Economic effects of Infrastructure Investment on output and productivity: A Meta-Analysis

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Abstract: Disentangling the size and magnitude of the direct and indirect effects of infrastructure on output and productivity remain a key issue in empirical studies, especially cost-benefit studies (CBA). Output elasticities reported by empirical studies vary a lot and some of them are implausibly large. This is due essentially to the application of different methodological approaches and analytical methods to estimate them, which in turn depend on the type and nature of infrastructural project and the geographical scale where they take place.
The aim of this paper is to explore the way empirical studies try to calculate and integrate the effects of infrastructure investment on economic performance i.e. productivity or growth. We use a simple meta-analysis to systematically synthesize the results of existing studies and analyze their source of variation.
We specifically ask the following questions: (1). To what extent may meta-analysis improve our understanding of the main causes underlying the differences in the estimated effects of infrastructure investment on (private) output; (2). How and to what extent can this statistical approach contribute to improve existing economic models?; (3). Are there specific lessons to be learned from the use of this meta-analytical method/approach?.

We find that estimated output elasticity of public capital show considerable heterogeneity. The type of capital, the level of aggregation of public capital data, the country type, and the econometric specification are identified as sources of this variation among studies analyzed in this paper.

Keywords: Infrastructure investment, Cost-Benefit Analysis, economic performance, Meta-analysis, Meta-regression.
JEL-Code: O40, H43, H54, C80, R11, R15, R53.

1. Introduction

Economic growth and development is not uniform in space in the sense that various countries and regions react differently to various forces leading to divergence and convergence. Since the 1990s, a large number of theoretical and empirical works, providing a framework for analyzing a wide range of force driving economic growth, has emerged. A growing interest by economists and policy makers was given to growth models which are concerned in the first place by the study of the mechanisms determining the economic growth at national as well as at regional level (see Romer, 1986; Lucas, 1988, 1990; Barro and Sala-i-Martin, 1995; Aghion and Howitt, 1988).

The literature shows that the central forces contributing to economic growth are technological changes, knowledge creation, the nature and the scale of human capital, expenditure on education, institutional conditions, agglomeration economies, and infrastructure development. From this wider range of forces driving economic growth, infrastructure is still considered as one of the most important factors driving economic growth to the regions and nations.

Indeed, infrastructure, such as transport networks and intangible networks (such as knowledge and information networks, and organizational networks), generate positive (as well as negative) externalities to the private sector i.e. productivity of firms, and contribute to the growth of output or stocks in localities (i.e. the well-being of households).

The economic effects of public investment in infrastructure and growth issues have been at the centre of the academic and policy debate for the last two decades.

One important issue in this respect is the growth of the demand for public investment in infrastructure e.g. public goods and public services. The complexity of this issue concerns the way researchers and policymakers deal with the different economic and environmental impacts of infrastructure investment on the local economy as well as on the national scale. This is because the nature and the magnitude of economic effects of infrastructure investment differ from case to case following the type, scale and purposes of infrastructure investment.

Beside the variety of economic effects, ranging from direct and indirect effects to purely specific internal effects and/or widely external effects, there are also different scale effects varying from purely locale effects (e.g. regional levels) to national effects (welfare effects) and even international effects (cross-border effects such as environment effects).

More generally, infrastructure investment may have positive and/or negative implications on the functioning of the locale and national economic systems, in term of waste or gain of time and resources. These may occur simultaneously or successively at different stage during and after the realization of the infrastructure project e.g. ex-ante and ex-post.

In opposite to the direct effects of infrastructure investment which are relatively easy to evaluate ex-ante in a standard cost-benefit analysis (CBA), the monetary evaluation of indirect and external effects is very difficult because they take place outside the sphere of the market and not directly subject to any prices mechanism. This pose serious challenge to researchers when dealing with the question on how to handle (quantify) indirect and external effects in CBA analysis and their implications at various spatial levels i.e. regions and countries.

In the Netherlands, the present Dutch guidelines for assessment of infrastructure projects (OEEI-leidraad (later OEI)) was subject to criticism, especially about the question concerning the risk of double counting of some effects and the ex-ante evaluation of indirect effects of infrastructure projects in standard cost-benefit analysis (CBA) (see reports, CPB, 2003, and Elhorst et al, 2004). More interesting in this respect is the absence of rigorous and unified method to evaluate these effects at regional level. This is because, the current practice of cost-benefit analysis has sever shortcomings with regard to the operationalization of indirect and external effects such as clustering effects, agglomeration effects, distributional and generative effects, which constitute key elements in the evaluation of infrastructure projects. Therefore, these incommensurables aspects of infrastructure project are still difficult to include in current practice of cost-benefit analysis.
As result, decision making process about the realization or not of infrastructure projects is based more on qualitative judgments than on a precise quantitative assessment. In addition, limited effects are taken into account, which are usually under or over-estimated (Flyvbjerg et al, 2003).

Furthermore, the monetary evaluation of external effects and agglomeration effects e.g. expected magnitude and additional indirect effects, present several shortcomings when evaluating infrastructure projects. First, the lack of appropriate aggregate data at very low spatial level (at city level) may lead to an under-estimation of the total effects of investment in infrastructure projects. Second, ex-post evaluation of infrastructure project, and thus the exact indirect (induced) effects, becomes difficult in the absence of rigorous analytical method, and a more unified theoretical framework of such concepts as externalities, external effects and agglomeration effects. However, from an analytical point of view a clear progress has been made over the last two decades of the twentieth century in this direction by developing and calibrating a number of sophisticated general equilibrium models. Most of these models are partly derived from spatial models developed in the field of the new economic geography (NEG models). Such models were applied in different empirical studies measuring the contribution of public capital to private output e.g. especially in terms of direct and indirect effects of infrastructure investment on productivity and employment (see for example the SACTRA and the IASON projects). Applying this kind of models makes it possible for researchers to combine different approaches, methods, tools and data when evaluating different effects of infrastructure investment.
Most studies have tried to measure the output elasticity of public capital by estimating a production function that includes the public capital stocks as an input. One of the first authors that investigated this issue for the USA in his attempt to explain productivity growth slowdown in the 1970s was Aschauer (1989, 1990). He provides causal evidence on the existence of linkage between public investment and aggregate labour productivity growth. In his study, Aschauer (1989) found that a 1% rise in public capital stock increased private output by 0,39%. Since then, various studies have been undertaken for the USA and various other OECD countries showing different results ranging from a significantly negative effect to a strong positive effect of public capital on output. So far, few studies have attached priority to reconciling these differences. In this paper, we quantitatively review the literature on the effects of public investment on infrastructure on private output by mean of meta-analysis. The aim of this study is to analyze the determinant of observed heterogeneity across and between studies.
The meta-analysis has gained in popularity as suitable statistical method to summarize, evaluate, and analyze empirical results from primary studies. In this sense, it presents a more systematic and objective way to assess

whether variations in results of such studies are due to differences in applied methods and analytical approaches, the specificity of data used, the difference in spatial and sector scale, and other specifications.
Furthermore, meta-analysis allows us to identify whether the empirical findings are sensitive to the adopted empirical methodology, and in the same time to explain the wide study-to-study variation by fundamental economic variables and the researcher's choice of research design.

Despite the fact that various authors have reviewed the literature on the effects of infrastructure investment on growth, very few studies, with the exception of Button (1988), have applied a meta-regression analysis.
Our study covers a large sample of all relevant studies up to the year 2010, giving rise to a meta-dataset of almost 241 studies. Our larger meta-regression dataset, including studies not reporting any estimated elasticities, incorporates 302 studies.
We test for a larger set of potential determinants of differences across studies, including variables describing the functional and econometric specification of the production function, the capital stock definition, the study area and the spatial level of studies, the year of publication and the period of studies, the analytical approach used by each study and various other variables such as the use of pooled data, first difference, time series or cross-section data.
We exploit the panel structure of the data by taking multiple observations from the same study and estimate various panel data models. Reported estimates show a substantial amount of observed heterogeneity among studies in our panel data. For example, studies employing core infrastructure, and using data at the federal/national level find larger output elasticities of public capital. In opposition, studies using data for the USA and imposing economies of scale restrictions on the coefficients of the production function find smaller output elasticities of output.

The organization of this paper is structured as follow. In section 2, we review and summarize existing literature so far on the relationship between infrastructure investment and economic growth, especially in CBA analysis. In addition, we analyze –in a more systematic way- the source of (quantitative) variation in results reported by previously obtained empirical studies concerning the difference in the elasticity's reported.
Section 3 presents and discusses applied methodologies used by empirical studies that estimate the elasticities of public capital, and give an overview of the criticisms launched against the production function approach.
Section 4 presents applied meta-analysis technique, the data used to construct our meta-sample, and the empirical specification of the meta-regression model. Section 5 presents and discusses the estimations results of simple meta-regression analysis, and section 6 concludes.

2. Infrastructure investment and economic growth: A review of the literature

Existing literature concerned with the study of the relationship between infrastructure investment and economic growth show a wide variety of point of view concerning the definition of the concept 'infrastructure' (Lakshmanan, 1989).

Although the literature is generally clear in the way in which specific public goods are categorized, the general tendency is the association of infrastructure to particular characteristics of physical features (e.g. large and costly installations) or public services (educational buildings, hospitals, information flows, water and power supply, etc.). Some authors define infrastructure in a broader way without making any distinction between physical and non-physical infrastructure (Hirschman, 1958 for example). Others restrict the definition of infrastructure to core infrastructure consisting of railways, airports, and utilities such as sewerage and water facilities, information flows and particular cases of externalities of public goods (Aschauer, 1990; Anderson, 1991).

Gramlich (1994, p. 1177) for example, defines infrastructure capital from an economic point of view as *"large capital intensive natural monopolies such as highways, other transportation facilities, water and sewer lines, and communications systems."*

More generally, most studies employ a *narrow definition* of public capital that includes the tangible capital stock owned by the public sector, excluding military structures and equipment and infrastructure capital based on private ownership. Other studies use a *broad definition* of public capital by including human capital investment (e.g., Garcia-Milà and McGuire 1992) or health and welfare facilities (e.g., Mera 1973). The latter components are hard to measure, which explains why most authors focus on narrowly defined public capital.

Note that the concept of public capital may also differ between studies, depending on the geographical scale level where it is measured. Studies focusing on the federal or national public capital stock for example include all levels of governments (federal, state, and local), whereas others deal only with capital stocks defined at the regional level (e.g., Garcia-Milà and McGuire 1992) or city level (e.g., Duffy-Deno and Eberts 1991).

Turning now to the relationships between infrastructure investments or public capital stock and economic growth, one may note an increasing interest by researchers and policymakers to the role of infrastructures in stimulating economic growth as well as the role of the state in providing them. This interest is due first, to the increase in demand for additional capacity of existing infrastructure networks, which in turn is due, among other things, to the rapid economic and technological development. Second, the relatively rapid development of transportation and telecommunication sectors in the era of increasing openness and globalization of economies and markets.

Another important element which may explain this interest to the role of infrastructure investment is the increasing conscience and awareness of governments of the fact that infrastructure investment may be used as instrument to control and guide the restructuring process and the economic development between regions.

It is worth to note here that the supply of infrastructure has largely different economic and spatial effects on the economies of cities, regions and nations. The spatial and economic effects depend on a wide range of factors such as the type and the nature of infrastructure investment (point or line infrastructure), the economic structure and the size of the region, type of activities and sectoral structure, the geographical and local specific conditions of the region, etc. Time sensitive effects of infrastructure investments are also important in this respect e.g. some effects are temporary other are non-temporary.

Globally, the economic effects infrastructure investment may be categorized into direct effects and indirect effects. Beside the direct effects of the construction, operation and maintenance (e.g. demand side) of infrastructure projects, the indirect effect concern mainly changes in trade patterns and distribution (distributional effect), the output and productivity levels of firms and sectors (economies of scale), the change in the housing and the labour markets, the change in the locational preferences of firms, the change in (monopolistic) price setting (supply side) and finally, the change in external effects (environmental effects, knowledge spillovers, etc.). Some of these effects have a temporary character while others have a more long-term character.

To deal with above mentioned effects in a more systematic approach, many European countries have established guidelines for analyzing the wide impact of infrastructure in a standard CBA framework. Therefore, forecasting the direct effects of infrastructure projects at the regional and national level is relatively standardized (Sactra, 1999). However, there is no consensus between researchers about the way indirect effects of infrastructure projects must be forecasted and monetized. This is due principally to the difficulty to separate these two effects because the indirect effects results directly from the direct effects and takes the form of additional induced effects of infrastructure projects.

Some indirect effects are approached through the evaluation of direct effects on the costs of infrastructure investment. In this case, there is a risk of double counting and/or (under)overestimating of these effects when assessing the exact magnitude of additional induced indirect effects to direct effects, especially in a welfare assessment approach.

Most empirical studies shows that indirect effects lies between 30% and 60% of the direct benefit effects (Brocker, 2002; Sactra, 1999), and up to 80% in a specific study conducted in the Netherlands (Elhorst et al, 2002)[1].

In addition, the market imperfection at one side, and the government intervention on the other side may cause distortions in the functioning of the economic system and make the evaluation of indirect effects even more difficult, when analyzing the welfare implications of infrastructure project.

A wide variety of CBA methods are used to estimate the magnitude of the direct and indirect effects of new infrastructure projects such as computational general equilibrium (CGE) and spatial computational general equilibrium (SCGE) models. The SCGE models are partly derived from the new economic geography (NEG) models. The aim of such applied methods is to isolate the indirect effects from direct effects of infrastructure investment on the long run and give them a monetary value (for a comprehensive discussion about the use of these models see; Venables & Gasiorek, 1996; Oosterhaven & Knaap, 2003, Oosterhaven & Elhorst, 2003;

[1] Note that, under the hypothesis of imperfect competition, non-linearity in production of goods and services and the presence of external economies, one may expect extra-induced effects (e.g. welfare effects) which could be internalized by some economic actors (e.g. producer surplus).

Bröcker, 1999)[2]. Table 2. 1 bellow gives an overview of methods used in empirical studies to evaluate the effects of infrastructure investment in standard CBA assessments.

Table 2.1. Methods of evaluating infrastructure projects.

Quantitative methods	Economic & Spatial effects	Economic cost-benefit
Models based on production function: (Cobb-Douglas, CES functions, etc.); CGE-models; SCGE-models; Land use-transport interaction models; Input-output models; Hedonic price; contingent valuation method, etc.	• Direct effects (Distributive and generative effects) • Indirect effects; • *Positive effects;* effects on labor market, housing market, land use market, etc., agglomeration economies, cluster effects, knowledge spillovers, etc.; • *Negative* effects; *contingent evaluation method; travel cost, congestion, pollution, etc.)*	Welfare effects: • Productivity and/or employment growth • Spatial competition • Inter-regional trade • Quality of infrastructure • Scale economies in production and transaction • Concentration/localization • Congestion, pollution, environnemental damage, etc.

Source : Author (2011).

Following Button (1994), the relatively low performance of forecasts in the CBA may be explained by the difficult to estimate the *[correct]* economic and social outcomes. He argues that; *"The general empirical evidence from existing work does not even generate a consensus as to the impact of, say, infrastructure investments on the level of economic activity and location patterns"(op cit., p. 509).*

As we argued before, the challenge for applied economic models is finding a way in converting indirect effects into economic costs and benefits and expressing them into monetary values. The empirical validation of these monetary values must take into account the changes in volumes (stock) and flux (monetary value) in different markets (labour market, housing market, land use, etc.) at regional level as well as at the level the whole economy. This leads to one of the most difficult analytical aspects when applying regression analysis to estimate the magnitude of direct and indirect effects, namely the fact that the effect of the variable of interest is not immediately quantified (Button, 1994., p. 513).

To get an idea of the impact of infrastructure investment on economic structure, one must take into account the relationship between the direct effects of the infrastructure investment and effects resulting from the evolution of economic conditions. In the following, we restrict our analysis to three important economic effects namely, the effect of infrastructure investment on employment (labour market), the effects of infrastructure investment on productivity and finally, the distributional and generative effects of infrastructure investment.

[2] These types of models are, often used to estimate the impact of changes in infrastructure investment (e.g. transport cost and/or time) on the markets included in the model. They thus estimate the wider economic impacts of, especially, spatial infrastructure (transport) policy initiatives.

2.1. Effects of infrastructure investment on employment

The effect of infrastructure investment on employment is one of the most discussed issues in CBA studies. This effect goes through substitution/complementarily effects that may occur between production factors due to infrastructure availability, and through differentiated effects of infrastructure investment on the competitive position of localities e.g. the regions and/or states.

Many arguments in favor of the positive impact of infrastructure investment on employment growth may be given. Among them the following important ones:

First, infrastructure supply improves external input of certain firms and sectors, which result in a shift in the production function of firms due to the economies of scale. However, external economies take place within and between firms and sectors with different scale and intensities because different sectors make use of different type of infrastructure with different production costs. In this sense, employment growth will first take place in those sectors with high price elasticities and higher intensities of infrastructure use (Rietveld & Button, 2001, p. 314).

Second, development of infrastructure may leads to decreasing transport costs and transaction costs due to the increase in intraregional and interregional trade. Also, the growing intensity of competition between firms may result in cost reduction, an increase in productivity levels, improving innovation conditions of firms, and increase knowledge spillovers between firms.

Note that changes in interregional trade patterns may be accelerated toward more specialization e.g. increase of employment in exporting regions and a decrease of employment in importing regions, allowing firms to internalize the benefits of economies of scale in production (i.e. agglomeration economies). At the end, the overall effects on welfare will be positive.

However, the overall impact on regional welfare will depend, among other things, on the existing quality of infrastructure as well as on the regions industrial structure, the flexibility of their labour market and others factors (real estate, land use, institutional setting, etc.).

In a core-periphery model (Krugman, 1991) for example, the core region where the most firms and consumers are located acquires most advantage (during the first stage of development). When transport costs become very low, a tendency of firm localization in the periphery may take place (during the second stage). In this case, the ultimate location of production is dictated by costs of production and the relocation of firms in response to infrastructure improvements occurring at a local scale (op cit., p. 414).

2.2. Effects of infrastructure investment on productivity

The most applied approach to evaluate the impact of infrastructure investment on productivity is the production function approach. This approach represents, in an implicit way, the sum of direct and indirect productivity effects. The reasoning is simple; an increase in the infrastructure stock leads to a shift in productivity. Note, however, that this does not mean a permanently higher growth rate, except of some cases when for instance infrastructure investments may lead to a higher level of knowledge production (through improvement of existing technologies, or the development of new technologies during the project) as showed by endogenous growth theory.

At regional level, an increase of productivity levels in sectors with high price elasticities will stimulate demand and hence an increase in overall production and demand for labour services. According to Rietveld and Button (2001, p. 313): *"An important factor in determining the overall impact of these forces is the price elasticity of demand –if it is high then one may anticipate a large increase in production volumes and thus also potentially in employment-."* .

However, the productivity impacts in empirical studies vary strongly among economic sectors and between various types of infrastructure according to their spatial range e.g. intra-regional, inter-regional, national (Fukuchi, 1978; Blum, 1982; Andersson, Anderstig and Harsman, 1989).
Because of the aggregate nature of the production functions, the exact contribution of infrastructure to productivity remains limited in a sense that the production function approach does not cover all welfare aspects of infrastructure supply. For example, the impact of infrastructure investments on the consumers is not taken into account. Furthermore, production function approach can hardly be used to give an ex-ante evaluation of specific projects.

2.3. Distributional and generative effects

The improvement of infrastructure will lead to both 'distributive' and 'generative' effects.
Distributive effects, both at sector and spatial/regional levels refer to positive effects of infrastructure improvements, which are distributed among larger numbers of sectors in the economy and/or between different localities. Note that infrastructure investment will generally have an impact not only on the host region or regions directly involved, but will often effects other regions in a country and sometime even on a (much) larger areas or regions e.g. cross-border regions.
Generative effects refer to the total net benefits resulting from infrastructure investment at the level of the economy of localities, regions and states e.g. increase or decrease in total welfare. Note that the generative effects of infrastructure investment may be overestimated in cases where the distinction between generative and distributive effects is not clear or when the study area is too small and narrowly defined.
The interdependencies between generative and distributive effects of infrastructure investment imply that their impacts vary over space and sectors within and between regions. In this sense, there will always be some regions, that may benefit from infrastructure investment whereas the indirect effects for other regions may be either positive or negative, depending on the nature and scale of the infrastructure project.

Concerning the effects of infrastructure provision on the localization behavior of firms, it is argued that the decrease in transport and transaction costs and in the commuting costs between regions, improve the flexibility in labor and housing markets, and facilitate the internalization of agglomeration and spillovers effects of localized firms.
On one hand, the decreasing transport and transaction costs increase competition between firms located in different regions and this result in a decrease of prices of goods and services that in turn, have indirect effects on the profit margin of producers. Firms that use these goods in their production process may be affected as well as the households, which consume these goods [i.e. consumer surplus].
On the other hand, the decreasing transport cost result in an increase of accessibility and the competition between regions. In a strategic interaction model with real transport costs based on the core-periphery model à la

Krugman (1991), Combes & Lafourcade (2000) show that a decrease of transport costs to a certain levels result first in agglomeration then dispersion and again to agglomeration. In their research, they show that the central regions benefit more from the effects of infrastructure investment than the peripheral regions.

More generally, one may argue that despite a wide difference in point of views between researchers on how to evaluate infrastructure investment, there is a preponderance of evidence suggesting that infrastructure capital stock contributes significantly to growth in output, productivity, employment, costs reduction and increases in profitability. However, the scale and the magnitudes of these contributions vary considerably between studies because of differences in applied methodological analysis, spatial level and the level of data aggregation[3].
Note that recent studies produce often a much lower estimate of the magnitude of the contribution of infrastructure capital to output and productivity growth than earlier studies. Most of these studies, particularly those conducted at the national level, use real GDP or value added as the dependent variable[4]. However, the gross output is an appropriate alternative measure because it includes purchases of intermediate inputs, along with the primary inputs of private capital and labour.
Finally, studies conducted at the industry level are confined to the manufacturing sector or a specific subset of this sector. Infrastructure capital, however, may have important effects on other sectors of the economy outside the manufacturing sector as well (distributive effects) and therefore on the whole economy (generative effects). It is very important to undertake a comprehensive study that includes all sectors of an economy in order to study the role and degree of externalities generated by infrastructure capital. In this perspective, impact analysis producing a complement set of supplement indicators, such as for example the accessibility benefits/gains, may be used as complement framework to CBA in evaluating non-monetary long run effects of the infrastructure project e.g. effects of re-localisation, functioning and development of economic activities (Combes & Lafourcade, 2000). Other external effects resulting from the intensity of use as well as the size of infrastructure capital such as the effects on nature, congestion and pollution must also be taken into account.

2.4. External effects of agglomeration and infrastructure investment

By surveying the literature on the relationship between agglomeration effects and the infrastructure investment e.g. external economies of scale, one may notice that –beside a consensus between researchers about the different type of externalities of agglomeration- there are many ambiguities concerning the source, nature and the definition of the concept of agglomeration economies. These ambiguities resulted in different interpretations of agglomeration economies and hence to different results measuring the magnitude of agglomeration effects on economic activities in a spatial-setting (cities and/or regions).

Indeed, there exist many definitions of the concept of agglomeration economies, also referred to as spatial externalities of agglomeration or external economies. Rosenthal & Strange (2003) consider agglomeration

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[3] Output elasticity estimates of infrastructure capital at the national level should probably be in the range of 0.16 to 0.25. Estimates based on state and metropolitan level data suggest elasticities of approximately 0.06 to 0.20.

[4] The use of the value-added data can be justified in the case when for example there is no substitution between intermediate inputs (e.g. if intermediate input prices are relatively stable), such as materials and energy, and primary factors of production, such as capital and labour.

economies as shifters of an establishment's production function and argue that "*external economies exist when the scale of the urban environment adds to productivity*" *(op cit., p. 3).* Fujita and Thisse (2002) give a more general formulation of agglomeration. They consider that *"agglomeration can be thought as the territorial counterpart of economic growth."*

Two main sources of agglomeration economies are considered by the literature; the localization economies and urbanization economies. Localisation economies stem from the co-location of firms in the same industrial sector and offer many possibilities for firms of obtaining specialised inputs, labour, information and knowledge particular to one sector. By contrast, urbanisation economies stem from a more diversified local economic structure of city or region that offers to all industries and firms the possibility to maximize the potential for a diverse range of inputs and services at lower costs.
In his seminal work on external economies, Marshall (1920) suggests tree sources of external economies or agglomeration economies: (1). Sharing of inputs whose production involves internal increasing returns to scale e.g. as inputs become more specialized, they tend to become more productive. (2). Labor market pooling, where agglomeration allows a better match between an employer's needs and a worker's skills, reducing risk for both. (3). Spillovers in knowledge that take place when an industry is localized, allowing workers to learn from each other's.
According to Marshall, the presence of these three supply-side factors will benefit localized firms in term of lower production, transport and transaction costs than if they operate in isolation. On the demand side, consumers will benefit from the presence of firms producing at lower price that will be translated in a more consumption and spending locally. The combination of these two sets of forces e.g. Marshall's spatial externalities and the savings on transportation costs, in case when activities are spatially concentrated, give rise to agglomeration economies.

Notice that the size of the local industry effect the intensity of agglomeration forces and reflect the importance of an existing industrial base in attracting new firms by providing greater potential of finding both specialised and diverse industrial input- and intermediate output markets (Venables, 1996). In the same time, the local industry size can be important for 'spin-off' of new firms in the same sector or in different sectors (Storey and Jones, 1987).

Globally, agglomeration forces are related to the presence of larger market size where firms can easily share inputs and sell their output. These two elements stimulate firms and consumers to concentrate spatially in specific regions because of the simultaneous presence of scale economies and lower transport and transaction costs. In addition to this elements, there are also others sources of agglomeration economies such as the "pure" externalities linked to the presence of public goods and services and to the transfer of information and knowledge[5].

[5] Beside the agglomeration forces, there are also dispersion forces acting against the agglomeration process. These forces are more related to the competition on the market of final goods and to different others phenomena such as congestion, saturation of local public transport, high wages of some categories of workers, high land rent and housing prices, etc.

Recent advances in spatial economy, particularly the so-called `new economic geography' (NEG), provide more evidence on the existence of strong relationships global economies of scale (e.g. economies of agglomeration), the increase in productivity (per capita real income), the variety of manufactured goods, and transport costs (see for example the model of Krugman & Fujita, 1995).
In NEG models, the increasing variety of manufactured goods, market access, transport costs, and their consequences on the concentration pattern of firms and households (i.e. saving on travel cost, higher land rent and increase in real income) are considered as the main driving force of the city formation and the economic growth of firms and regions. The circular linkage between economies of agglomeration and the concentration of production make a city more attractive to employees and firms i.e. through a 'snow-ball' effects (for more details, see Fujita et Thisse, 1997).

Although considerable progress that has been made in modelling urbanization and agglomeration, there have been few analyses that address the relationship between infrastructure investments, agglomeration and growth in general and between externalities, agglomeration and growth in particular. Up to now, there is little consensus about the sources of increasing returns that produce spatial agglomeration of economic activities and the scale where they operate (e.g. regional scale or at city level, or whether they are restricted to individual industries (intra-industry) or to all activities in the region (inter-industry)). The reason for that lie in the difficulties to capture spatial externalities of agglomeration in a unified approach because their effects extend over many different dimensions; within and between industries/sectors, within and between different geographical levels (intra and inter-metropolitan/regional level), and finally because of the temporal dimension of externalities of agglomeration e.g. effect of initial conditions on productivity and growth (networks, learning, knowledge, initial employment) (Rosenthal & Strange, 2003).
Nevertheless, recent empirical studies on agglomeration economies and spatial spillovers, using data on employment at a very fine spatial level i.e. the municipality or city level, suggest that agglomeration forces operate over relatively short distances (Ellison & Glaeser, 1997, Henderson et al., 1995; Glaeser et al., 1992; Combes, 1997; Duranton & Puga, 2000).

Concerning the spatial effects of infrastructure investment, these are usually studied within a general equilibrium and/or welfare framework e.g. welfare-improving effects. It is believed that any change in infrastructure brings about many changes in the whole economy. However, the significance and the magnitude of spatial effects owing to infrastructure improvement balance between two different interpretations: Some author's claims that there are substantial benefits, while others claim that such benefits, if they exist at all, would be generally small or non-significant. One possible explanation to this is that applied standard cost-benefit analysis (CBA) does not take into account the mechanisms conditioning the choice of localisation of economic agents (consumers and firms), and that CBA studies consider often the flow of goods and individuals/workers as given. However, the observed flow of agents is determined by their behaviour (economic decisions) concerning their choice to localise in cities and regions (Combes & Lafourcade, 2000). For example, the variation of one or more key parameters, such as transport costs or transaction costs, affect the choice of location of economic agents, and consequently the flows of agents as shown by the theoretical models of economic geography[6].

In the light of recent discussions about ex-ante evaluation of infrastructure project, theoretical models try to give answer to the following question; does a decreasing transport costs (as results of infrastructure investment) reinforce agglomeration or dispersion forces?

The fundamental challenge to this studies consist of determining if a decrease in transport costs reduce spatial and regional disparities and enhance productive efficiency or, contrarily it bring about further disparities between regions (and nations). In this respect, the NEG models seem to offer a new perspective to answer these questions[7]. However, the empirical validity of NEG models developed so far turn to be problematic because of the non-availability of data at a very low spatial level, especially data about generalized transport costs (see Combes and Lafourcade, 2000) [8]. As result, most empirical studies simulate the effects of a decreasing transport costs by using calibrated, and not estimated, models (Forslid *et al.*, 1999 for example) or by using real transport costs (i.e. considering transaction costs as an exponential function of transport costs deduced from distance data between regions) to estimate labour demand function, where the density of labour of a region is conditional to incomes of the whole economy.

Resuming, one may conclude that there is a little consensus among economists as to whether infrastructure has beneficial effects on agglomeration and on the spatial organization of activities. We think that the study of agglomeration economies in relation to infrastructure investment may be fruitful when using NEG framework, particularly the core-periphery (CP) model, that takes into account alternative formulation of preferences and transportation, and more particularly; (a). The impact of expectations in shaping the economic space, and (b). The effects of urban costs/benefits on the interregional distribution of activities.

3. Applied methodology in estimating public capital stock

Most empirical studies conducted so far have used the stock of public capital as an input into the production function approach in estimating the output elasticities of public capital. Very often, the perpetual inventory method is employed to measure the public capital stock. This method is based on an estimate of the initial value of the capital stock to which gross investment flows are added and from which technical depreciation of the existing stock –based on the expected lifespans of the various types of assets – is subtracted.

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[6] In these models, the effects of a decreasing transport costs on the spatial concentration/dispersion of economic activities (e.g. equilibrium between agglomeration and dispersion forces) are much more elaborated than in other standards models.

[7] These models suggest that the concentration of economic activities follow an inverse 'U-curve' which means that for high levels of transport costs, economic activities become more dispersed in space, and that the agglomeration forces will be dominated by competition effects on the markets of final goods. A further decrease in transport costs will cause an increase of spatial polarisation through cumulative effects of agglomeration. However, a very low transport cost in combination with an increase in land rent or the scarcity of labour force in highly concentrated areas may cause spatial dispersion of economic activities (Ottaviano and Puga, 1997).

[8] Combes and Lafourcade (2000) use data on the generalized real transport costs in an interregional trade model with imperfect competition to study the spatial organization of activities in France.

The supply side analytical approach is perhaps the most applied analytical method dealing with the issue of the role and importance of infrastructure investment as engine of economic growth.

The following approaches can be distinguished in the literature: the production function approach, the vector autoregression (VAR) approach, and cost-profit function approach, including the behavioral approach. Hereafter, we will devote more attention to the production function approach and the cost-profit approach.

3.1. Production Function approach

The production function framework is widely applied in empirical studies examining the effect of public infrastructure on growth and productivity. This approach considers the stock of public capital either as a separate input in private production or as a factor improving multifactor productivity (which is known as the growth accounting approach). In both cases, public capital is assumed to be strictly exogenous.

The applied basic method incorporate public infrastructure in an aggregate production function by including public capital to the private factors of production such as labour and capital.

Specifically, the standard production function takes the following form; $Y = A \times F(K, L)$, which may also be taken as; $Y = \tilde{A} \times F(K, L, S)$, (2.1)

Where ***Y*** is the level of output or real aggregate private output of a region or country. ***A*** is an index of economy-wide productivity. ***K*** is the stock of private fixed capital. ***L*** denotes employment (generally measured by total hours worked). ***S*** denotes the stock of public capital i.e. infrastructure, and $\tilde{A}$ denotes the total factor productivity (TFP) purged of the influence of the government capital stock. *F(.)* describes a general functional form. In equation 2.1, we dropped a time index *t* that is usually included in *Y*, *A*, *F*, *K*, *L* and *S*.

The general idea of the production function approach is that the services of public capital are proportional to the stock of public capital – which is generally assumed to be a pure public good – and in that way enhance private output.

Equation (2.1) shows that shows that public capital may affect aggregate private output directly, that is, $\partial F / \partial S \succ 0$, or through the rise of private production by increasing the economy-wide productivity index, that is, $\tilde{A}\, S$, with $\partial \tilde{A} / \partial S \succ 0$. Note that, equation 2.1 assumes Hicks-neutral public capital, which is a common assumption made in the public capital literature[9].

A commonly used specification of the Cobb-Douglas production function, estimated by Aschauer (1989b) and others, takes the following form: $Y = \tilde{A} K^{\alpha} L^{\beta} S^{\gamma}$ (2.2)

Where $\gamma = dlnY/dlnS$, is output elasticity of public capital, which is hypothesized to be positive. This specification imposes a unit elasticity of substitution between factors of production. In addition, public capital and private inputs are complementary factors of production, implying that the rise in *S* increases the marginal productivity of labour and private capital.

[9] Hicks-neutral public capital enters the production in such a way that the average and marginal products of all factors increase in the same proportion.

Taking natural logarithms on both sides of equation 2.2 yields the following linearized specification:

$$\ln Y = \ln \tilde{A} + \beta \ln K + \gamma \ln S \qquad (2.3)$$

Equation 2.3 can be estimated in logarithmic levels or in first differences of logarithmic levels (e.g. growth rates) to arrive at estimates of α, β, and γ.

Many studies include a constant and time trend as a proxy for technological progress i.e. *lnA* = $a_0 + a_1$, where $a_0>0$ and $a_1>0$.

Incorporating public capital into the production function raises the issue of returns to scale in production. Imposing the restriction of constant returns to scale across all inputs in (2.1), which is represented by α+ β+ γ =1 yields;

$$\ln\left(y/K\right) = \ln \tilde{A} + \beta \ln\left(L/K\right) + \gamma \ln\left(S/K\right) \qquad (2.4)$$

Which feature decreasing returns with respect to private inputs taken together i.e. α+β <1. Instead of using private capital productivity *ln(Y/K)* as the left-hand side variable, some studies subtract *lnL* from both sides of equation 2.3 so as to arrive at labour constant returns to scale in private inputs represented by α+β =1;

$$\ln\left(Y/K\right) = \ln \tilde{A} + \beta \ln\left(L/K\right) + \gamma \ln S \qquad (2.5)$$

Allowing for increasing returns to scale across all inputs i.e. α+ β+ γ >1.

Alternatively, various authors[10] have employed a translog specification, which nest many commonly used functional forms, including the Cobb-Douglas production function. The translog specification allows for non-unitary and non-constant elasticities of substitution between inputs. However, a potential problem of it use is that the second-order terms may give rise to multicollinearity.

Aschauer (1989a) estimates equation 2.3, and conclude that public infrastructure investment increases the productive capacity of the private sector and stimulates investment by enhancing the rate of return to private sector investment. He found a positive correlation between ***γ*** and the elasticity of output ***Y*** with respect to public capital ***S***, ranging from 0.39 to 0.56. The marginal product of public capital MP_s (defined as $MP_s = \gamma . Y/S$), implied by this result is 100% or more.

Munnell (1990a) extends this line of argument and found an elasticity of 0.33 for output per worked hour with respect to public capital. Here results support the proposition that there exist a strong and significant effect of public infrastructure capital on productivity growth.

More generally, evidence presented by these types of studies suggests that an increase in government capital pays for itself in terms of higher output.

The production function specification presented above is also used at the regional or state level. The general formulation of a production function for sector *i* in region *r*, with various types of infrastructure take the following form:

[10] See for example, Merriman (1990), Pinnoi (1994), and Dalamagas (1995).

$Q_{ir} = f_{ir} (L_{ir}, K_{ir}, IA_r, \ldots, IN_r)$, (2.6)

Where; Q_{ir} is the value added in sector i in region r; L_{ir} is the employment in sector i in region r; K_{ir} is private capital in sector i in region r and $IA_r, \ldots, IN_r$ is infrastructure of various types in region r.

Equation 2.6 indicates that production takes place by means of combining labour, private capital and infrastructure. The relationships between these inputs may have a substitutive or complementary character[11].

Empirical studies using the Cobb-Douglas specification estimate the relevant parameters by using either time-series data for a particular area (Aschauer, 1989; Munnell, 1990) or a cross-sectional analysis across regions (Biehl, 1991).

In general, studies based on state-level data show a relatively weak, but still positive, relationship between public infrastructure and productivity. Elasticity estimated by Munnell (1990b) for example show that, while public capital has positive effects on output, it is only half the size of the effects of private capital. This means that a one percent increase in public capital results in a 0.15 percent increase in output, whereas a one percent increase in private capital results in a 0.31 percent increase in output.

Hulten and Schwab (1984) test for the differences in growth rate between public capital and productivity growth at the regional level. They estimate the growth rates of productivity in the manufacturing sector for the period 1951-1978 in the major regions of the United States. Their finding point to the fact that differences in growth of output result mainly from the differences in growth rate of the production factors capital and labour and not to the growth of public infrastructure. Therefore, their conclusion suggests that public infrastructure has little impact on (regional) economic growth.

Similar findings have been reported in a number of other studies that use data at the metropolitan level (Eberts, 1988; Eberts and Fogarty, 1987; Duffy-Deno and Eberts, 1989). These studies generally test the direction of causation between infrastructure capital and output and estimate the magnitude of the elasticity of output with respect to infrastructure capital. Their findings suggest that the causation runs mostly from infrastructure capital to output growth. In addition, they show a slightly positive elasticity of output with respect to public capital than other studies based on the aggregate production function that link infrastructure to growth of output and productivity.

The wider ranges and disparate results produced by different empirical studies have generated a substantial amount of criticism in the 1990s. The most important criticism of the production function approach can be summarized in the following points;

(1). The estimated elasticities and their implied marginal productivity of public capital are extremely high. Various authors have criticized Aschauer's model for being misspecified due to the omission of relevant macroeconomic variables. Tatom (1991) for example, argues that Aschauer's approach is flawed because it omits energy prices, which should be included to account for the decline in the use of private capital induced by higher

[11] For example, the existence of better roads allow transport firm to use less trucks and less drivers to reach the same level of production (substitution). Subsequently, broader canals allow a transport firm to use larger ships (complementarily) so that the number of workers can be reduced (substitution).

oil prices during the 1970s. However, other authors (Gramlich, 1994), criticized Tatom's approach because of his mixing of production functions and cost functions. Instead of including energy prices, studies should employ a measure of the quantity of energy use in production or including imported raw materials in the production function as in Vijverberg et al. (1997).

(2). Another specification issue concerns the direction of causality. Aschauer (1989) and related studies assume that *S* is strictly exogenous, implying that the causality runs from public capital to private output. However, the aggregate time series correlation may not reflect a true causal relation between output/productivity and public capital, but rather, a spurious correlation (e.g., Munnell 1992; Gramlich 1994). In other word, the direction of causality may run from output/productivity to public capital rather than the other way around. Indeed, higher output may increase the demand for public capital and generate favorable budgetary conditions to support an increase in public investment.

(3). The existence of serious estimation problems in both aggregate national level time series studies and state and regional level studies that lead to highly disparate results. Estimates based on state level data indicate a relatively smaller contribution of public capital to output, but show clearly that the composition of infrastructure capital matters e.g. some types of infrastructure may have a larger effects on productivity than others infrastructure.

(4). Some studies using the production function approach have been criticized for not properly accounting for common trends. Time series on private output and the public capital stock are non-stationary time series e.g. they contain a unit root. If variables are non-stationary, the usual test statistics have non-standard distributions, implying that the application of standard inference procedures gives rise to misleading results. More particularly, one may find spurious relationships between inputs and outputs, and this trend in variables can be eliminated by taking first differences of the time series. Note however, that lagged effects of growth rate in the capital stock may take a number of years before infrastructure projects are completed and become productive.

(5). Finally, the issue of concerns the role of capacity utilization in the production function. Production function studies incorporate a capital utilization rate – or, alternatively, the unemployment rate – to capture the effect of business cycle fluctuations on production factor use. Because capacity utilization enters the productive function in an additive fashion in the logarithmic model, it does not affect the optimal capital–labour ratio.

Resuming, most studies estimating production functions, whether using national or state level data, treat the production function as a purely technological relationship between output and inputs. Firm's optimization decisions with respect to how much output to produce and what mix of inputs to use in the production process is not considered specifically. However, because inputs and output are simultaneously determined when firms maximize (minimize) their profit (costs), the marginal productivity conditions for the inputs should be estimated jointly with the production function to avoid mis-measurement in the estimated production function parameters e.g. biased estimates of production function coefficients.

3.2. VAR approach

Recently, a growing number of studies have employed VAR models with a view to capture the dynamic interactions between output, public capital, and private capital.
The VAR approach analyzes the relationships between public capital, private inputs, and private output without imposing a theoretical structure a priori. Econometric studies employ very different concepts of public capital, which makes it hard to compare the results of these analyses. Some authors employ narrowly defined public capital such as paved roads (Canning and Bennathan, 2000), whereas others define capital in a broad sense such as social public capital (Mera, 1973; Mas et al., 1996).
The multi-equation VAR approach employ the same set of variables as in the production function approach, but models every endogenous variable as a function of its own lagged value and the lagged values of the other endogenous variables. Therefore, VAR approach can assess whether there is any feedback effect from private sector variables to the public capital stock.

3.3. Cost-profit function approach

In opposition to the production function approach, the cost/profit function approach take into account the firms optimization decisions and may be considered as an alternative approach in studying the relationship between infrastructure investment and output and productivity growth.
The behavioral approach for example, employs cost or profit functions to assess whether public capital reduces firms' production costs or increases firms' profits (Sturm et al., 1998).
By taking explicit account of the firm's optimization behaviour, the cost function approach offers more detailed information on cost elasticity of output as well as specific effects of infrastructure capital on demand for private sector inputs than the production function approach. Consequently, by using cost function approach it is possible to trace, in considerable detail, the effect of infrastructure investment on a firm's production structure and performance including technical change, scale economies, and demand for employment, materials and private capital stock.
Also, the effect of public capital on the demand for inputs can be directly estimated. If the effect is positive, public capital and the private inputs are complements; if it is negative, public capital and private inputs are substitutes

To avoid shortcomings inherent in the Cobb-Douglas specification, most cost and profit function studies incorporate a more flexible functional form such as the translogarithmic or generalized Leontief functions. The cost functions yields direct estimates of the elasticities of substitution that describe patterns and degree of substitutability and complementarily among the factors of production, more specifically the so-called Allen-Uzawa elasticities of substitution.

Empirical studies using a cost/profit function are heterogeneous in their focus on infrastructure. Some of them focus on core infrastructure, while others focus on the total public capital stock at sector and/or territorial levels e.g. national and international level, state and metropolitan level, and industry level. Differences between these studies exist with respect to assumptions about the optimizing behaviour of firms, and the specification of the cost function.

More generally, the literature on cost/profit approach show that most of empirical studies provide clear evidence supporting the existence of positive relationship between infrastructure and output/productivity (Deno, 1988; Lynde and Richmond, 1992; Nadiri and Mamuneas, 1993; Morrison and Schwartz, 1991; Keeler and Ying, 1988, etc.). However, the magnitude of estimated elasticities is relatively smaller than elasticities found by studies using the production function method. In addition, most of the cost function studies suggest that private capital and public infrastructure capital are substitutes, although some studies report that they are complements.

4. Meta-analysis

4.1. Definition

Meta-analysis can be defined as a body of statistical method used to summarize, evaluate, and analyze results of a set of empirical studies. More specifically, meta-analysis refers to the *"statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings. It connotes a rigorous alternative to the causal, narrative discussion of research studies which typify our attempt to make sense of the rapidly expanding research literature"* (Glass, 1976., op cit, Florax el al., 2002). It has also been defined as the deviations found in various studies of the same thing (Rietveld & Button, 2001., p. 316).

In opposition to conventional literature reviews, meta-analysis has more quantitative orientation towards reviewing and summarizing the literature. The application of the meta-analysis technique has the advantage of bringing together various ranges of empirical works which has studied the relationship between infrastructure investment and various aspects of economic performance. It, therefore, provides a series of formal statistical techniques that allow the cumulative results of a set of individual studies to be pulled together (Button, 1994., p. 509).

The particularity of meta- analysis has the opportunity to review previous work quantitatively (not in form of taxonomies of findings) and gives an objective view of the differences and similarities of the results obtained by different studies on the basis of an analysis of the quality of data used and the reliability of techniques employed. In this sense, it forces the researcher to be more explicit about the weight assigned to the studies and hence, it leave much more room for objective elements in the analysis.

Note that meta-analysis has a well-established set of techniques in the medical and natural science and only recently has made significant progress in a range of economics research fields such as the environmental economics (van den Bergh et al. 1997), transportation (Nijkamp & Pepping, 1998; Rietveld & Button, 2001; Button, 1994) agriculture (Nijkamp & Vindigni, 2000), tourism (Baaijens et al, 1998) and labour market (Card & Kreuger, 1995).

As we argued before, the application of different analytical approaches in the evaluation of infrastructure projects and their impact on social and economic sphere has been intensively used and expanded in recent years. The ability to forecast the overall economic implications is however far from satisfactory.

Using meta-analysis as a complementary approach to more common literary type approaches when reviewing the usefulness of parameters derived from applied analytical approaches, as presented above, may give a greater insight into the scale of the economic costs and benefits involved with infrastructure investment in general, and their economic impact on growth/output.

4. 2. Meta-regression model; Empirical specification

Two steps must be followed before carrying out a meta-analysis; first, a selection of the available empirical literature that should be analyzed e.g. retrieving the relevant studies that are representative of the whole population. Second, a selection of sample study on the issue at hand from retrieved documents (Nijkamp & Poot, 2002., p. 7).
We employ an unbalanced panel consisting of N studies each of which covers e_i estimates of the output elasticity γ. The panel is unbalanced because the number of estimates differs by study.

There is a variety of techniques involved in conducting meta-analysis, depending on the nature of the topics addressed and the scope of statistical issues that must be addressed.
In our study, we apply the following general functional form, which underlies any meta-analysis;

$$Y = f(A, B, C, T, L) + \varepsilon$$

Where Y (may be a single measure or a variety of differing effects) is function of parameters A, B, C, a time period T, the origin of the study *L* by country/region and an error term ε.
A; is the specific cause of the problem,
B; represent features of those affected by the project (such as groups and income),
C; represent the characteristics of the research methods used in each study of the total population,
T; is the period covered by each study and,
L; indicates the origin of the study (country, region, etc.) and, ε the error term.

In economics, the parameters *C*, *L* and *T* are of great importance because of the need of quasi-experimentation which results in a considerable range of econometric specifications, estimation procedures being adopted, time period and the location covered by the study, etc. The raison for these is simple; several aspects of economic effects (indirect and external) and the local conditions are context specific in space and time e.g. they affect the preferences and behavior of individuals and economic agents. *A* and *B* are however, relevant when comparing strict experiments where methodologies are identical.

One of the most surveyed example of the application of meta-analysis in economics concern the evaluation of implications of transport investment (see Button, 1994; Rietveld & button, 2002). The estimation procedures adopted by these types of studies are based upon regressions of the variables of interest (e.g. travel time value) on a set of variables that encapsulate some of the key differentiating features of each study (e.g. country dummy variables; mode dummy variables with auto travel as the base; trip purpose dummies with commuting as the base,…etc.).

Rough set theory has also been used as a framework for comparative study by Nijkamp & Poot (2002) and Nijkamp & Vindigni (2000)[12]. They link multi-criteria analysis to meta-analysis and applied it to study the differences in productivity between OECD countries (Nijkamp & Vindigni, 2000).

Despite the fact that meta-analysis offers many opportunities to researchers who are interested in comparative studies, one may note that there are some difficulties and limitation in the application of meta-analysis, especially in economics. One raison lies in the economic research itself and the nature of its reporting e.g. many styles of presentation, methods and findings. As Button (1994, p. 513) put it; *"The reporting of assumptions, error distributions, data idiosyncrasies and so on is not standardized in economics"*.
Another raison for these difficulties consists in the body of information's collected from different studies that address the same questions, use similar output measures but using different methodology.
In this respect, by bringing together a great number of studies, the analyst cannot fully eliminate subjectivity that exists in assessing different studies. Consequently, several potential problems may rise when using meta-analysis such as for example a biased representation of reality and results of the sample, the comparability of the size of estimated effects (e.g. the elasticities obtained following different specifications; using double logarithmic specifications or point elasticities evaluated at the sample mean of prices and quantities), and the time horizon of reported elasticities (i.e. short- vs. long-run elasticities).

In addition, many meta-regression in economics rely on simple fixed and random effects to account for the variation in precision of effect sizes, due to different sample sizes of the underlying studies. Finally, because the available studies are limited in number, the assumption of independence of the observations (sampling more than one observation by single study) may lead to biased estimates in the meta-analysis. The potentially negative effects of this problem are simply disregarded.

4.3. Method and the meta-sample

To estimate the output elasticity of public capital, we focus on studies employing the pure production function, VAR approaches, and cost/profit approach, including growth and behavioral approaches. All the selected production function studies use a log-linearized production function. Consequently, they estimate a uniformly defined output elasticity of public capital, which measures the percentage change in real private output in response to a 1% increase in the public capital stock.
The sample studies used here cover a wide range of countries, which employ different data sets, a variety of model specifications, different levels of spatial and sector aggregation, a wide range of variables, and different time periods.
Via an extensive literature search (in electronic database such as Repec, WebEcon, EconLit, etc., as well as a primarily literature (published papers in specialized refereed journals or academic studies and working papers, research reports, etc.), we identified 302 studies up to the year 2010 that are potentially be included in our sample. Because not all studies in our sample report elasticities, we were forced to dismiss 61 studies.

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[12] Details of theory and application of rough set analysis can be found in Powlak (1992), Slowinski (1995) and Nijkamp & Pepping (1998).

Note that our large sample of studies with comparable results cannot, in any way, give a comprehensive coverage of the literature about the treated subjects. Being aware of this shortcoming, we focus our attention in this paper on rather limited output measures. However, the selection procedure may create a form of subjectivity but the choice for this method of work provides the easiest observable form of quality control. Therefore, this study may be seen as supplementary to conventional literary reviews, and the findings are intended to be indicative (not explorative, neither explicative).

It is also useful to point out, like the majority of studies using meta-regression analysis, that we use standard meta-regression technique. This means, that a set of parameter estimates is obtained from a range of studies and the variation in these estimates is decomposed in a parts that can be explained by features of each studie.

We are interested in the estimated elasticities of infrastructure investment reported by different studies in relation to other variables, which reflect various characteristics of case studies that could explain variations amongst studies in our sample.

The output elasticity of infrastructure investment (E_i) is a result of the production function $Y = f(L, K, J)$. It is defined as the percentage change in output caused by an increase in the infrastructure capital stock of 1 percent. In the standard Cobb-Douglas production function it simply coincides with the parameter associated with *J*.

The estimated model takes the following form:

$$E_i = \alpha + \sum_{l=1}^{L} \beta_i X_{ij} + \varepsilon, \qquad i = 1, ..., N, \quad j = 1, ..., J_i \tag{4.1}$$

Or,

$$E_i = \alpha + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \beta_5 X_{i5} + \beta_6 X_{i6} + \beta_7 X_{i7} + \beta_8 X_{i8} + \varepsilon \tag{4.2}$$

Where;

Ei: is the estimated elasticity of public capital reported in study *i,* and α is a constant/intercept.

X_{ij} is a set of L dummy variables, and β measure the impact on the output elasticity of study characteristics. The included set of dummy variables takes the following notations;

X_{i1}: takes the value of 1 for US and 0 otherwise.

X_{i2}: takes the value of 1 for studies at national level and 0 otherwise (e.g. regions, cities).

X_{i3}: takes the value of 1 for cross-section data and 0 otherwise.

X_{i4}: takes the value of 1 if pooled time-series-cross sectional data is used and 0 otherwise.

X_{i5}: takes the value of 1 if the study is in first difference and 0 otherwise.

X_{i6}: takes the value of 0 if the publication was prior to 1991 and 1 otherwise.

X_{i7}: takes the value of 1 if a Cobb-Douglas specification was used and 0 otherwise.

X_{i8}: takes value 1 if sector coverage is core infrastructure and 0 for all other types of public capital e.g. services, etc., and ε is an error term.

All variables in our samples are classified and codified following the specification of the set of X_{ij} (dummy) variables given in equation 4.2.

Based on the stylized facts and hypothesis, the expected signs of these variables are as follow; $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 < 0$, $\beta_4 < 0$, $\beta_5 < 0$, $\beta_6 < 0$, $\beta_7 > 0$, $\beta_8 > 0$.

3.4. Data description; the Meta-sample

As mentioned above, our dataset consists of 302 studies and encompasses 14 variables. We take all relevant elasticities from each study rather than using a single estimate per study. It is worthy to mention that the differences found in the number of elasticities reported per study may, potentially give rise to dependency between observations from the sample study in our meta-sample. In the panel data models, we have grouped the observations by study.

Three types of studies can be distinguished in our meta-sample;

- Studies using a standard macro-economic models where infrastructure is exogenously determined (i.e. supply side) with constant and/or increasing scale economies.
- Studies using a standard macro-economic models where infrastructure investment (private and public) is endogenously determined.
- Studies taking into account the 'non-stationarity' and the geographical specification, using either time-series or cross-section data. Most of these studies were conducted after 1991, and finally,
- Studies using panel data models with spatial and time effects.

Table 3.1 gives an overview of the characteristics and specification of studies in the meta-sample.

Table 3.1. Characteristics and specifications of studies in the sample

Aggregation level	sample size	%		Aggregate level	Simple size	%
(1). National/Federal level	*147*			*(2). Regional/state level*	*83*	
Analytical approach						
Production function	89	34%		Production function	64	25%
Behavioral approach	21	8%		Behavioral approach	10	4%
VAR approach	35	13%		VAR approach	9	3%
(3). Sectoral/Industry level	*31*					
Analytical approach						
Production function	8	3%				
Behavioral approach	19	7%				
VAR approach	4	2%				

As table 3.1 shows, the majority of studies use production function models (62%), with 34% of the studies taking are conducted at the level of national/federal level, and ¼ percent of total focus on regional/state level. Only a small amount of studies are conducted at the sectoral/industry level. The VAR approach is widely used at the national level, and to less extent at regional/state or industry levels.

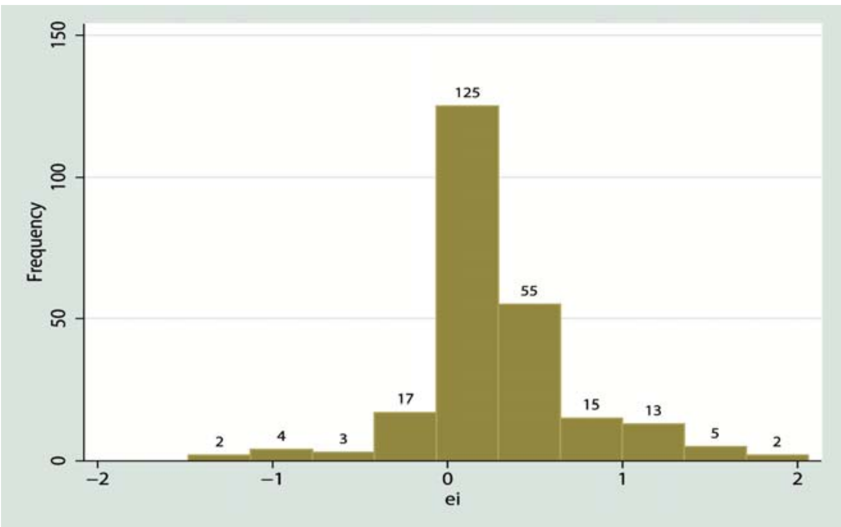
Table 3.2 (see appendix) gives a summary statistics of (large part of) the studies in the meta-sample. 123 studies in the sample deal with the USA at the national and regional level. 159 studies pertain to other OECD countries and other multiple countries. The number of elasticities per study differs between studies. The highest number of elasticities range from 1 (55 studies) to 12 (1 study), averaging to 6 estimations when taking into account all estimations in our meta-sample.

The mean of output elasticity range from a highest mean of 0,45 (study of Kamps (2004) of 22 OECD countries between 1960 and 2001), to the lowest mean of -1,22 (study of Vijverberg et al. (1997) on net stock of non-military equipment in the USA between 1958 and 1989) (for more details, see Table 3.2 in the appendix).

From the whole sample, 37 studies are conducted prior to 1991 and 265 studies in the sample (87,7% of the total sample) concern publications that toke place after 1991.
44 studies (14,5%) in the sample use cross-section data, and the remaining studies use time series data, that is a total of 258 studies (85,4%). About 37% of the studies in the sample use pooled data, and 17,8% of the studies applied first difference. Note that the majority of studies in the simple use country data (66% of the studies use country/federal spatial level), while 34% of the studies use regional data. However, estimated elasticities produced by these last studies do not differ systematically from other elasticities of studies conducted at the national level.
Others critical features of the meta-sample can be resumed as follow;

- The panel data studies tend to show the importance of location (country, region) and specificity of the model used.
- The majority of the studies (43%) use a Cobb-Douglas production function and the rest (57%) of the observations uses another specification e.g. quasi-production function, translog-cost function, labor demand function, profit function, TFP regressions, etc.
- The sector coverage in this studies concern mainly public capital stock (79,4%), including transportation, water, education, etc., and only 20,6% of the remaining studies examine specific sectors/industries.
- The time horizon of the analysis of almost all observations in the sample is relatively short. This is because many studies use only observations over a relative short time periods (from 4 to 42 years) and hence cannot provide information's on long-run effects. However, the long-term effects of public infrastructure investment are evident because their effects on growth emerge very gradually over time.

Figure 3.1 shows the distribution of output elasticities of public capital. It is clear that there is substantial variation across output elasticities of public capital across studies in our sample.
Figure 3.1 Distribution of the output elasticity of public capital.



Notes: The horizontal axis measures the output elasticity of public capital and the vertical axis the frequency.

Almost 75% of the estimates take on values between −0.15 and 0.50. The multi-country study of Kamps (2005) reports both the largest elasticity of 1.26 for Denmark, and the smallest elasticity of −0.57 for Portugal, with a mean elasticity of 0.45. Roughly 15% (35 out of 241) of the output elasticity estimates have a negative sign, of which 77% (27 out of 35) is statistically significant (at the 5% level). The small percentage of significantly negative output elasticities in our meta-sample provides a quantitative underpinning of stylized fact that public capital has a significant and positive effect on private output.
The simple (or arithmetic) average of the output elasticity of public capital in our meta-sample is 0.28, whereas the median elasticity amounts to 0.20, reflecting a distribution that is skewed to the right[13].

5. Results of the meta-analysis

If estimates of the effect size are considered to be homogeneous – and thus differences between estimates are due to purely random variation – a fixed effects model is the appropriate specification. However, often there are systematic differences between effect size estimates i.e. they are considered to be heterogeneous. In case of existing heterogeneity of effect size estimates, a random effects model is more appropriate because random effects specification assumes that there is unobserved heterogeneity across observations.
Differences between point estimates of studies in our meta-simple are not purely random but are the result of observed heterogeneity across studies, especially with regard to differences between studies concerning the type of public capital considered, the spatial level, country covered by the study, and the functional and econometric specification employed.

Table 5.1 shows the results of the meta-analysis for fixed effects (using 'within study' variation or the inverse of the variance of the *i*th estimate) and random effects meta-analysis model (using the inverse of the sum of the 'within' and 'between' study variance).

Table 5.1 Meta-analysis for various study characteristics and specifications

Study category	Sample size	Mean*	**Confidence**	**interval**
			Lower bound	Upper bond
(a). Fixed effects				
Aggregation level:				
National level	80	0.20	-0.015	0.420
Country (USA/Non USA)	132	0.337	0.167	0.507
Econometric specification:				
Pooled-data (CS, TS)	79	0.271	0.051	0.490
First difference	50	0.514	0.240	0.789

**. Weighted mean. Note: Random effects estimators (not reporter in table 5.1) do not show significant differences from fixed effects estimators reported above.*

[13] Note that the mean of the distribution does not take into account the difference in precision with which the output elasticities are estimated.

The fixed effects and random effects estimators are much smaller than the arithmetic average, reflecting the effect of the weighting scheme. Panel (b) of table 5.1 shows that the weighted average estimate of the output elasticity for national-level and country-level studies are respectively, 0.20 and 0,33, which are substantially larger than those of regional level studies and studies of the OECD and other countries. Furthermore, the output elasticity for studies estimating pooled-data is 0.27, which falls behind of the elasticity estimate of a model employing first differences.

Table 5.2 reports the correlation coefficients between the dependent and the various explanatory variables. As the table shows, there is a negative correlation between, pooled data and, respectively, the spatial level dummy (about -0.46) and country dummy (about -0,33), reflecting that most regional studies employ pooled data, especially by studies conducted in OECD and other countries than studies with focus on the USA.

Table 5.2 Correlation matrix.

	Output elasticity	Year of publication	Spatial level	Country (US)	Type data	Pooled data	First difference	sectors (core infra.)	specification
Output elasticity (ei)	1.0000								
Year of publication	0.0091	1.0000							
Spatial level	-0.1209	-0.1389	1.0000						
Country (US)	0.1509	0.0906	-0.0479	1.0000					
Type-data	-0.0362	-0.1319	0.3004	-0.0251	1.0000				
Pooled data	-0.0298	0.0165	-0.4593	-0.3294	-0.3011	1.0000			
First-difference	0.2775	0.1243	-0.2605	0.2706	-0.1712	-0.1642	1.0000		
Sector/core infrastr.	0.0870	-0.0182	-0.1424	0.0802	-0.3537	0.0543	0.0703	1.0000	
Specification	-0.0975	0.1035	0.1260	-0.0419	0.2074	-0.1760	-0.2537	-0.0524	1.0000

In addition, the relatively strong positive correlation between the type of data dummy and the national-level studies (i.e. spatial level dummy), suggest that cross section data are more prevalent in national-level studies.

Table 5.3 summarizes the empirical findings of the estimated equation 4.2. Various estimation methodologies were applied; (1). Pooled OLS, (2). Panel fixed effects, (3). Panel random effects, and (4), feasible GLS.

The pooled OLS results in column 1 – which forces a common slope and intercept – show a relatively good overall fit to the data although only a few of the explanatory variables are significant. The intercept is significant taking on a value closely in line with the unweighted average found in the meta-analysis. The dummies for the country (i.e. USA/Non USA), and panel studies (typedata) applying first difference are statistically significant. This finding is in line with the analysis of Button (1998), who finds only a significant and negative US dummy. This may be interpreted as evidence that studies on the USA tend to find lower output elasticities than studies conducted for other countries, reflecting the larger stock of infrastructure installed in these US.

In addition, results shows positive relationship between the size of output elasticity and investment in core infrastructure capital; a 1 point increase in infrastructure investment increase elasticity of output by 8%.

Also, the use of cross-section and pooled data seem to be positively related to output elasticities. The negative sign and scale of the variables *specifi*, *ypub*, and *tperiode*, confirm the importance of the level of aggregation and the specification of the model used when assessing the magnitude of output elasticities.

By pooling reported estimates we cannot analyze unobservable study-specific fixed effects that are likely to be relevant. Therefore, a panel fixed effects model is estimated as shown in column 2 of Table 5.3. The *F* test for the significance of the fixed effects cannot reject the null hypothesis of insignificant study-specific fixed effects. The panel fixed effects model performs poorly. The results for the panel random effects model –presented in column 3 – are not much better, which is not surprising given the presence of heteroscedasticity in the residuals. Consequently, the fixed effects and random effects models are inappropriate.

In the extended GLS model (columns 4 and 5), the standard errors are reduced, making a number of variables statistically significant.

Table 5.3 Results of the meta-regression analysis

Explanatory variables	(Pooled) OLS (1)	Fixed effects (2)	Random effects (3)	Feasible GLS Model A (4)	Feasible GLS Model B (5)
Constant	0.143	0.179	0.179	0.019	-0.022
	(0.026)	(0.125)	(0.123)	(0.138)	(0.080)
ypub	-0.056	-0.039	-0.039	-0.072	0.017
	(0.085)	(0.084)	(0.083)	(0.084)	(0.060)
spalevel	0.003	-0.023	-0.023	-0.037	-0.051
	(0.072)	(0.070)	(0.069)	(0.074)	(0.044)
country	-0.087	-0.090	-0.090	-0.087	-0.027
	(0.059)	(0.058)	(0.057)	(0.057)	(0.040)
tperiode	-0.002	-	-	-0.002	-
	(0.0028)			(0.002)	
typedata	0.029	0.056	0.056	0.057	0.108
	(0.096)	(0.090)	(0.088)	(0.094)	(0.063)
pooldata	0.031	0.017	0.017	0.043	-
	(0.071)	(0.071)	(0.070)	(0.070)	
firstdif	0.263	0.257	0.257	0.028	-
	(0.079)	(0.080)	(0.078)	(0.079)	
sectcov	0.080	0.046	0.046	0.128	0.042
	(0.740)	(0.073)	(0.072)	(0.072)	(0.052)
specifi	-0.014	-0.011	-0.011	-0.032	0.073
	(0.060)	(0.060)	(0.059)	(0.060)	(0.042)
Number of Obs.	227	236	236	232	241
R^2	0.1080	0.091	-	-	-
F-test	2.92	2.86	-	-	-
Probability > F	0.0028	0.004	-	-	-
Wald Chi^2 test	-	-	22.69	-	-
Log likelihood	-	-	-	-124.32	-57.077
Likelihood ratio test	-	-	22.69	15.88	8.96
Probability > Chi^2	-	-	0.0038	0.0003	0.1760

Standard errors in parentheses

**** and ** indicate statistical significance at the 1% and 5% level, respectively.*

Columns 4 and 5 of Table 5.3 present the extended GLS results for models A and B. Besides the significance of the country dummy, three additional explanatory variables are significant in model B. Core infrastructure (i.e. *sectorv*) is shown to be more productive than other types of infrastructure.

Studies based on core infrastructure capital stock, using Cobb-Douglas production function, estimating variables in first difference of logarithms, and not employing cross-sectional or panel data yield, generally, a higher output elasticity of public capital. Also, studies before 1991 (i.e. *ypub* and *Tperiod*) report larger estimates of output elasticity of public capital than studies conducted after 1991.

Model B shows that the dummies for logarithmic-level and national-level studies are not significantly positive if the *tperiod*, *pooldata*, and first difference dummies are dropped from the benchmark equation (model A). Compared to model A, it can be seen that the absolute size of almost all dummy variables drop significantly, whereas the regression intercept falls substantially to a (negative) negligible small level and becomes insignificant.

What can we learn from these results?

What does emerge actually from the meta-analysis is that elasticities derived from studies involving pooled data seem to produce lower estimates than those calculated in level.
Results show also, that specification of the model used, the type of data and the sector coverage determine to a great extent the scale and the magnitude of output elasticities obtained by studies in our sample data.
Also calculated elasticities are somewhat lower after 1991, taking account of the year of publication i.e. variable *ypub*, suggesting that most recent studies use improved data sources in combination with rich and more accurate econometric specification.
In line with several other meta-analysis studies trying to understand the main reasons of the difference in the scale and the magnitude of output elasticities obtained by various studies[14], our results confirm the evidence that these differences are strongly related to the level of aggregation (spatial level), the type of data used in the analysis (i.e. type of data used, pooled or not, cross-section or time-series data, etc.), and the specification of the model used by studies.
First, the spatial aggregation is important in determining the scale and level of elasticity in a sense that a small geographical area and a limited coverage of sectors studied (e.g. one or few sectors) may lead to a small output elasticity of public capital. A comparison of different studies on this matter confirms positively this observation.

Second, it is important to consider the long time span of studies in assessing the positive impact of infrastructure investment on output/productivity. The mean time span of the time series (most recent year of observation minus earliest year) is on average about 20 years. The elasticity of 0,42 suggests that a one-year increases in time span of the study increases the probability that a study finds significant benefits from infrastructure investment by 1,3 percent.

[14] Button (1988) reports a range of output elasticities between 0.03 and 0.39.

Third, applied models using panel data or cross-sectional data report a relatively smaller estimate of output elasticity of public capital i.e. positive correlation between investment in core infrastructure and output/growth. Also, the analysis of the meta-simple suggests that studies using national data are more likely to find higher elasticities than studies using more aggregated data at regional and/or sectoral level.

Finally, the probability that a study detects significant elasticities of public capital to output is greater, the longer the time span of the data used in the analysis.

6. Conclusion

In this paper we have used meta-analytical tools to assess the empirical evidence on the existence of positive relationship between public investment in infrastructure and output/productivity. Meta-analysis was applied to estimate the output elasticity of public capital stock in various countries. The sample features a substantial degree of (observed) heterogeneity. This has lead us to focus attention not to point to the direction and causality of the effects of public capital on output, but rather on the explanation of the differences and variations in the estimated elasticities produced by a substantial body of empirical studies on this subject.
The results of meta-analysis suggest that variations in estimates stem from the difference in aggregate level, type of data used in the studies, time period of the data, country of origin, and the methodological specification of the model applied by studies. It seems that studies employing core infrastructure, using capital data at national level, and estimating the equation in logarithmic levels find larger output elasticities of public capital.

More generally, meta-analysis shows that the sample average of output elasticity of public capital is about 0.20, which is quit bellow the value of 0.39 found by Aschauer[15], suggesting that marginal productivity of public capital is substantially above that of private capital. Therefore, investment in public capital e.g. infrastructure, should be encouraged from a macroeconomic point of view.
However, these results should be interpreted with care given the fact that the simple meta-analysis is just a partial analysis that does not control for other relevant factors such as the observed study heterogeneity, the composition of public capital e.g. same type or different types of public capital, and the financing method of public investment spending. In this sense, some type of infrastructure does not necessarily boost output or productivity. Consequently, a careful cost-benefit analysis (CBA) should precede any additional investment in infrastructure projects. However, despite the fact that there exist a strong relationship between investment in infrastructure and growth, little empirical evidence were provided by studies concerning the scale and the magnitude of indirect effects of infrastructure investments on growth, especially the indirect effects of agglomeration economies and other external effects.
This issue is one of the main challenges for the future research concerning the evaluation of the (overall) economic effects of infrastructure investment on growth.
Until now, none of the models used to estimate the direct and indirect effects of infrastructure on economic growth has succeeded to give an accurate estimation of the magnitude and the scale of indirect effects, especially

[15] The first results of our meta-regressions point out to an output elasticity of public capital of 0,14. However, these (first) results are very preliminary and need further analysis, especially when using the random effects model.

the effects of infrastructure on the spatial configuration of economic activities and the growth process at a much disaggregated level e.g. cities and/or region.

However, a comprehensive understanding of the relationship between transport and economic development must include the spatial effects of agglomeration and other external effects in relation to the infrastructure investment within a CBA framework. In these respect, one may note that a new generation of SCGE (spatial computational general equilibrium) models build up upon a methodological framework developed in the new economic geography seems to be promising in these area of research.

Finally, our meta-regression analysis can be extended by including additional explanatory variables such as country's per capita stock of public capital, GDP level, type of modeling approach i.e. production function and VAR v.s. single equation, and type of estimated method. Also, grouping variables by country instead of per study in the panel may allow to run a meta-regression analysis with country specific fixed effects.

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Appendix

Table 3.2. Summary statistics of the studies in the meta-sample

		Output elasticities				
Nr	**Authors**	**Number**	**Mean**	**Median**	**Minimum**	**Maximum**
1	Kamps (2004; 2005)	25	0,45	0,54	-0,56	1,26
2	Demetriades and Mamuneas (2000)	12	1,06	0,96	0,36	2,06
3	Aschauer (1989a)	8	0,35	0,34	0,06	0,74
4	Ford and Poret (1991)	8	0,43	0,43	0,29	0,62
5	Fernald (1993)	6	0,64	0,50	0,00	1,40
6	Garcia-Milà and McGuire (1992)	5	0,04	0,05	-0,06	0,17
7	Lynde and Richmond (1991)	5	-0,04	0,05	-0,45	0,20
8	Sturm and De Haan (1995)	5	0,72	0,82	0,26	1,15
9	Conrad and Seitz (1992)	4	-0,11	-0,06	-0,27	-0,03
10	Eisner (1991)	4	0,22	0,22	0,17	0,27
11	Evans and Karras (1993)	4	-0,08	-0,08	-0,19	0,04
12	Gamble et al. (1997)	4	-0,13	0,05	-0,79	0,18
13	Munnell (1990)	4	0,28	0,25	0,14	0,49
14	Pereira and Andraz (2010b)	4	0,11	0,23	-0,80	0,80
15	Stephan (2000)	4	0,31	0,25	0,11	0,65
16	Tatom (1991)	4	0,07	0,08	-0,01	0,14
17	Abdih and Joutz (2008)	3	0,38	0,39	0,13	0,61
18	Albala-Bertrand and Mamatzakis (2004)	3	0,03	0,03	-0,34	0,39
19	Canning (2000)	3	-0,15	-0,15	-0,15	-0,15
20	Costa et al. (1987)	3	0,22	0,20	0,19	0,26
21	Holtz-Eakin (1988)	3	0,20	0,23	-0,02	0,39
22	Hulten and Schwab (1991)	3	0,12	0,12	0,03	0,20
23	Mas et al. (1993)	3	0,17	0,20	0,07	0,24
24	Mera (1973)	3	0,13	0,12	0,03	0,23
25	Merriman (1990)	3	0,42	0,46	0,20	0,59
26	Momaw et al (1995)	3	0,24	0,27	0,07	0,37
27	Morrison & Schwartz (1991)	3	0,02	0,07	-0,20	0,18
28	Nadiri and Mamuneas (1994)	3	-0,15	-0,12	-0,21	-0,11
29	Otto and Voss (1994)	3	0,34	0,38	0,17	0,46
30	Pereira (2001a)	3	0,18	0,26	0,02	0,26
31	Pereira and Roca (1999)	3	0,42	0,50	-0,31	1,08
32	Pinnoi (1992)	3	-0,04	-0,11	-0,11	0,09
33	Aaron (1990)	2	0,19	0,19	0,09	0,28
34	Ai and Cassou (1995)	2	0,18	0,18	0,15	0,21
35	Baltagi & Pinnoi (1995)	2	0,14	0,14	0,12	0,16
36	Boscá et al. (2000)	2	0,09	0,09	0,08	0,09
37	Canning and Bennathan (2000)	2	0,29	0,29	0,14	0,44
38	Carlino and Voith (1992)	2	0,61	0,61	0,22	1,00
39	Cutanda and Parício (1992)	2	0,21	0,21	0,12	0,30
40	Dalamagas (1995)	2	0,79	0,79	0,52	1,06
41	Eberts (1986)	2	0,04	0,04	0,04	0,04

42	Fox & Murray (1988)	2	1,00	1,00	1,00	1,00
43	Holleyman (1996)	2	0,01	0,01	-0,07	0,09
44	Holtz-Eakin and Schwartz (1995)	2	0,05	0,05	0,05	0,05
45	Keeler and Ying (1988)	2	0,13	0,13	-0,07	0,33
46	Ligthart (2002)	2	0,28	0,28	0,20	0,36
47	Mamatzakis (1999)	2	0,25	0,25	0,25	0,25
48	Nourzad and Vriese (1995)	2	0,36	0,36	0,31	0,40
49	Picci (1999)	2	0,26	0,26	0,08	0,44
50	Shah (1992)	2	-0,89	-0,89	-0,92	-0,87
51	Shioji (2001)	2	0,13	0,13	0,10	0,16
52	Sturm (1998)	2	0,36	0,36	0,25	0,46
53	Vanhoudt, Matha and Smid (2000)	2	0,14	0,14	0,12	0,16
54	Wylie (1996)	2	0,32	0,32	0,11	0,52
55	Smith&Venables (1988)	1	0,00	0,00	0,00	0,00
56	Andrews and Swanson (1995)	1	0,04	0,04	0,04	0,04
57	Attaran & Auclair (1990)	1	0,35	0,35	0,35	0,35
58	Attaray (1988)	1	0,25	0,25	0,25	0,25
59	Bajo-robio and Sosvilla-Rivero (1993)	1	0,18	0,18	0,18	0,18
60	Bell et al. (1994)	1	0,35	0,35	0,35	0,35
61	Berndt & Hansson (1991)	1	0,20	0,20	0,20	0,20
62	Biehl (1991)	1	0,20	0,20	0,20	0,20
63	Boarnet (1998)	1	0,23	0,23	0,23	0,23
64	Cadot et al. (1999)	1	0,10	0,10	0,10	0,10
65	Calderón and Servén (2003)	1	0,16	0,16	0,16	0,16
66	Charlot (1999)	1	0,00	0,00	0,00	0,00
67	Crihfield & Panggabean (1995)	1	-0,01	-0,01	-0,01	-0,01
68	Crowder and Himarios (1997)	1	0,27	0,27	0,27	0,27
69	Dalenberg & Duffy-Deno (1993)	1	1,44	1,44	1,44	1,44
70	Dalenberg & Partridge (1995)	1	0,11	0,11	0,11	0,11
71	De La Fuente and Vives (1995)	1	0,21	0,21	0,21	0,21
72	Declercq (1995)	1	-0,63	-0,63	-0,63	-0,63
73	Deno (1988)	1	0,69	0,69	0,69	0,69
74	Duffy-Deno & Eberts (1991)	1	0,08	0,08	0,08	0,08
75	Duffy-Deno (1991)	1	0,23	0,23	0,23	0,23
76	Duggal et al. (1999)	1	0,27	0,27	0,27	0,27
77	Evans and Karras (1994)	1	-0,19	-0,19	-0,19	-0,19
78	Evans and Karras (1994)	1	0,04	0,04	0,04	0,04
79	Everaert (2003)	1	0,14	0,14	0,14	0,14
80	Everaert and Heylen (2004)	1	0,31	0,31	0,31	0,31
81	Ferreira (1994)	1	0,07	0,07	0,07	0,07
82	Finn (1993)	1	0,16	0,16	0,16	0,16
83	Flores de Frutos et al. (1998)	1	0,21	0,21	0,21	0,21
84	Forslid & al. (1999)	1	0,00	0,00	0,00	0,00
85	Fritsch & Prud'homme (1994)	1	0,07	0,07	0,07	0,07
86	Fritsch (1995)	1	0,12	0,12	0,12	0,12

87	Gasiorek & Venables (1997)	1	0,00	0,00	0,00	0,00
88	Gasiorek&Smith&Venables(1992a; 1992b)	1	1,00	1,00	1,00	1,00
89	Greenstein and Spillar (1995)	1	0,10	0,10	0,10	0,10
90	Haaland & Norman (1992)	1	1,00	1,00	1,00	1,00
91	Hanson (1998)	1	0,00	0,00	0,00	0,00
92	Harmatuck (1996)	1	0,03	0,03	0,03	0,03
93	La Ferrara and Marcelino (2000)	1	-1,48	-1,48	-1,48	-1,48
94	Lagarrigue (1994)	1	0,30	0,30	0,30	0,30
95	Lau and Sin (1997)	1	0,11	0,11	0,11	0,11
96	Lynde (1992)	1	1,20	1,20	1,20	1,20
97	MacGuire (1992)	1	1,50	1,50	1,50	1,50
98	Martin & Rogers (1995)	1	0,00	0,00	0,00	0,00
99	Moomaw and Williams (1991)	1	0,17	0,17	0,17	0,17
100	Munnell with Cook (1990)	1	0,15	0,15	0,15	0,15
101	Prud'Homme (1996)	1	0,08	0,08	0,08	0,08
102	Ram and Ramsey (1989)	1	0,24	0,24	0,24	0,24
103	Ramirez (1998)	1	0,11	0,11	0,11	0,11
104	Ratner (1983)	1	0,06	0,06	0,06	0,06
105	Seitz (1995)	1	-0,13	-0,13	-0,13	-0,13
106	Seitz and Licht (1995)	1	-0,22	-0,22	-0,22	-0,22
107	Song (2002)	1	0,00	0,00	0,00	0,00
108	Trionfetti (1997)	1	0,00	0,00	0,00	0,00
109	Vijverberg et al. (1997)	1	-1,22	-1,22	-1,22	-1,22