factors explaining firms' location at some point in time. If the underlying spatial distribution is an equilibrium phenomenon as assumed in NEG models[40], then changes in the underlying factors such as infrastructure-related transport costs would imply different equilibrium values for the relevant parameters (themselves resulting from a different spatial equilibrium distribution). This may be compounded by possible

[40] See Dumais, Ellison and Glaeser (2002) for supporting evidence.

complementarities or substitutability between these factors, as well as by the strongly non-linear effects that are at the root of NEG models. Simulations based on static estimates, or assuming only smooth linear variations around these estimates may therefore be inadequate.

Moreover, the spirit of NEG models tells us that what we observe is not that better access makes firms more efficient, but a spatial form of selection bias linked to firms locating according to the network's characteristics. Then, if for example more efficient firms are the ones relocating in secondary centers as links are formed, the estimates of the impact of market access are likely to be biased upward. A related issue is the fact that location decisions also imply simultaneous endogenous technological choices, which are partly responsible for the differences in efficiency observed across firms, a problem very difficult to address with this type of data. Indeed, a Heckit type of procedure might help control for this if technology choices are of a 0/1 nature (i.e. deciding to produce or shut-down), but continuous choices among technologies with different levels of productivity are more difficult to address.

Finally, an additional issue relates to the potential endogenous placement of specific infrastructure. Indeed, the essence of infrastructure policy is to make investments where they are likely to have the largest effect. Therefore, evaluating the impact of past investments is unlikely to provide reliable estimates for the effect of future works. This issue, however, can be tackled provided panel data are available. Some "first nature" characteristics, such as geographical aspects, can then be used as instruments for the placement of specific infrastructure, which suitability depends on local conditions.[41]

4. Microeconometric Studies

Some microeconometric contributions have looked into the issue of infrastructure's impact on development outcomes. To mention a few prominent ones, Gibson and Rozelle (2003) look at the effect of access to road in Papua New Guinea on poverty at the household level, and show that reducing access time to less than three hours where it was above this threshold leads to a fall of 5.3% in the head count index. Esther Duflo and Rohini Pande (2007) study the effect of irrigation dams in India on agricultural production and poverty. Their cost-Benefit analysis suggests that dams have very low rate of return and adverse distributional effects. Using Tanzanian household survey data, Fan, Nyange and Rao (2005) look at the impact of public investment and roads on household level income and poverty and find very positive effects, with a ratio of 1 to 9 in the case of public capital investment. Ilahi and Grimard (2000) show that the development of water infrastructure has a significant impact on women's time allocation in Pakistan. Thomas and Strauss (1992) analyze the determinants of child height in Brazil, a standard development outcome, and include electricity, water and sewerage connections as explanatory variables. They find the number of electricity connections per capita in the community to be positively correlated with height of babies, with a complementary effect of mother education. Positive results are also found for water and sanitation, with variations by

[41] Duflo and Pande (2007) use GIS data on land inclination to instrument for the endogenous placement of dams in India.

children age class and level of mother education. Galiani et al. (2006) show that the privatization of water in Argentina has significantly reduced the incidence of child mortality due to water-borne diseases and that most of this effect has been the result of an expansion in household access to the water network.

Another group of studies looks at firm-level data. Reinikka and Svensson (2002) use a survey of Ugandan firms to analyze how entrepreneurs cope with deficient public capital. They show that faced with unavailable and especially with unpredictable services, many firms invest in substitutes such as electricity generators. In that sense, poor public capital crowds out private investment. Moreover, in their sample, firms that have invested in generators invest less conditionally on public capital turning out to be not that bad. Their findings are similar to those coming out of a number of reports on investment climate assessments, such as Anas, Lee and Murray (1996) and Lee, Anas and Oh (1996) on Indonesia, Nigeria and Thailand, and Alby and Straub (2007) on eight Latin American countries. Finally, Jensen (2007) illustrates nicely in the context of south Indian fisheries how access to mobile telephony enhances market efficiency and welfare of the participants.

While household and firm survey data help solve some of the problem specific to macroeconomic data, they also generate some issues of their own. First of all, household level data, although they help identify direct effects on human development outcomes, also rule out the identification of effects on the economic activities of firms not owned at the household level. Moreover, microeconometric data have specific endogeneity problems, namely the fact that access variables cannot be considered to be exogenously determined. This arise for two reasons: endogenous service placement, because public investment decisions are likely to be affected by the expected returns and be non-randomly attributed, and endogenous placement of households and firms, as for example wealthier households or more skilled entrepreneurs may take location decisions based on the potential availability of infrastructure services. At the firm level, an alternative version of this last issue is endogenous technology choices, whereby firms faced with different quality and availability of infrastructure services would choose different technologies.[42]

The problem of endogenous placement has been addressed in various ways. Gibson and Rozelle (2003) take advantage of the fact that highway development occurred progressively from coast to inland areas to use the timing of highway penetration in each district as an instrument for road density. However, it is clear that this strategy is only made possible by the specific geographic characteristics of Papua New Guinea. Duflo and Pande (2007) use GIS data on land inclination to instrument for dams placement choices. The issue of endogenous technological choices, a crucial one when outcomes such as economic activity indicators are considered, poses a greater challenge. Haughwout (2002) and Jacoby (2000) circumvent the problem by using local prices of either land, houses or labor as dependent variable, under the assumption that these prices reflect potential profits resulting among other things from infrastructure availability, but are not affected by technological choices. However, as signaled by Gibson (2005), it is not clear that any of these assets fully captures the present value of future profits, especially in the non-farm sector.

[42] An attempt to address this issue in the context of ICA surveys is in Escribano and Guasch (2005).

5. Main Lessons from Empirical Studies

Coming back to the two set of issues stressed in the introduction, how much do we learn from the empirical literature reviewed above?

Linkages between Infrastructure and Growth

Concerning the link between infrastructure investment and growth, section III.1 above provides a summary of the results. In a nutshell, close to two-thirds of the studies surveyed here conclude there is a positive and significant link. However, the diversity of techniques, indicators, samples and time frames paints a rather confusing picture when it comes to answering specific questions of interest to policy makers.

How much spending should be allocated to infrastructure at different stages of development? It is fair to say that the literature provides no clear guidelines on this issue. Considering the three sectors for which more than a handful of studies are reviewed (electricity, road transport and telecommunications), a positive link is more often found in developing countries samples than in developed countries or in mixed ones. It is hard, however, to go beyond this general statement and in particular to provide a numerical assessment of the desired levels of investment, both in and across sectors. While in recent years major Latin American countries have invested less than 3% of GDP on average (Fay and Morrison, 2007), some East Asian countries like China and Vietnam are investing around 10% of their GDP in infrastructure (Straub, Vellutini and Warlters, 2007). Although some attempts have been made to develop a theoretical framework that could help identify these optimal investment levels, this is clearly an aspect that requires further research. [43]

An additional difficulty stems from the issue of network externalities. Indeed, even if we believe the results from some studies that show increased returns to infrastructure investment in some sectors (e.g. telecommunications) at higher levels of development, should we conclude that LDCs should invest less?

What is the impact of infrastructure investment on development gaps between countries, regions within these countries, rural and urban areas, etc.? The review of the new economic geography literature shows that this remains an area where major empirical developments are due.

Composition, Sequencing and Efficiency of Alternative Investments

Going beyond spending levels requires addressing the issue of the quality of spending. The quality dimension can be linked both to the composition of these investments and to the sequencing of the supporting reforms. While we have

[43] See Fay and Morrison (2007), appendix B. The simple extrapolation of results from macroeconomic estimates provides a simple, but unsatisfactory way to do that, raising a number of issues such as the heterogeneity across countries and along the development path, and the relevance of the steady-state versus transitional dynamics (see Barro and Sala-i-Martin, 2005, for more details).

mentioned above that theory has dealt very little with these issues, some interesting insights can be found in the empirical literature.

On the topic of new investment versus maintenance expenditures, little empirical evidence is available. While the theory discussed previously suggests a bias toward new investments (Rioja, 2003; Kalaitzidakis and Kalyvitis, 2004), there is an obvious need to generate adequate data to assess this issue. Ideally, this means data on both infrastructure investments and maintenance expenditures, of the type used in Kalaitzidakis and Kalyvitis (2005) for Canada. However, this would generate compatibility issue with the growing emphasis on physical indicators.

How much maintenance spending is necessary to maintain the integrity of networks given demand projections, is probably best addressed in practice by economic-engineering models that allow identifying maintenance expenditure standards. Fay and Morrison (2007) mention standards of 2% of the replacement cost of capital for electricity, roads and rail, 3% for water and sanitation and 8% for mobile and fixed telephone lines. These expenditures should then be added to projected investment needs. However, as mentioned above, while these magnitudes are well known, politicians often face incentives that lead them to distort maintenance needs downwards. Empirical evaluations of how these distortions are affected by the characteristics of the political game and by the nature of the relationships between policy makers and financing agencies would be a first step towards understanding how the right incentives can be created.

In the context of developing countries and physical infrastructure indicators, maintenance can be alternatively approached from the quality side. Hulten (1996) uses an effectiveness index of infrastructure in cross-country estimations and reports an impact more than seven times larger than that of public capital. Systematic assessment of the quality of services could be included in microeconomic surveys, as is already partially the case in ICAs. Databases such as ROCKS in the case of road construction (see Deichmann, Buys and Wheeler, 2006), can then be used to estimate the cost of maintenance expenditures corresponding to given quality improvements and compare them to the cost of new investments.

As for empirical insights about the sequencing of reforms supporting infrastructure investment, they are mostly found in studies looking at some form of private sector involvement in these sectors. In essence, researchers have been concerned with the timing of restructuring measures (before or after privatization), the implementation of regulation and, if so, the institutional aspects of it, and the potential introduction of competition.

The common wisdom seems to be that when some form of privatization is considered, restructuring should be undertaken prior to its implementation, a regulatory framework should be put in place and supported by institutional arrangements including transparency and independence of the agencies in charge, and competition should be introduced whenever the characteristics of the activity make this possible (World Bank, 2004). Although reviewing the vast literature dealing with the evaluation of privatization and with the impact of regulatory governance on performance is beyond the scope of this paper[44], some supporting evidence is available in the specific case of infrastructure. Andres et al. (2007) review the performance of 181 privatized firms in 3 sectors (telecommunications, electricity distribution, water and sewerage) across 15 Latin American countries. Controlling for existing pre-privatization and transition-period trends, they conclude that overall there are consistent improvements in operating performance and quality, reduction in the workforce, a tendency to price increases but with a lot of variability, and no significant impacts on output and coverage. When adding to their estimations contractual and regulatory characteristics, they conclude for example that regulatory autonomy and stability induce additional decrease in employment and output, while price cap regulation results in additional decreases in employment and labor productivity. Their main conclusion is clearly that regulation is a multi-dimensional issue, with complex effects on the array of outcomes they analyze. On the other hand, Guasch et al. (2007) show that price cap regulation also leads to numerous contract renegotiations.

A number of caveats are in order here. First of all, even the most recent contributions provide only indirect links, through firm-level output, coverage and prices, to outcomes that matter to policy makers, such as aggregate output growth, welfare and poverty reduction. Exercises such as the ones performed in 4 Latin American countries and summarized in McKenzie and Mookherjee (2003) are still to be repeated on a larger scale.

Moreover, while privatization is certainly a very exciting issue for researchers as well as a very controversial one in practice, the private sector still represents a rather small share of overall infrastructure spending and the current momentum indicates that it is not likely to grow substantially in the short term.

IV. Directions for Future Research

1. Main Challenges and Key Working Objectives

Based on the papers and contributions reviewed above, this section summarizes the main challenges to be addressed by each strand of literature, as well as a number of "key working objectives" that could constitute reasonable short to medium term research objectives in each area. The next section looks at related data development issues. Finally, Table 5 in the conclusion summarizes the main recommendations.

1.a. Macroeconomic Literature

As discussed in section 3.2 above, the main limitation is not a technical one but rather the fact that the interesting questions cannot be addressed with data at that level of aggregation, or to put it differently, that this line of research will not provide policy implications able to guide detailed investment decisions on the field. The situation is

[44] See the review in Martimort and Straub (2006).

somewhat similar to that of the literature on institutional quality and development: Pande and Udry (2005) conclude that this literature has provided reasonably strong certainties on the fact that good institutions are a necessary condition for economic development to take place, but that it is time to move to a finer, microeconomic approach to specific institutions in order to derive meaningful policy implications. In that sense, Jorgenson's statement ("The intrusion of macroeconomists armed with conventional econometric techniques into the infrastructure debate has been counterproductive") could probably be adapted to: "The intrusion of macroeconomists armed with conventional econometric techniques into the infrastructure debate has yielded some useful insights (as well as a lot of confusion), but sticking to this approach much longer would be counterproductive".

So, what can macro-data still do for us?

- *They are useful to provide a general picture of the level of infrastructure development across countries (see introduction), but as I argue below, the aggregation of microeconomic survey data is the more promising avenue to develop such data.*
- *They should give up the central role that they have had in the last twenty years in the empirical literature on the effect of infrastructure on development.*
- *One area, however, in which they may prove useful, is the study of how institutional, regulatory and political economy characteristics of countries or regions affect the amount and quality of infrastructure services provided at the sector level. This implies strengthening the systematic collection of data on these aspects, such as is currently the case for telecommunications in the ICT "At a Glance" table in the Development Data Platform, or the recent logistic data (World Bank, 2007).*
- *It would also benefit from a major theoretical modeling effort of the channels involved.*

Key Working Objectives

- Step up current efforts to analyze the link between infrastructure sectors' organization (including, among others, degree of competition, ownership, etc.), regulatory governance and sector's performance (See Andres, Guasch and Lopez Azumendi, 2007, for an example of this approach with Latin American data). The objective should be to end up having a systematic picture of the results with broad international coverage, allowing for lessons to be drawn at the sector level, discriminating by initial level of development and other relevant country level characteristics (political system, inequality, etc.), as envisioned for example in Vagliasindi (2007).
- Some of the key aspects to be analyzed include optimal organization, regulatory institutions, the sequencing of policy measures, the impact of measures geared towards the development of capacity to coordinate infrastructure development, etc.
- More generally, when it comes to political and institutional aspects, an effort should be made to disentangle formal laws and regulations from the quality of their implementation, their enforcement, etc.
- The empirical objective described above should be guided by an important modeling effort of the different channels involved. Key areas here include the impact of fiscal constraints on public investment (Servén, 2007), the link of

these constraints with optimal infrastructure investment needs at different stages of development (Fay and Yepes, 2003), the interplay between country and sector governance and different aspects of infrastructure development (level of investment, incentives to invest in maintenance vs. new investments, efficiency of different configurations, etc.). Conclusions should take into account the characteristics of the different sectors / countries under consideration.
- These aspects involve crucial and complex interactions on which theoretical insights are missing, such as the link between financial constraints (of government and operators) and involvement of external financing agents (either private or multilateral) and how the multiprincipal nature of this situation affects the level and performance of investments.

1.b. Microeconometric Literature

These contributions have in general yielded more robust insights into the human development effects of infrastructure, in particular because they allow for a better understanding of the interactions between service availability and other aspects such as financial development (Binswanger et al., 1993), level of education of household members (Thomas and Strauss, 1992), etc. This is particularly useful because infrastructure policies are not implemented in a vacuum and policy makers need to understand how they interact with other policies that affect different groups of the population. Moreover, household access data to services such as water, sanitation, electricity and telecommunications can be aggregated at the village / district /state level and used in large scale policy evaluations (more on this below when discussing sector level data recommendations).

There are of course drawbacks to the microeconomic approach. First, microeconometric contributions are by nature focused on specific cases and contexts, so they may not always provide lessons that can be generalized. Second, as already mentioned, they have difficulties in capturing entrepreneurial activities that are not owned at the household level.

The answer to this last point seems to be the development of large scale firm surveys such as the investment climate assessments (ICAs). Unfortunately, the “infrastructure content” of ICA surveys has been reduced over time. For example, Lee, Anas and Oh (1996) where able to assess infrastructure constraint for several sectors and had access to data on the cost of substitute capital investments by firms that have disappeared from more recent waves of these surveys. Moreover, apart from specific issues in the design of ICA surveys, their use to address infrastructure issues runs into a specific difficulty discussed at the end of the previous section, namely the fact that they are ill-equipped to address endogenous technological choices by entrepreneurs.

It seems reasonable that micro-data should become the main focus of data development efforts.
- *Household surveys should systematically incorporate module on infrastructure, designed in such a way to enable upwards aggregation with sufficient coverage of large geographic areas.*
- *This would enable the collection of data on two additional aspects: the quality and the cost of services.*

- *Firm surveys such as ICAs should be designed with the specific objective in mind to address endogenous placement and (especially) endogenous technology choices.*

Key Working Objectives

- Build on Briceño-Garmendia and Klytchnikova (2006) to define gaps and adjustment to be made to current household survey data collection. Define strategy implementable at the World Bank / multilateral donors' level to generate such data, taking into account institutional / political constraints related to the ownership of such surveys. This should give special care to reach a complete coverage of infrastructure sub-sectors, for which linkages are often not well understood (e.g. rail, ports, airports, etc.).
- Retake and evaluate existing ICA work and define gaps and adjustment to be made to current data collection to make infrastructure (one of) the prime objective of such surveys.
- One crucial objective to be kept in mind when designing surveys should be to address correctly issues of innovations and productivity changes induced by infrastructure investment (e.g. new information technologies), that is the endogenous technological choice issue.
- The sectoral coverage should also be as inclusive as possible. For example, transport should not include only roads but also ports, airports, railways; telecommunications should encompass different modes such as fixed and mobile telephony, internet access, etc.
- Once this is done, generate pictures of interactions between infrastructure sectors and development outcomes (from macro to micro) on the basis of household/firm survey data.

1.c. Economic Geography

Ideally, suitable empirical tests of new economic geography models will rely on household and firm-level data, together with spatially disaggregated infrastructure indicators. In a sense, these models represent an opportunity to apply micro-econometric techniques on a large enough scale to generate interesting policy conclusions.

A number of key issues remain to be addressed:

- *Can we enrich these models to include a better, more realistic representation of (all) infrastructure sectors, without making them intractable?*
- *Technically, what is the best way to test these models? How do we go about addressing threshold effects in a dynamic context? How do we deal with multiple equilibria? There clearly needs to be more work on these issues.*
- *Panel data are an absolute requirement to test models, which by nature imply dynamic changes in the distribution of economic activity as infrastructure investment occurs.*

Key Working Objectives

- Sustain a large theoretical effort to develop new economic geography models that include more explicitly the different infrastructure sectors. This implies

- Build on the outcomes of actions outlined above (microeconomic data) to develop suitable panel data to test these models.
- Develop suitable econometric techniques to address the challenges raised by new economic geography models.

2. Data Development

Transport

Country-level roads length statistics need to be disaggregated at the regional / state level, and should also distinguish between different types of road. An example of the standard road statistics data that should be aimed can be found in Fan and Chan-Kang (2005) for China. They provide length of roads for 6 different classes, from expressways to substandard types, with more than 20 years coverage and disaggregated numbers at the regional level. Similarly disaggregated figures for alternative transport modes (railways, airports, ports, etc.) may complete the picture.
Simultaneously, household / firm survey data should be generated on access to service (roads, railroads, etc.), assessment of cost / quality, and ownership of different types of vehicles.

Energy

Electricity is mostly proxied for by country-level electricity generation capacity. However, this is often a rather bad proxy to the availability and quality of electric services (see examples in Straub, 2007). Instead, we should aim at connection data at the household level and then aggregate these to get average connections rates at the village and district level. Similar data should be aimed at for gas connections.
Additionally, both household and firm surveys infrastructure modules should include questions aimed at capturing:

- The quality of services (number of outages, appliances or machines failures).
- The cost of services (share of household budgets and of firms' total costs).
- The institutional nature of service providers and regulatory arrangements.
- When applicable, investments in alternative supply mechanisms (generators, pumps) and their costs.

Telecommunications

Connection data on use and ownership of fixed telephone lines / mobile telephone lines / internet connections, should be collected at the household /firm level and then aggregated to get average connections rates at the village and district level. Distance to the closest available service point should be considered when no service is available in rural communities. As in the case of energy, additional information on the nature of the services (public phones, shared private phones, etc.), their quality, their cost and their institutional nature should complete the picture.

Water and Sanitation

Water and sewerage connection data should be collected at the household / firm level and then aggregated to get average connections rates at the village and district level. Distance to the closest available service point should be considered when no service is available in rural communities. Standard information on the nature of the services, their quality, their cost and their institutional nature should complete the picture. This last aspect is especially relevant for water, which is often provided by local operators and regulated at the local rather than the national level.

V. Conclusion

The review of the infrastructure and development literature performed in this paper sustains a number of conclusions in terms of potential research areas and associated data development need, which can be organized in three related parts, relating to macroeconomic, microeconomic and economic geography aspects. In terms of data development, the main effort should be concentrated in the microeconomic part of the picture, through a strategy to gather data from both household and firm-level (ICAs) survey on aspects including access, quality and costs of services. Indicators, aggregated at different levels, could then be used both in macro-level and economic geography types of estimations.

At the macro-level, the relevant challenges imply to move away from a long string of contributions that have tried to estimate the link between output or growth and aggregate indicators of infrastructure (public capital or physical indicators) and rather concentrate on how aspects linked to the political, institutional and regulatory environment have affected the delivery and efficiency of services in the different sectors. This also implies continuing with ongoing efforts to develop large databases on these features of the environment, and stepping up theoretical effort to understand the underlying mechanisms at work.

The economic geography approach appears very promising, but infrastructure related work, both at the theoretical and at the empirical level, is still in its infancy. Significant efforts are necessary to develop the relevant theories, include additional aspects of infrastructure beyond transportation, and develop suitable empirical strategies to test the models. The main related recommendations are summarized in Table 5.

Table 5: Summary of Recommendations

	Key working objectives	Data
Macroeconomic aspects	**Theory**: - Optimal infrastructure investment needs and fiscal constraints. - Interplay between country and sector governance and different aspects of infrastructure development. - The link between financial constraints (of government and operators) and involvement of external financing agents and how the multiprincipal nature of this situation affects the level and performance of investments. **Empirical**: - Step up current efforts to analyze the empirical link between infrastructure sectors' organization (degree of competition, ownership, etc.), regulatory governance, the sequencing of policy measures, the impact of measures geared towards the development of capacity to coordinate infrastructure development, etc., and sectors' performance.	- Strengthen the systematic collection of data on institutional, regulatory and political economy characteristics of sectors / regions / countries. - For infrastructure access / quality / cost data, use output from microeconomic data gathering effort.
Microeconomic aspects	**Empirical**: - Define gaps and adjustment to be made to current household survey data collection and strategy implementable at the WB level to generate such data, taking into account institutional / political constraints related to the ownership of such surveys. - Retake and evaluate existing ICA work and define gaps and adjustment to be made to current data collection to make infrastructure (one of) the prime objective of such surveys. - Address endogenous technological choice issue in the context of firm-level data.	- Generate data on access, quality and costs in the four main sectors, to feed in both macroeconomic and economic geography research.
Economic Geography	**Theory**: - Develop new economic geography models that include more explicitly the different infrastructure sectors. - Address shortcomings to the current modeling of transportation. - Include other aspects, such as telecommunications, electricity and water, in the theoretical framework. **Empirical**: - Develop suitable econometric techniques and panel data to test these models.	- Use output from microeconomic data gathering effort, to develop adequate GTC measures for developing countries, as well as indicators for other dimensions of infrastructure.

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