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# ON THE ECONOMIC EFFECTS OF PUBLIC INFRASTRUCTURE INVESTMENT: A SURVEY OF THE INTERNATIONAL EVIDENCE

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This paper provides a survey of the significant literature on the effects of public infrastructure investment on economic performance and therefore constitutes a comprehensive reference for academic researchers and policy makers alike. It presents a comprehensive discussion of the empirical research regarding the impact of public infrastructure investment on economic performance in terms of both the methodological approaches followed and respective conclusions. It includes an integrated discussion of the methodological developments that successively have led to the estimation of production functions, cost and profit functions and, more recently, vector autoregressive models. Finally, it identifies some important areas for future research and highlights the natural convergence of this literature with the macroeconomic literature on the effects of fiscal policies.

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## 1. INTRODUCTION

The economic impact of public investment in infrastructure has been at the center of the academic and policy debate for the last two decades. Infrastructures generate positive externalities to the private sector, contributing to the well-being of households and the productivity of firms. Therefore, it is hardly surprising that in many countries development strategies have been based on infrastructure investment while in others the failure to achieve adequate growth has been attributed to the lack of adequate infrastructures. The slowdown in productivity growth in many OECD countries during

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the 1970s and 1980s, for example, has often been attributed to deteriorating infrastructures due to fiscal consolidation policies or benign neglect. In the 1990s, less developed European Union countries, such as Greece, Ireland, Portugal and Spain, pursued development strategies based on large public infrastructure investment projects while the economic recovery of many Eastern European countries seemed to depend to a large degree on the revamping of obsolete infrastructures. In Africa the absence of infrastructure networks seems to condemn the entire continent to poverty. More recently in the late 2000s, fiscal stimulus packages to address the ongoing recession included, in many countries, a very significant public investment component.

Aschauer (1989a, 1989b) serves as a seminal work that has spawned a substantial literature on the effects of public investments in infrastructures on economic performance. Using a production function approach relating output, employment, and private capital as well as public capital, Aschauer (1989a, 1989b) estimated the elasticity of output with respect to public capital to be between 0.34 and 0.39. These estimates were interpreted as implying an annual marginal productivity of public capital of about 70 cents on the dollar and that public capital would pay for itself close to three times in the form of additional tax revenues (see Reich, 1991).

Aschauer's work led to an explosion in this literature. Subsequent analyses applying the same methodology to international, regional and sector-specific data, however, failed to replicate such large effects and, indeed, often failed to find meaningful positive effects. In addition, the approach used in Aschauer's work and most of the earlier literature was challenged on econometric grounds. It was observed, for example, that OLS estimation of static, single-equation production functions suffer from simultaneity bias and that, even if this bias is corrected, conclusions about causality still cannot be drawn. These concerns generated a body of literature that branched out into a multivariate static cost-function approach and ultimately into a dynamic multivariate vector autoregressive (VAR) setting considering private sector employment, investment and output in addition to public capital.

In this paper, we survey the literature in the last two decades focusing on the empirical relationship between public investment in infrastructures and economic performance that followed Aschauer's contributions. While this is not the first survey of this literature (see Munnell, 1992; Gramlich, 1994; Romp and de Haan, 2007), beyond updating the literature review, it departs from previous surveys in two critical aspects. First, it provides a comprehensive discussion of the methodological developments, successively leading from estimating production function, to estimating cost and profit functions and, more recently, vector autoregressive models. Second, it has a much broader scope in that it covers studies of the US and at the international level, and contributions at the national, regional, and industry levels. Details of the literature reviewed are presented in Appendix (Tables A1, A2, and A3) for the contributions with an aggregate, regional, and an industry focus, respectively.

The remainder of the paper is organized as follows. Section 2 presents the methodological debate and the key methodological features of the studies. Section 3 reviews the national level studies. Section 4 reviews regional level studies. Section 5 reviews studies focusing on industry level effects. Finally, Section 6 presents our main conclusions and identifies important avenues for future research.

## 2. THE METHODOLOGICAL DEBATE

The static single-equation production function approach was widely followed in earlier studies. Typically, aggregate private output is regressed on private sector variables - employment and the non-residential private fixed capital stock - and public capital as an additional input which affects multifactor productivity. The effects of public capital are measured by the coefficient of this variable in the regression, which often is directly interpreted as the elasticity of output with respect to public capital and from which a measure of the marginal product of public capital can be derived. Variations to the standard model specification include both a constant and a trend as a proxy for multifactor productivity and as a proxy for the capacity utilization rate to control for the influence of business cycle fluctuations. The significant data requirements, together with the high level of co-linearity caused by including second order terms in the Translog specification adopted in some studies led to the widespread use of the log-linear Cobb-Douglas specification.

The credibility of the large output elasticities reported the early studies, most notably Aschauer (1989a, 1989b), was seriously challenged on econometric grounds (see section 3.1 below for a detailed discussion of these issues). The problems come from the fact that, by its very nature, the production function methodology is a single-equation and static approach which does not account for simultaneity among the different variables and much more so for any non-contemporaneous effects. As a corollary it really cannot address the issue of causality. Indeed, further research highlighted the issue of the direction of causality between public capital and private output - what causes what. On one hand, it is conceivable that public capital can affect the demand for private inputs, as well as their marginal productivity, production costs and, finally, the aggregate level of production. On the other hand, the evolution of private inputs can affect public investment decisions, as declining employment has often led to short-term policy packages involving increased public investment spending, and variations in output can directly affect the size of the tax base and therefore the government's capacity to finance new investment. These concerns highlight the possibility of reverse causality.

To get around some of the econometric problems of the production function approach the literature eventually evolved into a multivariate framework by estimating dual cost functions (and less frequently profit functions) and the derived input demand systems. Firms produce a given level of output at minimum cost, fully accounting for technical change, scale economies and input demand. Public capital is assumed to be publicly provided and external to the firm but directly affects the firms' optimization problem.

The total effect of public capital on output can now be measured by the reduction in production costs resulting from an increase in public capital, fully accounting for the direct effect of public capital and its indirect effects on private input demands. This effect corresponds to the cost side concept equivalent to the marginal product in the production function framework. It corresponds to the shadow price of public capital, a proxy for the market price of public capital. Furthermore, the signs of these indirect effects on private inputs provide information about the nature of the relationships between inputs, something which by definition was not possible in the production function approach.

Despite its advantages over the production function approach, several issues persist with the multivariate cost function approach. Public capital is assumed to be an exogenous variable, which means that the issue of reverse causality remains unaddressed. The analysis remains static in nature, not accounting for potentially important non-contemporaneous effects and leaving unresolved the issue of causality. In addition, by not addressing the time series properties of the data, problems of spurious correlation, nonstationarity and non-cointegration remain a concern.

In recent years VAR models have become increasingly popular to the point of currently being the standard approach in this literature. Their widespread use is in great part due to the fact that this approach addresses the above econometric concerns in a rigorous and comprehensive manner. It also brings a more precise conceptual focus to the debate about whether or not public capital is productive. In fact, both the single-equation static production function approach and the multivariate cost function approach exclude the presence of feedbacks between private inputs and public capital as well as dynamic feedbacks among all the inputs. This exclusion is of paramount importance for it is very likely that these feedbacks exist and are relevant in which case, a zero elasticity of private output with respect to public capital, as obtained for example, from a single-equation static production function approach, is neither a necessary nor a sufficient condition for public capital to be ineffective in influencing output.

The VAR approach is predicated on the idea that accounting, in a comprehensive manner, for dynamic feedbacks is essential to understanding the relationship between public capital and private-sector performance. As a positive externality, public capital leads directly to higher private production through time. Public capital also affects private production indirectly via its dynamic effects on private inputs. It is conceivable that a greater availability of public capital could reduce the demand for private inputs. The greater availability of public capital, however, also increases the marginal productivity of private inputs. This lowers the marginal costs of production, thereby potentially increasing the level of private production. The evolution of private inputs and outputs can, in turn, be expected to affect public capital formation. Indeed, increasing private output provides the government with a growing tax base and the potential for greater investment. Furthermore, declining private employment has often led to short-term policy packages that involve increased public investment. In the context of VAR analyses, the effects of public investment in infrastructures are obtained from the accumulated impulse-response functions associated with the estimated VAR model and measure the total effects of anticipated exogenous shocks to the path of public investment. These measures capture the contemporaneous correlations among innovations in the different variables under consideration, the dynamic interactions among these variables, as well as any long-term cointegrating relationships.

Naturally, the VAR approach is not without its shortcomings. One can think of a VAR model as a reduced form of a dynamic model of the economy. Private inputs and public capital are used to generate private output according to the production technology and the private sector decides on the appropriate level of input demand. In turn, the public sector, using a policy function relating public capital formation to the evolution of the private sector variables, defines public capital investment levels. As a result, the estimated VAR model corresponds to a reduced form for the production function, input demand functions and policy functions. Although this means that the VAR approach is not a-theoretical, it also leaves out a conceptually more satisfying structural and forward-looking approach. In addition, the identification of exogenous shocks is a well-know problem as the effects suggested by the cumulative impulse response analysis can be rather sensitive to the ordering of the variables. Indeed, these restrictions must be based on exogeneity assumption for the innovations which can only be derived from theoretical considerations. Finally, there is a non-irrelevant semantic issue. The comparison of results with the previous literature is not trivial as similar terms, like elasticity or marginal product, are being used in ways that are not necessarily comparable. Within the VAR context, the elasticities and marginal products are not based on *ceteris paribus* assumptions, but instead, reflect the total accumulated long-term changes, direct and indirect, in each private sector variable due to an initial shock in public capital.

## 3. THE EMPIRICAL EVIDENCE OF AT THE NATIONAL LEVEL

### 3.1. Evidence for the US

After Aschauer's seminal work reporting rather large estimates for the output elasticity with respect to public capital, several studies were undertaken that tended to corroborate this evidence with elasticities estimated to be in a very narrow range between 0.23 and 0.39 (Duggal *et al.*, 1999; Eisner, 1991; Finn, 1993; Ford and Poret, 1991; Holtz-Eakin, 1988; and Munnell, 1990). Several studies consider different types of public capital. For instance, Aschauer (1989a) and Munnell (1990) distinguish between the total stock of public capital and core infrastructure and conclude that the stronger effects on output come from core infrastructure. Attaray (1988) and Finn (1993) consider the stock of capital in highways and estimate elasticities of 0.25 and 0.16, respectively. In turn, Holtz-Eakin (1988) and Ram and Ramsey (1989) disaggregate public capital stock into its federal and state components and obtain elasticities of 0.39 and 0.24, respectively.

Although in general terms these results are consistent with economic theory, the magnitude of the effects was considered implausible high by many (Gramlich, 1994;

Jorgenson, 1991; and Tatom, 1991). Indeed, further research raised several econometric problems, which could have explained the high estimates in the literature (Aaron, 1990; Eisner, 1991; Finn, 1993; Harmatuck, 1996; Holtz-Eakin, 1993, 1994; Hulten and Schwab, 1991a, 1991b, 1993; Sturm and De Haan, 1995; and Tatom, 1991).

A first problem has to do with stochastic trends. In fact, during the sample period used by most studies, which runs from the 1950s to the early 1980s, public capital and private productivity moved together which muddles the issue of causality. Several studies, after correcting for non-stationarity provide conflicting evidence on the effects of public capital on output and, when positive and statistically significant, the reported estimates are lower than the previous studies. Aaron (1990) and Finn (1993) find lower elasticities of 0.09 and 0.16, respectively. Finally, Tatom (1991), Harmatuck (1996), Hulten and Schwab (1991b) and Sturm and De Haan (1995) find statistically non-significant output elasticities with respect to public capital. Nevertheless, the use of first differences has been contested on both conceptual grounds (Munnell, 1992; and Duggal *et al*., 1995) and empirical grounds in that it leads to implausible coefficients for private inputs and for public capital (see Evans and Karras, 1994; Hulten and Schwab, 1991b; Sturm and De Haan, 1995; and Tatom, 1991).

A second problem has to do with misspecification due to missing variables that might be correlated with the stock of public capital. In this context, several papers provide a comparative analysis by re-estimating Aschauer's specification with the inclusion of other variables and report statistically significant coefficients. Aaron (1990) includes the exchange rate yen/dollar, and Tatom (1991) and Ram and Ramsey (1989) include energy prices, while Hulten and Schwab (1991b) include an oil shock dummy variable. The inclusion of extraneous variables in the production function was itself criticized, in particular the inclusion of energy prices. Berndt (1980) argues that energy costs represent very little in total costs and Duggal *et al*. (1995) suggests that energy prices, being cost factors, should be included in a firm's cost and factor demand functions. An extension of these concerns led to the studies of Lynde and Richmond (1991) and Vijverberg *et al*. (1997) who estimate translog cost functions models and of Lynde (1992) and Lynde and Richmond (1993a) who estimate translog profit functions and find significantly lower effects of public capital on output.

A third econometric problem concerns the direction of causality between public capital and private output. This issue was raised by Eisner (1991) and Hulten and Schwab (1991a, 1993) who conclude that causality may run stronger from output to public capital. Several approaches were developed to deal with the problem of causality: estimating panel models (Canning and Bennathan, 2000; and Canning and Pedroni, 1999), estimating simultaneous equation models (Cadot *et al*., 2002; Demetriades and Mamuneas, 2000; and Kemmerling and Stephan, 2002) and using instrumental variables (Ai and Cassou, 1995; Calderón and Servén, 2002; and Finn, 1993). More to the point, several studies addressed the problem of reverse causality by estimating a four-variable VAR model with output, labor, private capital and public capital or public investment (Batina, 1997; Cullison, 1993; Crowder and Himarios, 1997; Lau and Sin, 1997; McMillin and

Smyth, 1994; Pereira and Flores, 1999; and Pereira, 2000, 2001a, 2001b). In general, these studies report evidence of reverse causality, positive long-run responses of output to shocks in public capital stock, and that most types of public investment crowd in private inputs, that is public capital and private inputs are complements in the long term.

Pereira (2000), for example, reports that in the long term, aggregate public investment crowds in private investment and, to a lesser extent, private employment and has a positive effect on private output with a long-term accumulated marginal product of $4.46, which corresponds to a rate of return of 7.8%, a result that is at least three times smaller than the one initially estimated by Aschauer (1989a). Consistent with the aggregate results, all types of public investment crowd in private investment while investment in core infrastructure in highways and streets and in sewage and water systems actually crowds out private employment. It is also shown that while all types of public investment have a positive effect on private output, core infrastructure investments in electric and gas facilities, transit systems, and airfields, as well as in sewage and water supply systems, have the highest marginal returns.

### 3.2. International Evidence

The patterns of results at the international level are reminiscent of the discussion above for the US. In general, studies using the production function approach, tend to identify large positive effects of public capital (see, for example, Bajo and Sosvilla, 1993, for Spain; Ligthart, 2002, for Portugal; Otto and Voss, 1994, 1996, for Australia; Sturm and de Haan, 1995, for the Netherlands; and Wang, 2004, for Canada; as well as multi-country studies by Aschauer, 1989c; Ford and Poret, 1991; and Kamps, 2005). Other studies, however, present considerably smaller effects. By estimating cost functions, both Berndt and Hansson (1992) and Demetriades and Mamuneas (2000) conclude that their exists an excess of public capital in Sweden and twelve OECD countries, respectively. On the other hand, the use of the VAR approach led to the identification of positive effects of public capital on output in several countries (see, for example, Mamatzakis, 1999, 2002, for Greece; Pereira and Andraz, 2005, for Portugal; Pereira and Roca-Sagales, 1999, for Spain; as well as Kamps, 2005; and Pereira, 2001b, for a group of developed countries).

Comparisons of the international evidence are not easy. This is primarily because of the use of diverse econometric techniques and the fact that the definitions of public investment vary wildly. Although comparisons are difficult they are not impossible. The results for Spain in Pereira and Roca-Sagales (1999), and for Portugal in Pereira and Andraz (2005), for example, are directly comparable to the results for the US in Pereira (2000). Pereira and Roca-Sagales (1999) consider the effects of public capital in transportation infrastructures in Spain. The empirical results suggest a marginal product of private investment with respect to public investment of 10.2 and that one million euros in public investment create 129 jobs in the long-term. Moreover, the results indicate that the marginal product of public investment in Spain is 5.5 Euros, which corresponds to a rate of return of 8.9%. In turn, for transportation infrastructures in Portugal, Pereira and Andraz (2005) report long-term effects of 8.1 on private investment and of 230 new jobs per million euros in public investment and a marginal product of 9.5 Euros, which corresponds to a rate of return of 15.9%. Clearly the results for Spain and Portugal tend to be substantially higher than those for the US presented in the previous section. This is understandable given the relatively greater scarcity of public infrastructures in these countries and the fact that much of the Portuguese and Spanish public investment was financed by EU funds.

An important corollary of the results in these studies for Spain and Portugal is that public investment would more than pay for itself over time in the form of added tax revenues over the life span of the public assets. This is reminiscent of the supply-side Laffer-curve effect found for the US by the early literature but disputed by subsequent research. Some of the international evidence for more developed economies such as for Canada, France, Germany, Holland, Japan, and the UK tends to confirm the absence of this Laffer-curve effect (Mittnik and Newman, 1998). This leaves open the question as to whether a supply-side Laffer-curve effect while not present in more developed economies could be a fixture in less developed ones.

## 4. THE EMPIRICAL EVIDENCE AT THE REGIONAL LEVEL

### 4.1. Evidence for the US

The empirical evidence on the effects of public investments at the regional level has traditionally been unable to replicate the large effects of public investment in infrastructures identified at the aggregate level. Some of the early contributions provide evidence of a positive effects on output with elasticities ranging from 0.03 to 0.20, and, therefore, clearly lower than the estimates reported by the aggregated studies (Costa *et al.*, 1987; Duffy-Deno and Eberts, 1991; Eberts, 1986, 1991; Garcia-Mila and McGuire, 1992; Merriman, 1990; Moomaw and Williams, 1991; Munnell and Cook, 1990; and Munnell, 1993). Later studies, however, find that after controlling for region and state specific unobserved characteristics, public capital effects are not significant (Andrews and Swanson, 1995; Eisner, 1991; Evans and Karras, 1994; Garcia-Milà *et al.*, 1996; Holtz-Eakin, 1993, 1994; and Moomaw *et al.*, 1995).

One possible explanation for this paradox is that spillover effects captured by aggregate level studies are not captured at the regional level (Boarnet, 1998; and Mikelbank and Jackson, 2000). As such, it could be argued that spillover effects should be an integral part of the analysis of the regional impact of public capital formation (Haugwout, 1998, 2002) as the effects of public capital formation in a region can be induced by public infrastructures installed in the region itself as well as public infrastructure outside the region. Paradoxically, possibly due to the inconclusive nature of the results on the impact of public capital on output at the regional level, the issue of the possible existence of regional spillovers from public capital formation has received little attention. Munnell (1990) deals marginally with this issue. Holtz-Eakin (1993, 1995) concludes that regional level estimates are essentially identical to those from national data, suggesting no quantitatively important spillover effects across regions. On the other hand, several other studies report evidence of spillovers (Boarnet, 1998; Cohen and Paul, 2004; and Pereira and Andraz, 2004, 2010b).

The empirical results reported in Pereira and Andraz (2004), for example, suggest that only about 20% of the aggregate effects of public investment in highways in the US are captured by the direct effects of public investment in the state itself. The remaining 80% correspond to the spillover effects from public investment in highways in other states. The spillover effects are generally more important for the western states, the states along the corridor from the Great Lakes to the Gulf Coast and, to a lesser extent, for some the states along the Eastern Atlantic Coast. This suggests that there are intensive economic connections among the states located in each of these areas and that they depend heavily on the regional network of highway and implicitly on investment in highways located in the other states. As a follow up, Pereira and Andraz (2012) report that public investment in highways affects private sector variables positively in most states but that relative to their share of the US private sector variables, the biggest beneficiaries of public investment in highways tend to be the largest states in the country. This suggests that public investment in highways has contributed to the concentration of private sector activity in the largest states.

### 4.2. International Evidence

Evidence on the effects of public capital at the regional level for other countries is again in many respects similar to that for the US. In general, output elasticities are positive and relatively large in Japan (Mera, 1973; and Merriman, 1990), Spain (Cutanda and Paricio, 1992; and Mas *et al*., 1996), Belgium (Everaert and Heylen, 2004) and Germany (Stephan, 2003) and substantially lower for France (Cadot *et al*., 1999) and the more developed Mexican states (Looney and Frederiksen, 1981). Furthermore, the adoption of cost and profit equation approaches appears to have led to smaller estimates for the effects of public capital on economic performance (Boscá *et al*., 2000; Everaert, 2003; and Moreno *et al*., 2003). In addition, the significance of spillover effects is observed in some countries such as Portugal (Pereira and Andraz, 2004) and Spain (Pereira and Roca-Sagales, 2003, 2007), which can explain some of the divergences found between regional and aggregate studies.

These studies also tend to reinforce the idea that public investment in infrastructures affects the regional pattern of economic activity. For Spain, for example, Pereira and Roca-Sagales (2007) show that among the largest regions, Andalucía, Castilla-León, Madrid, Valencia, and País Vasco, benefit more than proportionally than their share of the Spanish GDP, while among the smallest regions the beneficiaries are Baleares, Canarias, Cantabria, Castilla-Mancha, and Murcia. Accordingly, public infrastructure investment has contributed to the concentration of economic activity in these ten regions, to the detriment of the remaining seven. This is particularly important since five of the ten regions that benefit the most in relative terms are among the six largest in the country.

## 5. THE EMPIRICAL EVIDENCE AT THE INDUSTRY LEVEL

### 5.1. Evidence for the US

Studies with an industry focus are not common. Although several studies make reference to specific industries, manufacturing in particular, they have essentially a regional focus (Deno, 1988; Duffy-Deno and Eberts, 1991; Eberts, 1986; Evans and Karras, 1994; and Moomaw and Williams, 1991). The industry dimension is more directly relevant in the studies by Costa *et al*. (1987), Fernald (1993, 1999), Greenstein and Spillar (1995) and Pinnoi (1992) using the production function approach, Nadiri and Manuneas (1994, 1996) with a cost function approach, and Pereira and Andraz (2003) with a VAR approach.

Public capital seems to affect industries differently and industries react differently to different components of public infrastructure. Specifically, manufacturing industries seem to benefit from public investment in highways, public buildings and water and sewer systems. In contrast, agriculture, traditionally a declining sector, does not seem to benefit much. Accordingly, whatever positive results are found at the aggregate level tend to hide a wide variety of industry-level effects. Empirical results reported in Pereira and Andraz (2003) for example suggest that public investment in infrastructures in the US tends to shift the sectoral composition of employment toward construction and transportation and the composition of private investment toward manufacturing, public utilities, and communications. Furthermore, public investment tends to shift the composition of private output toward construction and durable manufacturing and to a lesser extent toward transportation and wholesale trade.

In turn, studies estimating production and cost functions tend to find evidence for substitution between capital and private inputs, but when allowing for output and production input responses, considering a long-term horizon, the relationship appears to be complementary. The evidence with a VAR approach, such as that in Pereira and Andraz (2003), provides a more detailed picture with public investment affecting private employment positively in only six of the twelve industries considered and private investment in only five.

### 5.2. International Evidence

The research on the impact of infrastructure development on industry performance at the international level includes country specific contributions such as Berndt and Hansson (1992) for Sweden, Conrad and Seitz (1994), Seitz (1993, 1994, 1995), Seitz and Licht (1995) for Germany, Lynde and Richmond (1993b) for the U.K., Shah (1992) for Mexico, Pereira and Roca-Sagales (1998, 2001) for Spain, and Pereira and Andraz (2007) for Portugal. It also includes contributions with a multi-country focus, such as

Evans and Karras (1993).

Results reported in Pereira and Andraz (2007) for Portugal suggest that in absolute terms the industries that benefit the most from public investment in transportation infrastructure are construction, trade, transportation, finance, real estate, and services. In turn, relative to their size, the industries that benefit the most are mining, non-metal products, metal products, construction, restaurants, transportation, and finance - public investment tends to shift the industry mix toward these industries. For the vast majority of industries, a long-term relationship of complementarity between infrastructure investment and private inputs is identified.

## 6. CONCLUDING REMARKS

Overall, and maybe not surprisingly, little consensus emerges from such a wide and disparate body of literature. There are, however, a few stylized facts that should be highlighted. While there is little consensus about the magnitudes of the effects of public investment in infrastructures, there is also little doubt that they are positive and significant but substantially smaller than the earlier estimates. In addition, the magnitude of the effects tends to be substantially higher for less developed countries. Another interesting pattern is that as the geographic focus narrows, the effects of public capital become smaller. One possible conjecture for this relies on the existence of regional spillover effects. Indeed, when correcting for region-specific characteristics and regional spillovers it is possible to recapture the aggregate effects. Finally, the aggregate results, whatever they may be, tend to hide a wide variety of disaggregated effects. Empirical results suggest that public investment affects long-term private-sector performance in a way that is rather unbalanced across industries and regions. It contributes therefore in an important manner to changes in the regional and industry mix in the economy and may contribute to the concentration of economic activity in the largest sectors and regions.

In terms of the scope of the analysis we believe that there are several avenues open for future research. First, it is important that the literature shifts gears into the comparative analysis of different types of investment including private and different forms of public investment in infrastructures. Indeed, the big policy question is not as much whether or not infrastructures are productive but whether or not at the margin they are the most productive form of investment. Second, the possibility of structural breaks has received scant attention. Nevertheless, even casual considerations would suggest that there are reasons, both conceptual and methodological, why such possibility should be considered in detail. In fact it is likely that some of the discrepancies in the results in the literature are due to the use of different sample periods and to the fact that structural breaks have been ignored. Third, the issue of the financing the investment efforts has to be addressed. While infrastructures have a positive effect on economic performance one would expect their financing to have opposite effects and that not all types of financing would be equally desirable. For example, if tax financing is used which taxes would be preferable? And is tax-financing preferable to debt-financing? Or, how would the use of public-private partnerships affect the outcome? Fourth, the literature on less developed countries is very limited. That may in itself be explained by the paucity of local infrastructures and the fact that it is difficult to identify the effects of infrastructures before a certain threshold of network effects is in place.

In a different vein, we see the literature with a regional focus gain momentum. Differences in the direct regional and aggregate effect and the relevance of regional spillover effects, suggests interesting avenues for analysis. Understanding the contribution of public investment to the concentration of economic activity and identifying the regions that benefit disproportionately from public infrastructures raises the intriguing possibility that these benefits may in some way be linked to the ability of these regions to capture, in a disproportionate manner, the spillover effects of public investment. Furthermore, once the importance of regional spillover effects has been established, a fundamental question arises with respect to the optimal location of public investment projects. Because public infrastructures in a given region have a positive impact on economic performance in other regions, identifying the locations which generate the greatest overall effects becomes of crucial importance. In addition, a more intense and systematic industry-specific analysis is long overdue. The potential diversity of effects on infrastructure investment across industries raises the question of the effects of such investments in the economic fabric of a country. Additionally, public infrastructure investment must be recognized as a critical component of industrial policy as much as industry-specific tax incentives and subsidies are. This policy argument can be extended to relate inter-industry differences in effective corporate income taxes and the benefits captured by each industry from public investment infrastructure.

Although overall the literature shows little consensus in terms of the empirical evidence, a clear consensus has emerged with respect to several methodological aspects. Indeed, the importance of considering the indirect effect of infrastructures on output through its effects on private inputs, as well as the importance of accounting for simultaneity, is now widely recognized. Furthermore, the importance of addressing issues of causality between public capital and private sector variables as well as other dynamic feedbacks is also widely recognized. These considerations, in fact, explain the almost universal use in the recent literature of VAR techniques. In this vein, we believe that the most promising avenues of research, in terms of methodological issues associated with estimating the economic impact of public infrastructure investment, reside in furthering the simultaneous and dynamic nature of the analysis. This could assume the form of panel VAR techniques to obviate the scarcity of date at the regional or industry-level or to highlight international comparison of the effects of infrastructure investment. In addition, research with a more structural bent using a dynamic behavioral approach to investment would bring the analysis closer to standard economic theory. In this respect, it may be worth mentioning that we see a great part of the body of literature surveyed here, in particular at the more aggregate level, fast linking with the macroeconomic literature on the effects of fiscal policies and monetary policies which has long relied on a VAR and dynamic behavioral approaches.

# APPENDIX

**Table A1.** Studies at Aggregate Level

| Author (Year) | Data | Public Capital Measure | Model Specification | Conclusions |
|---|---|---|---|---|
| Production Function Approach | | | | |
| Aaron (1990) | U. S.; T.S. 1951-1985 | Public capital stock | C-D; log and Δlog | Positive effects of public capital on output. Elasticities from 0.09 to 0.27. Results are not robust. |
| Abdih and Joutz (2008) | U.S.; T.S. 1984-2004 | Public capital stock | C-D; Δlog; cointegration | There is a positive and significant long run effect of public capital, skill-adjusted labor, and technology/ knowledge on private sector output, with estimated long run elasticities of 0.39, 0.61, and 0.13 respectively. |
| Albala-Bertrand and Mamatzakis (2004) | Chile; T.S. 1960-1998 | Infrastructure capital stock | Translog | Infrastructure capital growth seems to reduce productivity slightly up to 1971. From 1972 onwards, the reverse seems to be true. |
| Arslanalp *et al.* (2010) | 48 OECD and non-OECD countries; T.S. 1960-2001 | Public capital stock | C-D; Δlog | Positive -but concave- elasticity of output with respect to public capital. In non-OECD countries the growth impact of public capital is higher once longer time intervals are considered. |
| Aschauer (1989a) | U. S.; T.S. 1949-1985 | Public capital stock; core infrastructures | C-D; log | Positive effects of public capital on output. Elasticity of output with respect to total public capital is 0.39. The elasticity of output with respect to core infrastructure is 0.24. |
| Aschauer (1989c) | G-7 countries; P.D. 1966-1985 | Public capital stock | C-D; Δlog | Positive effects of public capital on output. Elasticities between 0.34 and 0.73. |
| Aschauer (1995) | 12 OECD countries; P.D. 1960-1988 | Ford and Poret (1991) | TFP growth | Positive effects of public capital on output. Elasticities between 0.33 and 0.55. |
| Bajo and Sosvilla (1993) | Spain; T.S. 1964-1988 | Public capital stock | C-D; log | Positive effects of public capital on output. Elasticity is 0.18. Public capital is exogenous. |

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|---|---|---|---|---|
| Batina (1999) | U.S.; T.S. 1948-1993 | State public capital | C-D; log | The productivity of public capital depends on the proxies used for private and public capital. |
| Calderón and Servén (2003) | 101 countries; PD 1960-1997 | Infrastructure capital stock | C-D; Δlog | Positive effects of public capital on output. Elasticity is 0.16. |
| Canning (1999) | 57 countries; PD 1960-1990 | Telephones, electricity, roads and railways | C-D; Δlog | Electricity and transportation routes have normal capital rate of return; telephone above normal. |
| Canning and Pedroni (1999) | Set of countries; P.D. 1950-1992 | Canning (1999) | Dynamic error-correction model | Evidence of long-run effects running from infrastructure to growth. Telephones and paved roads are provided at the growth maximizing level on average, but are under supplied in some countries and over supplied in others. Evidence that electricity generating capacity is under provided on average. |
| Canning and Bennathan (2000) | 62 countries; PD 1960-1990 | Canning (1999) | C-D and translog | On average, only the low-and middle-income countries benefit from more infrastructures. Specific types of infrastructure complement physical and human capital in supporting output per worker. Elasticity of output with respect to public capital varies from 0.04 to 0.144. |
| Duggal *et al*. (1999) | U.S.; T.S. 1960-1989 | Public capital stock | C-D; log | Positive effects of public capital on output. Elasticity is 0.27. |
| Eisner (1994) | U. S.; T.S. 1961-1991 | Public capital stock | C-D; log | Positive effects of public capital on output. |
| Evans and Karras (1994) | 7 OECD countries; P.D. 1963-1988 | Public capital stock | C-D; Δlog | Insignificant effects of public capital on output. |
| Everaert and Heylen (2004) | 43 Belgian regions; P.D. 1965-1996 | Public investment | Translog; general equilibrium model | Elasticity is 0.31. Strong positive effects of public capital on private output and capital formation. Public capital and private employment are found to be substitutes. Negative effect of public capital on employment. |

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|---|---|---|---|---|
| Fernald (1999) | U.S.; T.S. 1953-1989 | Stock of roads and highways | TFP growth | Significant. Explains half of the observed decline in productivity growth. Roads contribute about 1.4 percent per year to growth before 1973 and about 0.4 percent after 1973. |
| Finn (1993) | U. S.; T.S. 1950-1989 | Highways | C-D; Δlog | Positive effects of public capital on output. Elasticity is 0.16. |
| Ford and Poret (1991) | 11 OECD countries; T.S. 1960-1989 | Narrow and broad definitions | C-D; Δlog | Significant positive effects in Belgium, Canada, Sweden and Germany. For the U.S. positive effects of public capital on output. Elasticities are 0.29 (Narrow) and 0.33 (broad). |
| Harmatuck (1996) | U. S.; T.S. 1949-1985 | Highways | Transfer function; Δlog | Insignificant effects of public capital on output. Elasticity is 0.03. |
| Hulten and Schwab (1991b) | U. S.; T.S. 1949-1985 | Public capital stock | C-D; log and Δlog | Insignificant effects of public capital on output. Elasticity is 0.03. Results not robust. |
| Kamps (2005) | 22 OECD countries; T.S. and P.D. 1960-2001 | Public capital stock | C-D; log and Δlog | Positive effects of public capital on output. Elasticity is 0.22 in panel data model and higher in Time series model. |
| Kavanagh (1997) | Ireland; T.S. 1958-1990 | Public capital stock | C-D; log | Insignificant effects of public capital on output. |
| Ligthart (2002) | Portugal; T.S. 1965-1995 | Public capital stock | C-D; Δlog | Positive effects of public capital on output. Roads, railways and airports are more productive. |
| Munnell (1990) | 7 OECD countries; P.D. 1963-1988 | Public investment | C-D; log | Positive effects of public capital on output. Elasticity of output with respect to total public capital is 0.31 and Elasticity of output with respect to core infrastructures is 0.49. |
| Neusser (1993) | G-7 countries; PD 1963-1988 | Ford and Poret (1991) | TFP growth | Unstable and unreliable results. |

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|---|---|---|---|---|
| Nourzad and Vriese (1995) | U. S.; T.S. 1949-1987 | Public capital stock; core infrastructures | C-D; log | Positive effects of public capital on output. Elasticities between 0.31 and 0.39. |
| Otto and Voss (1994) | Australia; T.S. 1966-1990 | Construction and equipment | C-D; log | Elasticities from 0.38 to 0.45 (poor results at sectoral level). |
| Sturm and De Haan (1995) | U. S.; T.S. 1949-1985 | Public capital stock | C-D; log and Δlog | Positive but insignificant effects using time differences. |
| Sahoo *et al.* (2012) | China; T.S. 1975-2007 | Composite index of major infrastructure indicators | CD; Δlog | positive contribution to growth |
| Sturm and de Haan (1995) | Netherlands; T.S. 1960-1990 | Public capital stock, buildings, and core infrastructure. | C-D; log and Δlog | Estimates are fragile. Elasticities are 1.15, 0.98 and 0.80. No evidence of cointegration. |
| Tatom (1991) | U. S.; T.S. 1949-1989 | Public capital stock | C-D; Δlog | Insignificant effects of public capital on output. Elasticity is 0.04. |
| Vijverberg *et al.* (1997) | U. S.; T. S. 1958-1989 | Net stock of non-military equipment | C-D and semi-Translog | Results not conclusive due to multicollinearity problems. |
| Wang (2004) | Canada; T. S. 1961 - 2000 | Human capital, debt charges, social services, protection infrastructure | Private investment equation; Δlog | Expenditures on education affect positively private investment. |
| Wylie (1996) | Canada; T.S. 1946-1991 | Infrastructure capital stock | C-D; Translog; log | Positive effects of public capital on output. Elasticities: 0.11-0.52 |
| Behavioral Approach | | | | |
| Berndt and Hansson (1992) | Sweden and U.S.; T.S. 1960-1988 | Core infrastructure | Cost: Generalized Leontief; levels. | Reduction in costs; excess of infrastructures; public capital and labor are complements. |
| Dalamagas (1995) | Greece; T. S. 1950-1992 | Total public investment Infrastructure | Cost and profit: Translog | Cost: -2.35; Profit: 1.06. Increase in public capital reduces costs and increases profits. Public capital and private inputs are substitutes. |
| Demetriades and Mamuneas (2000) | 12 OECD countries; P.D. 1972-1991 | Public capital stock | Cost: Quadratic function | Increases in public capital reduce costs. Elasticity varies from 0.36 in the UK to 2.06 in Norway. |

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| Lynde (1992) | U. S.; T.S. 1958-1988 Non-financial corporate sector | Total; federal; state and local public capital stock | Profit; C-D; log | Elasticity of profit with respect to public capital is 1.2. Significant share of profits is attributable to state and local public capital. |
| Lynde and Richmond (1991) | U. S.; T.S. 1958-1989 Non-financial corporate sector | Total; federal; state and local public capital stock | Cost: Translog; log. | Cost savings. Public capital has positive marginal product. Public capital and private capital are complements. Public capital and labor are substitutes. 40% of the productivity decline can be explained by a fall of the public capital-labor ratio. |
| Lynde and Richmond (1993a) | U. S.; T.S. 1958-1989 | Dwellings | Profit: Translog; Δlog | Output elasticity is 0.20; 40% of productivity slowdown is explained by the slowdown of public capital. |
| Vijverberg *et al.* (1997) | U. S.; T.S. 1958-1989 | Federal, state and local public capital stock | Cost and profit: Translog; log | Cost reduction elasticities of -1.22 (Federal) and -0.14 (State and local). Multicollinearity problems. |
| VAR Approach | | | | |
| Agénor *et al.* (2005) | Egypt, Jordan, Tunisia; T.S. 1965-2002 | Public capital stock | VAR; log | There is a weak effect, short-lived and usually insignificant effect of public capital on private capital. |
| Ai and Cassou (1995) | U. S.; T.S. 1947-1989 | Public capital stock | VAR; Δlog | Positive effects of public capital on output. Elasticity between 0.15 and 0.20. |
| Batina (1998) | U. S.; T.S. 1948-1993 | Public capital stock | VAR and VECM | Positive effects of public capital on output and vice versa. |
| Belloc and Vertova (2006) | 7 countries; T.S. 1970-1999 | Public investment | VECM | In 6 of the 7 cases there is a positive effect of public investment on output. |
| Clarida (1993) | U.S., France, Germany, U.K.; T.S. 1949-1989 | Public capital stock | VECM | Total productivity factor and public capital are cointegrated but the direction of causality in not clear. |
| Crowder and Himarios (1997) | U. S.; T.S. 1947-1989 | Public capital stock | VECM | Public capital is at the margin slightly more productive than or as productive as private capital. |
| Cullison (1993) | U. S.; T.S. 1961-1991 | Public capital stock | VAR; Δlog | Strong effects of investments in education. |

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| Flores *et al.* (1998) | Spain; T.S. 1964-1992 | Transport and communications | VARMA; Δlog | Existence of a cointegration vector. Positive effects on output, private capital and employment.The long run output elasticity with respect to public capital is 0.21. |
| Ghali (1998) | Tunisia; T.S. 1963-1993 | Public capital stock | VECM | Public investment has negative effects on growth. |
| Kamps (2005) | 22 OECD countries; T.S. 1960-2001 | Public capital stock | VECM | Positive effects on growth in most countries. |
| Lau and Sin (1997) | U. S.; T.S. 1925-1989 | Public capital stock | VECM | Elasticity is 0.11, smaller than typical values obtained in single-equation studies. If the share of capital income is taken to be one-third, the spillover effect due to private capital is positive but may be as low as 0.10. |
| Ligthart (2002) | Portugal; T.S 1965-1995 | Public capital stock | VAR; log | Positive output effects of public capital on output. Elasticity from 0.20 to 0.35 |
| Mamatzakis (1999) | Greece; T.S. 1959-1993 | Public capital stock | VECM | Positive effect on productivity. No reverse causality. |
| Mamatzakis (2002) | Greece; T.S. 1959-1997 | Public capital stock (core infrastructures) | VECM | Elasticity of 0.14. Positive effects of public capital on the industrial sector. |
| McMillin and Smyth (1994) | U. S.; T.S. 1952-1990 | Total, state and local public capital stock | VAR; log and Δlog | No significant effects of public capital. |
| Mittnik and Newman (2001) | 6 countries; different sizes | Public investment | VECM | Weak positive effects of infrastructure; public investment induces private investment; no reverse causation. |
| Otto and Voss. (1996) | Australia; T.S. 1959iii-1992ii | Construction and equipment | VAR; Δlog | Existence of a cointegration vector. The long run output elasticity with respect to public capital is 0.17. The public capital seems to be exogenous. |
| Otto and Voss (2002) | U.S.; T.S. 1951-1997 Canada; T.S. 1951-1996 | Construction and equipment | VAR; Δlog | For both countries there is no evidence of crowding in due to complementarities between public and private investment. Innovations to public investment tend to crowd out private investment. |

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| Pereira (2000) | U. S.; T.S. 1956-1997 | Public investment (different types) | VAR; Δlog | All types affect positively private output. Crowding in effects on private investment. |
| Pereira (2001a) | U. S.; T.S. 34 obs. | Core infrastructures | VAR; Δlog | Positive effects of public capital on output. Elasticity is 0.257 |
| Pereira (2001b) | 11 countries; T.S. 1960-1990 | Core infrastructure | VAR; Δlog | Elasticities from 0.021 to 0.257. Positive and statistically significant short-run effects. |
| Pereira and Andraz (2004) | U.S.; T.S. 1956-1997 | Highways | VAR; Δlog | Only about 20% of the aggregate effects of public investment in highways in the US are captured by the direct effects on each state output of public investment in the state itself. The remaining 80% correspond to the spillover effects from public investment in highways in other states |
| Pereira and Andraz (2005) | Portugal; T.S. 1976-1998 | Transportation | VAR; Δlog | Public investment positively affects private investment, employment and output. |
| Pereira and Flores de Frutos (1999) | U. S.; T.S. 1956-1989 | Public capital stock | VAR; Δlog | Public capital is productive but less than suggested by Aschauer (1989). |
| Pereira and Roca-Sagales (1999) | Spain; T.S. 1970-1989; national and regional | Infrastructure capital (transport and communications) | VAR; Δlog | Positive and significant long-run effects on output, employment and private capital. |
| Pereira and Roca-Sagales (2001) | Spain; T.S. 1970-1993; national and sectoral | Infrastructure capital (transport and communications) | VAR; Δlog | Positive and significant long-run effects on output, employment and private capital. |
| Pereira and Roca-Sagales (2003) | Spain; T.S. 1970-1995 national and regional | Infrastructure capital (transport and communications) | VAR; Δlog | Positive and significant long-run effects on output, employment and private capital. |
| Pina and St. Aubyn (2005) | Portugal.; T.S. 1960-2001 | Public capital stock | VAR; Δlog | Inexistence of feedback effects. The rates of return on public investment are higher than on private investment. |
| Pina and St. Aubyn (2006) | U.S.; T.S. 1956-2001 | Public capital stock | VAR; Δlog | Taking crowding out on private investment into account lowers rate of return of public investment. |

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|---|---|---|---|---|
| Sturm *et al.* (1999) | Netherlands; T.S. 1853-1913 | Public investment | VAR; log | Positive and significant short run effect. No long run effects. |
| Voss (2002) | U.S. and Canada; different sizes (Q) | Public investment | VAR; Δlog | Public investment crowds out private investment. |

*Notes*: T.S.: Time series; P.D.: Panel data; C.S.: Cross-Section; C-D: Cobb-Douglas; TFP: Total Factor Productivity; VAR: Vector Autoregressive; VECM: Vector Error Correction Model; VARMA: Vector Autoregressive Moving Average.

**Table A2.** Studies at the Regional Level

| Author (Year) | Data | Public Capital Measure | Model Specification | Conclusions |
|---|---|---|---|---|
| Production Function Approach | | | | |
| Andrews and Swanson (1995) | U. S.; 48 states; P.D. 1970-1986 | Public capital stock | Translog; log; state specific effects | Insignificant effects of public capital on output. Elasticity is 0.04 |
| Aschauer (1990) | U. S.; 50 states; C.S. 1965-1983 | Core infrastructures | C-D; log | Elasticity of output with respect to public capital varies from 0.055 to 0.11 |
| Baltagi and Pinnoi (1995) | U.S., 48 states; PD 1970-1986; | Public capital stock from Munnell (1993) | C-D, fixed and random state effects. | Effects of highways on output are not significant. Effects of water and sewer are significant. |
| Boarnet (1998) | California; counties; P.D. 1969-1988 | Streets and highways | C-D; Δlog | Evidence of negative spillovers. |
| Canning (1999) | Cointegrated panel ; 57 countries; 1960-1990 | Infrastructure capital stock | C-D; log | The productivity of physical and human capital is close to the levels suggested by microeconomic evidence on their private returns. 2) Electricity generating capacity and transportation networks have roughly the same marginal productivity as capital as a whole. |
| Cadot *et al.* (1999) | France; 21 regions; P.D. 1985-1991 | Transportation | Simultaneous equation approach | Elasticity is 0.10 |

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|---|---|---|---|---|
| Carlino and Voith (1992) | U.S.; 48 states; P.D. 1963-1991 | Highway density, educational attainment | CES; fixed and random effects | Elasticity from 0.22 to 1.00 for highways, education (significant) |
| Cutanda and Parício (1992) | Spain; 17 regions; C.S. 1980-1989 | Productive and social capital | Linear equation | Elasticity of output with respect to productive capital is 0.297 Elasticity of output with respect to social capital is 0.118. |
| De La Fuente and Vives (1995) | Spain; 17 regions; P.D. 1981, 1986, 1990 | Transportation infrastructure, education | C-D; translog; time effects | Elasticity of output with respect to public capital is 0.21. |
| Duffy-Deno and Eberts (1991) | U.S.; 28 metropolitan areas; P.D. 1980-1984 | Public capital stock | Model of the effects of public infrastructure on personal income | Public investment and public capital stock have a positive and statistically significant effect on per capita personal income. |
| Eberts (1990) | U. S.; 36 SMSAs; P.D. 1965-1977 | Public capital stock | TFP equation; log | Positive and statistically effects on TFP. |
| Eisner (1991) | U.S.; 48 states; P.C.S. 1970-1986 P.T.S. 1970-1986 | Public capital stock Highways and roads Water and sewers Other | C-D; translog; log; Δlog | Insignificant effects of public capital on output. |
| Evans and Karras (1994) | U.S.; 48 states; P.D. 1970-1986 | Public capital stock Education | C-D; translog; log; Δlog | Elasticity of output with respect to total public capital is -0.19. Elasticity of output with respect to education is 0.04 (not significant). |
| Garcia-Milà and McGuire (1992) | U. S.; 48 states; P.D. 1969-1983 | Highway capital and Education expenditure | C-D; log; time effects | Elasticities are 0.045 (Highways – not significant) and 0.165 (Education - significant) |
| Garcia-Mila *et al.* (1996) | U. S.; 48 states; P.D. 1970-1983 | Highways, water and sewers, and other | C-D; fixed and random state effects; Δlog | Insignificant effects of public capital on output (effects from -0.058 to -0.022). |
| Hofmann (1995) | Germany; Hamburg; T.S. 1970-1992 | Transportation infrastructure | C-D; Δlog; error correction model. | Not significant or implausible results. |
| Holtz-Eakin (1994) | U.S.; 48 states and 9 regions; P.D. 1969-1986 | Revised public capital stock from Munnell (1993) | C-D; fixed and random state effects; time effects; IV estimation. | Insignificant effects of public capital on output. Elasticity is -0.022. |

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|---|---|---|---|---|
| Holtz-Eakin and Schwartz (1995) | U.S.; 48 states; P.D. 1971-1986 | Infrastructure capital and public capital stock | C-D; Δlog | Infrastructure has negligible effects on output. |
| Hulten and Schwab (1991a) | U.S.; 9 regions; T.S. 1949-1985 | Public capital stock from Munnell (1993) | TFP growth; time effects. | Insignificant effects of public capital on output. |
| Kelejian and Robinson (1997) | U.S.; 48 states; P.D. 1970-1986 | Public capital stock from Munnell (1993) | C-D; spatial correlation; | Insignificant effects of public capital on output. |
| Kemmerling and Stephan(2002) | Germany; 87 cities; C.S. 1980, 1986, 1988 | Infrastructure public Capital | Simultaneous-equation approach C-D | Public capital is a significant factor in private production. Simultaneity between output and public capital is weak; thus, feedback effects from output to infrastructure are negligible. |
| Mas *et al*. (1996) | Spain; 17 regions; P.D. 1980-1999 | Productive capital Social capital | C-D; log | Elasticity of output with respect to public capital is 0.24.. Insignificant effects of social capital. |
| Merriman (1990) | Japan; 9 regions; P.D. 1954-1963 | Public capital stock from Costa *et al*. (1987) | Translog; fixed effects; SUR estimation. | Elasticities from 0.46 to 0.58; Public capital and private capital are substitutes; Public capital and labour are complements. |
| Merriman (1990) | U.S; 48 states; C.S. 1972 | Public capital stock from Costa *et al*. (1987) | Translog; fixed effects; SUR estimation. | Elasticity is 0.20; Public capital and private capital are substitutes; Public capital and labour are complements. |
| Moomaw and Williams (1991) | U.S; 48 states; P.D. 1959-1976 | Transportation Education | TFP growth; Δlog | Positive effects of public investment on output. Elasticity is 0.17. |
| Moomaw *et al*. (1995) | U.S.; 48 states; P.D. 1970, 1980, 1986 | Public capital stock from Munnell (1993) | Translog. | Elasticities from 0.007 to 0.26 (Total public capital), from 0.001 to 0.027 (Highways), from 0.0003 to 0.3045 (water and sewers) and negative (other). |
| Munnell (1993) | U. S.; 48 states; P.D. 1970-1986; different industries | Highways; Water and sewer systems; Other types. | C-D; Translog | Elasticity from 0.14 to 0.17. Public capital and private capital substitutes. |

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|---|---|---|---|---|
| Munnell with Cook (1990) | U. S.; 48 states and 4 regions P.C.S. 1970-1986 | Public capital stock Highways, Water and sewers, Other | C-D; log. | Significant positive effects of highways and water and sewers on output. Public capital and labor are complements. Public capital and private capital are substitutes. |
| Picci (1999) | Italy; 20 regions; P.D. 1970-1991 | Public capital stock | C-D; fixed and random effects; Δlog | Elasticities between 0.08 and 0.43; Significant short-run effects, but long-run effects are not significant. |
| Pinnoi (1994) | U. S.; 48 states, 4 industries; P.D. 1970-1986 | Public capital stock from Munnell (1990) | Translog; fixed and random effects; log | Elasticities of output with respect to public capital vary from -0.11 to 0.08. |
| Prud'Homme (1996) | France; 21 regions; P.D. 1970-1990 | Transportation infrastructure | C-D; TFP growth. | Elasticity is 0.08. |
| Seung and Kraybill (2001) | U.S.; Ohio; calibrated on 1990 | Total public capital | C-D; general equilibrium model | Welfare effects of infrastructure are nonlinear. |
| Shioji (2001) | US; States; P.D. 1963-1993 Japan; regions; P.D 1955-1995 (5 year interval) | Public capital stock | C-D; Computable general equilibrium model | Elasticity between 0.10 and 0.15. |
| Stephan (2000) | West German and French regions; different sizes | Infrastructure capital stock | C-D; Translog | Elasticity of output with respect to public capital is 0.11. Translog specification runs into multicolinearity problems. |
| Stephan (2003) | West Germany; 11 regions; P.D. 1970-1996 | Infrastructure capital stock (transportation and communications) | C-D; log and Δlog | Elasticities between 0.38 (first differences) and 0.65 (log levels). |
| Behavioral Approach | | | | |
| Boscá *et al.* (2000) | Spain; regions; P.D. 1980-1993 | Infrastructure capital stock (transportation, communication) | Cost: Generalized Leontief | Elasticity is 0.08. |

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|---|---|---|---|---|
| Cohen and Paul (2004) | U.S.; 48 states; P.D. 1982-1996 | Highways | Cost: Generalized Leontief | Infrastructure investment reduces own costs and increases cost reduction effects of adjacent states. |
| Moreno *et al.* (2003) | Spain; regions P.D. 1980-1991 | Transportation and communication | Cost: Translog | Public and private investments increase efficiency. Public capital and labor are complements. Private and public capital are substitutes. |
| Morrison and Schwartz (1996a) | U. S.; 48 states; P.D. 1970-1987 | Motorways, water and sewers | Cost: Generalized Leontief; log. | Cost elasticities of public capital: 0.07-0.17. Public capital has been below the social optimum. |
| Morrison and Schwartz (1996b) | U. S.; 6 states; P.D. 1970-1987 | Motorways, Water and sewers | Cost: Generalized Leontief; log | Cost reduction is decreasing over time. Private and public capital are complements. Private capital is more valuable for society than public capital. Public investment is warranted if public policy is ineffective at increasing private investment. |
| VAR Approach | | | | |
| Everaert (2003) | Belgium; regions; T.S. 1953-1996 | Public capital stock | VECM | Elasticity of output with respect to public capital is 0.14 (lower than elasticity with respect to private capital). |
| Pereira and Andraz (2003) | U. S.; 48 states; T.S. 1977-1999 | Highways | VAR; Δlog | Spillovers correspond to 80% of the total effects |
| Pereira and Andraz (2006) | Portugal; 5 regions; T.S. 1980-1998 | Transportation | VAR; Δlog | Effects unevenly distributed |
| Pereira and Andraz (2010) | Portugal; 5 regions; T.S. 1977-1998 | Road infrastructure | VAR; Δlog | Road infrastructure investments promote long-term growth in all regions. It generates fiscal effects that largely exceed the initial investment itself and the authors concluded that there is no trade-off in the long-term between the potentially positive economic effects and the potentially negative budgetary effects of such investments. |

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| Pereira and Andraz (2012a) | Portugal; 5 regions; T.S. 1980-2003 | Railroads | VAR | Railroad investment crowds in private investment and employment and has strong effects on output. Regional spillovers. |
| Pereira and Andraz (2012b) | Portugal; 5 regions; T.S. 1980-1998 | Road infrastructure | VAR; Δlog | Investments in SCUTS have positive economic effects in all regions of the country. Regional spillovers account for about three-quarters of the total effects of these investments. For all SCUTS, the equilibrium tax rate, i.e., the rate that would balance the tax revenues induced by these highways and the shadow tolls the government has to pay, is lower than the effective tax rate for the economy. |
| Pereira and Andraz (2012c) | U.S.; 48 states; T.S. 1977-1999 | Highways | VAR; Δlog | Investment in highways affects private sector variables positively. The regional spillover effects are very significant for all private sector variables and they tend to be more important in western states and the corridor between the Great Lakes and the Gulf Coast. |
| Pereira and Roca (1999) | Spain; 17 regions; T.S. 1970-1989 | Transports and communications | VAR; Δlog | Elasticities from -0.31 to 1.07 |
| Pereira and Roca (2003, 2007) | Spain; 17 regions; T.S. 1970-1995 | Transports and communications | VAR; Δlog | Spillovers represent 50% of the total effects |

*Notes*: P.C.S.: Pooled Cross-section; P.T.S.: Pooled Time-series; SUR: Seemingly Unrelated Regression. For other abbreviations see note in Table A1.

**Table A3.** Studies at the Industy Level

| Author (Year) | Data | Public Capital Measure | Model Specification | Conclusions |
|---|---|---|---|---|
| **Production Function Approach** | | | | |
| Evans and Karras (1993) | 7 countries; P.D. 1963-1988 Manufacturing | Public capital stock | C-D; Δlog; time and country effects. | Estimates are fragile and not significant. |
| Fernald (1993) | U.S.; P.D. 1953-1985 34 individual sectors | Roads, highways | C-D; Δlog. | Annual rate of return of public investment from 60% to 140%. |
| Fernald (1999) | U.S; P.D. 1953-1989 29 sectors | Roads | Sectoral productivity growth | Roads contribute 1.4% per year to growth before 1973, specially in vehicle-intensive industries, and 0.4% thereafter. |
| Greenstein and Spillar (1995) | U.S.; P.D. 1986- 1992 Fire, insurance & real estate, manufacturing | Telecommunications | Linear equation; log. | Elasticities of output with respect to public capital are 0.10 in fire, insurance & real estate, and -0.02 in manufacturing. |
| Pinnoi (1992) | U.S.; C.S. 1972 Private industry, manufacturing, agricultural, other | State and local public capital (disaggregation into highways, water and sewers and other) | Translog; log. | Elasticities of output with respect to public capital are -0.11 in private industry, 0.08 in manufacturing, –0.10 in agriculture, and 0.003 in other industries. |
| **Behavioral Approach** | | | | |
| Conrad and Seitz (1992) | W. Germany; P.D. 1961-1988 4 sectors | Core infrastructure | Cost: Translog | Cost elasticities of -0.07 to 0.27. Increases in public capital reduce costs. Inexistence of productivity spillovers. |
| Conrad and Seitz (1994) | W. Germany; P.D. 1961-1988 Manufacturing, trade, transport and construction | Core infrastructure | Cost: Translog; log. | Cost savings from -0.056 to -0.031. Public capital in short supply during 1961-79 and in excess supply during 1980-88. Slowdown in public capital partially responsible for productivity slowdown. |

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|---|---|---|---|---|
| Holleyman (1996) | U. S.; P.D. 1969-1986 Manufacturing industries | Highways | Cost: Translog; log. | Cost elasticities from -0.07 to 0.09. |
| Lynde and Richmond (1993b) | U.K.; T.S. 1966-1990 Manufacturing | Dwellings | Cost: Translog; log. | Output elasticity is 0.20. Higher public capital in the 80s could have increased labor productivity growth by 0.5% per year. |
| Mamatzakis (1999) | Greece; P.D. 1959-1990 20 industries | Core infrastructure | Cost: Translog; log | Cost elasticity ranges from 0.02% in food manufacturing to 0.78% in wood manufacturing. |
| Nadiri and Mamuneas (1994) | U. S.; P.D. 1956-1986 Manufacturing industries | Public capital stock and R&D | Cost: Generalized C-D; log. | Cost elasticities are -0.11 for public capital and -0.21 for R&D capital stock.<br>Public capital and private inputs are substitutes. R&D and private capital are substitutes. R&D and labor are complements. R&D and private capital have higher rates of return than public capital. |
| Nadiri and Mamuneas (1996) | U. S.; P.D. 1947-1989 Manufacturing industries | Highway capital | Cost: Symmetric Generalized MacFadden. | Significant positive effects. |
| Seitz (1993) | W. Germany; P.D. 1970-1989 Manufacturing | Roads (monetary) and motorways (physical) | Cost: Generalized Leontief; log. | Shadow values are significant for 22 sectors. Complementary relationship between private capital and public capital is negligible. |
| Seitz (1994) | W. Germany; P.D. 1970-1989 Manufacturing | Public capital stock Core Infrastructures | Cost: Generalized Leontief; log. | Public investment has a stabilizing but decreasing impact on private imputs demand. Public capital and private capital are complements. Public capital and labor are substitutes. |
| Seitz (1995) | W. Germany; P.D. 1980-1989 Manufacturing | Public capital stock | Cost: Generalized Translog; log | Cost savings: -0.127. |

| | | | | |
|---|---|---|---|---|
| Seitz and Licht (1995) | W. Germany; P.D. 1970-1988 Manufacturing | Public capital stock | Cost: Translog; log | Cost savings: -0.216. Distinction between private stock of buildings and private stock of machinery is crucial. The former is more affected by public capital than the latter. |
| Shah (1992) | Mexico; P.D. 1970-1987 Manufacturing | Core infrastructures | Cost: Translog; log | Cost elasticity between -0.915 and -0.866. Public and private capital are substitutes in the short-run and complements in the long-run. Public capital and labor are complements in the short-run and substitutes in the long run. |
| VAR Approach | | | | |
| Pereira and Andraz (2003) | United States; T.S. 1956-1997 12 sectors | Total public capital | VAR; Δlog | Different effects among industries. |
| Pereira and Andraz (2007) | Portugal; T.S. 1956-1997 18 sectors | Transportation | VAR; Δlog | Different effects among industries. |
| Pereira and Roca-Sagales (1998) | Spain; T.S. 1970-1991 4 sectors | Transportation | VAR; log | Positive and significant long term effects on output, labor and private capital. |
| Pereira and Roca-Sagales (2001) | Spain; T.S. 1970-1993 4 sectors | Transportation and communications | VAR; Δlog | Positive and significant long term effects on output, labor and private capital. |

*Note*: See Table A1.

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