Infrastructures and economic performance: a critical comparison across four approaches

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November 2009

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Abstract. The paper reviews studies analysing the relationship between infrastructures and economic performance. Four different approaches are separately considered along an ideal path from theory-based to data-oriented models: the production function approach, the cost function approach, growth-models, and vector autoregression models. The review shows that, even with different shades and points of caution, the general idea that infrastructure has an economic enhancing effect appears to be quite robust across studies belonging to different methodological approaches.

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1. Introduction

The link between infrastructure and economic performance has been widely explored in literature utilising many different theoretical approaches and achieving also variegate results and implications for policy-makers.

To begin with, there are theoretical arguments developed in order to sustain thesis based on infrastructures' contribution to productivity considering them as initiating factor.

The first approach to address this issue consisted in considering (public) infrastructures as a free input provided by government (Aschauer, 1989). This input, like all other inputs, contributes to the productive process; yet, it has the peculiar characteristic of being a *public good* in the proper economic sense, so that, once produced represents a structural input common to all firms' production function.

From a different angle, infrastructures rather than be considered directly as inputs, could be considered as cost-saving factors.

The underlying idea is that infrastructures, providing a more favourable setting for the development of economic activity, indirectly (and positively) affect the productive process by reducing or allowing to combine more efficiently other factors (e.g. labour and capital).

Thus, according to this approach, infrastructures' effects have to be analysed *via* the cost function, and the expected result is in favour to a reduction of production costs.

Put differently, a territory well endowed with infrastructures increase productivity because it provides firms with a more favourable cost structure and making accessible more efficient combinations of inputs.

A more general approach consists in considering infrastructures as components of capital as a whole and, in turn, capital formation is considered as the key factor to the growth process.

According to this approach capital has to be intended in a broader sense comprising its traditional meaning (physical capital), intangible "human capital", "knowledge capital", and just infrastructures.

Therefore, infrastructures contributing to capital formation, belong to the key endogenous features explaining differences in the economic performance.

Although the massive body of literature developed in this field, there are still points of criticism and debate involving many aspects (e.g. infrastructure definition and measurement, productive and unproductive infrastructures, causality direction and magnitude of their impact, short-run and long-run temporal dimension of their impact).

Inside this puzzle of counter-arguments the strongest point of criticism, considering infrastructures a *normal good*, extremes the discourse to completely deny the effects of infrastructures on productivity.

On this approach's view the empirical evidence of a positive relationship between infrastructures and productivity has to be read in the sense that the former are just *accommodating factors* which demand increases as the economic system increases its activity.

Hence, in order to deal with the issue free from a preconceived idea, data-oriented approach has been also adopted to analyse the relationships between infrastructures and measures of economic performance.

Models belonging to this approach are often labelled as Vector Autoregressive models (VAR); the peculiar feature of these models consists in explaining a limited numbers of variables (including infrastructures) by their own lags and lags of other variables without imposing no a priori causality among them.

Across studies, generally speaking, the existence of a positive impact going from infrastructure to productivity is confirmed, but the empirical evidence is really composite.

However, analysis's outcome depends both on the empirical setting and on methodology. Moving from this consideration, this paper reviews the four approaches mentioned above following an ideal path from the first-generation partial approaches based on production and cost function(s) to the general VAR approach aiming at emphasize the underlying idea characterising each one.

The structure of the paper is as follows. It starts with reviewing, in section 2, studies utilising the production function approach; section 3 reviews studies adopting the cost function approach; section 4 presents studies implementing growth-models, and section 5 deals with vector autoregression models. Section 6 presents some concluding remarks.

2. The production-function approach

The production function approach models the amount of output that can be produced for each factor of production, given technological constraints.

The seminal work using this approach to measure the economic impact of infrastructure goes back to Aschauer (1989) that introduced government expenditure intended as a public good into the production function.

Studies following this approach share the same underlying idea that public capital can be considered as an additional *input factor* having the characteristic of a public good in the proper economic sense (i.e. being *not rival* and *not excludable*).

A general form of production function utilised across studies is

$$Y = f(A, L, K, G) \tag{1}$$

Where the variable introduced above are defined as follows:

- Y is the level f economic output
- A is the “technological progress”
- K is the stock of private capital
- L is the stock of labour
- G represents a measure of public capital.

Clearly, in order to quantify the impact of various input on output we need a specific functional form. In other words, we need to explain what f “means”.

Usually, an aggregate Cobb-Douglas production function is utilised in empirical works:

$$Y = AL^{\alpha} K^{\beta} G^{\gamma} \tag{2}$$

The most common econometric method to estimate the parameters α, β, γ is the ordinary least squares (OLS) and since one of the basic requirements of OLS method is that the relation must be linear, equation (2), is often transformed taking natural logarithms of both the left and the right side, obtaining the following

$$\ln Y = \alpha \ln AL + \beta \ln K + \gamma \ln G \tag{3}$$

A further transformation consists in put equation (3) in per-worker terms and assuming constant returns to scale across all inputs (i.e. assuming that $\alpha + \beta + \gamma = 1$). The result is given by the following (4)

$$\ln \frac{Y}{L} = \ln A + \beta \ln \frac{K}{L} + \gamma \ln \frac{G}{L} \tag{4}$$

According to specification (4) – and (3) - the main research question consists in estimating the parameter "γ" which represents the elasticity of output with respect to infrastructures.

Note that, given the difficulties to model technological progress, Aschauer (1989)'s attempt to measure the role of infrastructure utilising (4) introduced a constant and a trend variable as a proxy for $\ln A_t$.

As discussed rather in length in Torrisi (2009) an important issue is what "put in place of" *G*.

Put differently, when attempting at estimating (4) scholars have to decide – compatibly with data availability- not only if use, in Romp and de Haan (2007)'s words, "(the monetary value of) the public capital stock (or the monetary value of the stock of infrastructure) ", but also if use a stock or a flow (monetary) measure of public capital.

Nevertheless, at this regard Irmen and Kuehnel (2008) argue that "the analysis […] *using* the stock *measure* confirms most results that are obtained in the flow case", although they continue noting that different results arise in the welfare analysis.

Whatever the choice between different solution available three main issues arise in using production function approach, namely the fact that (i) labour and capital are exogenous (i.e. this approach does not take into account the role of factor prices in determining their utilisation), (ii) reverse causation from income to investments and, in turn, to private capital (see Romp and de Haan (2007) for a general discussion).

However, most important from the point of view of this analysis, is (iii) the potential feedback from income to a demand for infrastructure.

Indeed, on the one hand exist arguments in favour to the thesis arguing that infrastructure increases the output level according to what Looney and Frederiksen (1981) in their paper call the "Hansen (1965) thesis".

On the other hand have been developed arguments in favour to the thesis asserting that infrastructure is only an accommodating factor so that the demand for infrastructure increases with the level of income (Glover and Simon, 1975; Evans and Karras, 1994; Zegeye, 2000) following the same behaviour of a *normal good*:

public sector spending may be a normal good. That is, as income rises the demand for public infrastructure increases so that the correlation between infrastructure and output may reflect the marginal propensity to consume public goods rather than any productivity enhancing effects of infrastructure (Zegeye, 2000).

In this regard various solutions have been proposed to deal with the issue of causality.

Fernald (1999), for example, derives an appropriate test to investigate the direction of the causality between infrastructure and income.

The strategy chosen by the Author works as follows: using data for 29 sectors in the US economy regarding the period from 1953 to 1989, he finds that changes in road growth are associated with larger changes in productivity growth in industries that are more vehicle intensive.

This circumstance leads Fernald (1999) to assert that infrastructure (rather roads) are exogenous. In fact, if road were endogenous, any particular relationship between industry's vehicle intensity and its relative productivity performance should be found when road growth rate changed.

Nonetheless, Canning and Pedroni (1999) find that the causality run in *both* direction by mean of a dynamic error correction model (DECM). In short, since physical stock of infrastructure and per capita income are individually non-stationary but cointegrated, they use a DECM and then test restrictions with the final purpose to study the direction of causality. As said, it appears that causality is not unidirectional but infrastructure enhance productivity and *vice versa*.

A second approach in studying the causality direction consists in using panel data methods. The underlying idea is that pooling data across different unit allows identifying the long-run production function.

Following this approach, Canning and Bennathan (2000), find an high rate of return for electricity generating capacity and the length of paved roads.

With the same aim to capture the results of infrastructure investments (and not the results of economic growth) by mean of panel data approach, Demetriades and Mamuneas (2000) and- in another work- Esfahani and Ramìres (2003) handled the causality issue by introducing a "time-lag" between variables for public infrastructure and productivity.

In these studies, investments were compared to the productivity data several years afterwards, in order to reduce the chance of misrepresentation of economic growth impacts as productivity impacts.

Both studies cited above found that public infrastructures do have a considerable impact on increasing productivity and economic growth. In particular, Esfahani and Ramìres (2003) find that the contribution of infrastructure services to GDP is substantial and, in general, exceeds the costs of provision.

Finally, instrumental variable (IV) is another approach used to deal with causality. Calderon and Serven (2002) adopting the IV approach estimate a Cobb-Douglas production function (in first difference) using lagged values of explanatory variables. Their main finding is an average elasticity of 0.16 for different types of infrastructure.

To summarise: this section focused on the production function approach to measure the economic impact of infrastructure on productivity. The main contents expressed here can be expressed as follows: (i) although estimates vary sensibly from one study to the other, a statistically significant relationship between infrastructure investment and productivity is found in most studies; (ii) the direction of causality is still object of debate. However, most authors, using different approaches, tend to support the thesis that public capital drives productivity, and not the other way around.

Next section focus on the cost-function approach which is an alternative approach developed with the principal purpose to take into account factor prices here not considered at all.

3. The cost-function approach

One of the limitation of the production function approach is that it does not take into account the role of factor prices in determining their utilisation: it reflects only technological relations.

Indeed, private factors inserted in the production function are considered exogenous and it is implicitly assumed that they are paid according to their marginal productivity. At this regard some studies have used a translog function because it is more general than the Cobb-Douglas function (among others Puig-Junoy, 2001; Stephan, 2002; Kemmerling and Stephan, 2002; Wylie, 1996).

An alternative way to deal with this issue consists in adopting the cost function approach. According to the latter the impact of infrastructure on productivity should be analysed in terms of *cost savings*.

Studies following the cost function approach aim to examine if the cost of output *decreases* as the infrastructure endowment *increases*.

The main idea followed by this approach is that public capital can be considered as a *free input* provided by government able to reduce the cost sustained by firms.

In this setting input prices are exogenously determined, so that the variables that firms can choose to produce a given level of output at minimum private cost (*C*) are the quantities of private input.

In symbols

$$C(p_t^i, q_t^i, A_t, G_t) = \min \sum p_t^i q_t^i \quad sub\, Y = f(q_t^i, A_t, G_t) \tag{5}$$

where p and q index respectively the input price and the quantities of private input.

The parameter of interest is the *shadow price* (s_g) of the public capital[1] which is obtained by taking the negative of the partial derivative of the cost function with respect to the public infrastructure measure (G) by mean of the Shepard's Lemma. In short, shadow price can be expressed as follows

$$s_g = -\frac{\partial C(p, q, A_t, G)}{\partial G} \tag{6}$$

It is worth noting that an alternative approach consists in assuming that firms aim to maximise their profits (π) given the output prices (p^y) and input prices. This second way can be expressed in symbols as follows

$$\pi(p_t^y, p_t^i, q_t^i, A_t, G_t) = \max\ p_t^y Y_t - \sum p_t^i q_t^i \quad sub\, Y = f(q_t^i, A_t, G_t) \tag{7}$$

Thus, according to this approach the amount of public capital available (*G*) is an *environmental* variable that firms take into account when they optimise their behaviour. A key point at this regard is that

although the stock of infrastructure is considered externally given […], each individual firm must still decide the amount it wants to use. This […] leads to the need of a demand function for infrastructure that must satisfy the conditions of standard marginal productivity theory (Romp and de Haan, 2007).

It was noted (Sturm, Jacobs et al., 1995) that an important advantage of the cost function approach compared to the production function approach is that it represents a more flexible functional form.

For example, it does not require *a priori* restrictions regarding substitutability of inputs. The cost function approach allows also to investigate both direct – as the production function does - and *indirect* effects of public capital, in the sense that firms

[1] Note that conceptually the shadow price represents the cost-side equivalent of the marginal product, reflecting the reduction in variable costs of production due to an additional infrastructure investment (see Morrison, C. J. and A. E. Schwartz (1996). "State Infrastructure and Productive Performance." American Economic Review **86**(5): 1095-1111.)

can vary their demand for private inputs in light to the fact that public capital might be either a substitute or a complement to other input.

Nevertheless, all this flexibility presents also a critical implication. Indeed, It requires good-quality data in order to estimate parameters and to deal with possible multicollinearity problems.

Hence, its strength point becomes, in turn, also its weakness one and a careful consideration involving the trade-off between the two aspects should be made before adopting it.

Overall, studies using the cost function approach shows that public capital is *cost reducing*. However, estimates following this approach give a smaller effect than those estimates following the production function approach.

For example, Ezcurra, Gil et al. (2005) (in their study regarding Spanish regional production costs in the agricultural, industrial, and services sectors for the period from 1964 to 1991) find that public infrastructure reduces private costs and increases productivity.

Their estimate shows that while agricultural and service sector behave similarly, the greatest saving in private costs are found in the industrial sector: -0.154 (dollar costs per unit of public capital) for the latter, -0.145 and -0.144 for services sector and agricultural sector respectively.

Cohen and Morrison Paul (2004), realised a study regarding the cost-saving effects of infra-state public infrastructure investment in US which is worth mentioning according to (at least) three different point of view.

First, their model distinguishes between *intra* and *inter*-state effects of public infrastructure taking into account the possibility of interaction between the two categories of infrastructure.

In general terms, they find that taking spill over effect into account raises the average elasticity from -0.15 to -0.23. More deeply, they found that the largest *intra*-state effects appear in the western part of US confirming the theoretical reasoning that *inter*-state infrastructure is not crucial for state – such California - large and relatively densely populated.

Second, regarding the relationship between public and private capital (in terms of complementarity or substitutability) the Authors argue that "the output growth motivated by cost-depressing effects of infrastructure investment may stimulate capital investment and labour employment, even though overall short run public infrastructure-private output substitutability is evident at existing output levels" (Cohen and Morrison Paul (2004)).

Third, the study also address the issue of *causality* by means of the Hausman test[2] concluding that the null hypothesis of infrastructure exogeneity is not rejected. This result is important because it empirically confirms that infrastructure does affects costs and not the other way around.

In conclusion, even if with different shades across sectors and level of analysis, studies following the cost function approach confirm the finding of those following the production function approach: infrastructure and production are positively linked, and, generally speaking, the direction of causality goes from the former to the latter.

[2] Most studies test for endogeneity and find that infrastructure can be considered exogenous, but not all the studies do so. For example, the first study here cited -Ezcurra, Gil et al. (2005)- does not perform the Hausman test, arguing that since it regard regional data, endogeneity was not a significant problem. At this regard, as argued in Infrastructure Canada (2007), should be noted that "this may not be a sufficient justification to rule out the endogeneity problem"(Infrastructure Canada, 2007).

4. Growth-model approach

Growth models aiming to test the economic impact of infrastructure are based on the general idea that economic growth is not driven merely by exogenous factors rather by dynamics which are internal to the economic system itself.

Indeed, since the mid-1980s, many studies were developed in order to explain why difference in income both over time and across countries did not disappear as the neoclassical growth models predicted.

The main feature of this tradition is the assumption that growth is an *endogenous* phenomenon affected by economic agents' behaviour. A key feature in explaining different performance is assigned to capital formation which meaning has to be intended in a broader sense including physical capital as well as human capital, knowledge capital and infrastructure.

The general economic framework to empirically test these assumptions can be expressed as follows:

$$\Delta \ln\left(\frac{Y}{L}\right)_{0,T} = \alpha + \beta\left(\frac{Y}{L}\right)_{0} + \gamma\left(\frac{I^{G}}{Y}\right)_{0,T} + Z \tag{8}$$

Where $\left(\frac{Y}{L}\right)_{0,T}$ represents the average per capita GDP over the period [0; *T*], $\left(\frac{Y}{L}\right)_{0}$ is the initial level of real per capita GDP and $\left(\frac{I^{G}}{Y}\right)_{0,T}$ is factor added to represent government investment (rather the average rate of public investment as percentage of GDP over the [0; *T*] period); *Z* captures a set of conditional variables such as private investment (as percentage of GDP), proxy for human capital (usually primary and/or secondary enrolment), political instability (assassinations, revolts and coups, and war casualties), freedom, and the ratio of government consumption to GDP.

Note that while the parameter β measures technological catch up (if negative), the parameter γ - being a measure of the impact on *growth* - is not the same as the marginal productivity of capital when the measure of economic performance (for example GDP) is considered in level.

Easterly and Rebelo (1993)'s article represents an important piece of work using public capital in an empirical growth model. The Authors run pooled regressions (using individual country decade averages for the 1960s, 1970s and 1980s) of per capita GDP growth on a set of conditional variables and on public investment in various sector (added one at time): agriculture, education, health, housing and urban infrastructure, transport and communication, industry and mining.

Their work shows that the share of public investment in transport and communication infrastructure is robustly correlated with growth (with coefficient ranging from 0.588 to 0.661 according to different specifications used) as well as almost all other variables except agricultural spending which is consistently *negatively* related with growth with a coefficient between - 0.34 and - 0.231).

Moving from Easterly and Rebelo (1993) other works have been realised adopting also regional data.

Mas, Maudos et al. (1996), for example, regarding Spanish regions found that the initial stock of public capital (as share of gross value added) positively affects output expressed in per-capita terms.

Crihfield and Panggabean (1995), using two stages estimation technique to take into account also capital and labour endogeneity, achieved the conclusions that public infrastructures that they considered (e.g. education, streets, highways, sewerage, sanitation) surely play a role, with the caution that their contribution may be less than that the one of other forms of investment.

With respect to the contribution of specific infrastructures, Cellini and Torrisi (2009), focusing on infrastructure specific to the tourism sector, show that this particular kind of infrastructure, separately considered, has a weak impact on several indicators of economic performance (e.g. gdp, touristic presence, hotels' structures) considered also in terms of growth rate.

However, various authors have pointed at problems associated with cross-section regressions.

To begin with, biases due to omitted variables, reverse causation (Levine and Renelt, 1990; Levine and Zervos, 1993) and sample selection (De Long, 1988) could affect the results which interpretation, as pointed out by Solow (1994), is often tempted by wishful thinking.

Furthermore, cross-section regressions are often not very robust. Indeed, several models *ex-ante* reasonable given the data, achieve different conclusions about the parameter of interest.

Put in Levine and Renelt. (1992)'s words,

given that over 50 variables have been found to be significantly correlated with growth in at least one regression, readers may be uncertain to the confidence they should place in the findings of any one study (Levine and Renelt, 1992).

In order to deal with the issue of how robust the result concerning a certain variable is to the inclusion of other relevant variables Levine and Renelt. (1992), using a variant of Leamer (1978), elaborated the so-called extreme bound analysis (EBA).

According to the EBA approach should be reported an upper and an lower bound for parameter estimates obtained in regressions using as explicative variables different subsets of the set of explanatory variables.

The relationship between a certain variable and economic growth *is not* considered *robust* either if a certain variable became statistically insignificant or if the sing of its parameter in the upper bound case is different from the one obtained in the lower bound case.

Unfortunately, one of the main results of the latter study is that "few findings can withstand slight alterations in the list of explanatory variables" (Levine and Renelt, 1992).

Going further on the empirical exploratory ground, next section focuses on vector autoregression models which represent a set of *data oriented* models, i.e. models developed to use as little theory as possible in order to manage theoretical and empirical problems affecting approaches discussed above.

5. Vector Autoregression Models

Vector Autoregression (VAR) models represent a theoretical framework used with the specific purpose to deal with theoretical limitations and significant empirical controversies over the impact of infrastructure on productivity summarised above.

Indeed, the peculiar characteristic of a VAR model is that no *a priori* causality directions are imposed among variables[3]. In a VAR model a limited number of variables is considered and explained by their own lags and the lags of the other variables, so that all variables are treated as jointly determined.

[3] Note that since the VAR approach does not completely reveal the underlying production process, estimates do not represent elasticity as in the production function approach. However, in order to get specific elasticity estimates starting from a VAR model can be adopted the impulse-response functions. This method allows to estimate the long-run effects of different shocks on the estimated system. Applying this method requires rewriting the VAR into its Vector Moving Average (VMA) representation and, in turn, the model needs to be stable in order to make this conversion. A sufficient condition that makes the model stable is that the variables used are stationary or co-integrated.

In a formal way a VAR including two variables (let they be *y* and *g*) can be expressed as follows[4].

$$y_t = \partial_0 + \sum_{i=1}^{L_y} \alpha_i y_{t-i} + \sum_{i=1}^{L_g} \gamma_i g_{t-i} + u_t \quad (8a)$$

$$g_t = \eta_0 + \sum_{i=1}^{L_y} \beta_i y_{t-i} + \sum_{i=1}^{L_g} \rho_i g_{t-i} + \varepsilon_t \quad (8b)$$

Where L_y and L_g index respectively the number of lags of *y* and *g* to be considered; each equation contains also an error term (u_t, ε_t) that has zero expected value given past information on *y* and *g*.

An unrestricted VAR model can be estimated using OLS even if variables are integrated and possibly cointegrated (Sims, Stock et al., 1990).

Note that if *n* variables are included with each p lags then $n^2 \times p$ coefficients need to be estimated, besides the deterministic variables. A way to deal with this problem consists in using Akaike's (1969, 1970) Final Prediction Error (FPE) criterion in order to select the appropriate lag specification for each explanatory variable in each equation and save a substantial number of degrees of freedom.

Alternatively, an F test for jointly significance can be used in order to choose how many lags have to be inserted for each variable (Wooldridge, 2002).

Typically, studies following this approach apply *Grainger-causality* tests to find relationships between variables. In our case researchers are particularly interested in testing if infrastructure Grainger-causes productivity - i.e. if the time series prediction of GDP (or some other measure of productivity) from its own past improves when lags of measures of infrastructure are considered - and\or *vice versa*.

[4] Usually, a four-variables model (output, employment, private capital, and public capital) is utilised.

At this regard should be noted that although VAR models allow us to test whether the hypothesis that infrastructure *causes* productivity is valid or whether there are feedback effects from output to public capital (Romp and Haan, 2007; Sturm, Kuper et al. (1996), Infrastructure Canada, 2007), VAR models do not definitively solve the problem of endogeneity.

Indeed,

the term “causes” in “Granger causes” should be interpreted with caution. In particular, it has nothing to say about contemporaneous causality […], so it does not allow us to determine whether [a certain variable] is […] exogenous or endogenous (Wooldridge, 2002).

In a recent study utilising VAR models with Spanish regional data Pereira and Sagalés (2006) foundnd that infrastructure investments positively affect private output and also *crowd-in* private sector inputs.

Put differently, the study shows that public investment in infrastructure and private expenditure in the same field are complementary rather than substitutes.

The same conclusion has been achieved in Karadag, Ozlem Onder et al. (2005) with respect to the Turkish case.

Another interesting conclusion driven by Pereira and Sagalés (2006) is that surprisingly infrastructures contribute in creating disparities between regions due to fact that new investment on infrastructure are most often directed to central regions disadvantaging peripheral regions.

Sturm, Jacobs et al. (1995) (using data regarding the Netherlands from 1853 to 1913) consider GDP, investment series on public infrastructure, private machinery, and equipment capital to provide evidence for *unidirectional* positive relationship from *basic* infrastructures to GDP only, while the *complementary* ones appear to be not effective.

Nonetheless, Xiaobo and Fan (2001) (using data regarding Indian economy) find that infrastructure and productivity often affect *each other* in the long term (i.e. estimating the model in levels).

With respect to short term (i.e. estimating the model in first differences), instead, the Authors find that the coefficients are not statistically significant.

In conclusion, papers designed on data based models reviewed in this section confirm, although once more with different shades, that public capital investments positively impact private sector output, despite the fact that they use different datasets and theoretical constructs.

More precisely, regarding the most debated point involving (Grainger-)causality, some authors conclude that *at least* infrastructure and productivity affect *each other* but no study find evidence to support the hypothesis of strict *reverse causation* from output to infrastructure.

6. Concluding remarks

This paper briefly reviewed the vast literature concerning the relationship between infrastructure and productivity focusing on some critical points.

Indeed, since the first-generation studies primarily based on production function and cost function approaches a significant amount of discussion on some of the theoretical and econometric issues have been developed.

This paper reviewed some of them along an ideal path from (more) theory-based approaches to data-oriented models.

The actual area of significant debate, besides the magnitude of infrastructures impact on productivity and/or the causality direction, concerns other mentioned issues of (i) short-run and the long-run significance of their contribution and (ii) the effectiveness of different category of infrastructures.

In order to deal with these issues several studies and approaches have been developed reporting that the peculiar feature in this field is represented by *heterogeneity*: the effects of public investment differs across countries, regions, and sectors.

It is worth noting that this result is reasoned according to arguments based both on economic and political grounds.

On the economic ground should be noted that the effects of new investment depend on "past history" (i.e. the quality and the quantity of the capital stock in place): the larger the quantity and the better its quality, the lower the impact of additional investment.

However, as said above, another source of heterogeneity can be found at the institutional and political ground, even if this issue (probably) have not been well researched.

Indeed, in Estache (2006)'s words

there is strong anecdotal evidence now that politics matter. [First, because] politicians will never give up the control of a sector that buys votes in democratic societies. Moreover, in societies in which corruption is rampant, they will nt give up control of a sector involving large amount of money and in which contract award processes often provide opportunities for unchecked transactions (Estache, 2006).

Nonetheless, even with several points of caution, the general idea that infrastructures have an economic enhancing effect appears to be quite robust across studies belonging to different methodological approaches.

References

Akaike, H. (1969). "Fitting Autoregressive Models for Prediction." Annals of the Institute of Statistical Mathematics, **21**: 243-247.

Akaike, H. (1970). "Statistical Predictor Identification." Annals of the Institute of Statistical Mathematics **22**: 203-217.

Albala-Bertrand, J. M., E. C. Mamatzakis, et al. (2004). "The Impact of Public Infrastructure on the Productivity of the Chilean Economy." Review of Development Economics **8**: 266-278.

Aschauer, D. A. (1989). "Is Public Expenditure Productive?" Journal of Monetary Economics **23**: 177-200.

Barro, R. J. (1988). "Government Spending In A Simple Model Of Endogenous Growth." National Bureau Of Economic Research **Working Paper No. 2588**.

Belloc, M. and P. Vertova (2006). "Public Investment and Economic Performance in Highly Indebted Poor Countries: An Empirical Assessment. ." International Review of Applied Economics **20** 151-170.

Biehl, D. (1991). The Role of Infrastructure in Regional Development. in Infrastructure and Regional Development R.W.Vickerman. London, Pion.

Bonaglia, F., E. La Ferrara, et al. (2001). " Public Capital and Economic Performance: Evidence from Italy." IGIER **Working Paper No. 163.**

Calderon, C. and L. Serven (2002). "The Output Cost of Latin America's Infrastructure Gap." **Central Bank of Chile Working Paper No. 186.**

Canning, D. and E. Bennathan (2000). "The Social Rate of Return on Infrastructure Investments." **World Bank Working Paper No. 2390.**

Canning, D. and P. Pedroni (1999). " Infrastructure and Long Run Economic Growth." Mimeo.

Cass, D. (1965). "Optimum growth in an aggregative model of capital accumulation." Review of Economic Studies **32**: 233-240.

Cellini, R., and G.Torrisi (2009): "The Regional Public Spending for Tourism in Italy: An Empirical Analysis " MPRA paper **No.16131.**

Cohen, J. P. and C. J. Morrison Paul (2004). "Public Infrastructure Investment, Interstate Spatial Spillovers, and Manufacturing Costs." Review of Economics and Statistics **86**: 551-560.

Crihfield, J. and M. Panggabean (1995). "Is public infrastructure productive? A metropolitan perspective using new capital stock estimates." Regional Science and Urban Economics **25**: 607-630.

De Long, J. B. (1988). "Productivity Growth, Convergence, and Welfare: Comment." American Economic Review **78**: 1138-54.

Demetriades, P. O. and T. P. Mamuneas (2000). "Intertemporal Output and Employment Effects of Public Infrastructure Capital: Evidence from 12 OECD Economies." Economic Journal **110**: 687-712.

Easterly, W. and S. Rebelo (1993). "Fiscal policy and economic growth An empirical investigation." Journal of Monetary Economics **32**: 417-458.

Esfahani, H. and M. T. Ramìres (2003). "Institutions, Infrastructure and Economic Growth." Journal of Development Economics **70**: 443-477.

Estache, A. (2006). "Infrastructure. A Survey of Recent and Upcoming Issues." World Bank. Mimeo.

Evans, P. and G. Karras (1994). "Is government capital productive? Evidence from a panel of seven countries " Journal of Macroeconomics **16**(2): 271-279.

Everaert, G. and F. Heylen (2004). "Public Capital and Long-Term Labour Market Performance in Belgium." Journal of Policy Modelling **26**: 95-112.

Ezcurra, R., C. Gil, et al. (2005). "Public Capital, Regional Productivity and Spatial Spillovers." The Annals of Regional Science **39**: 471-94.

Fernald, J. (1999). "Assessing the Link between Public Capital and Productivity." American Economic Review **89**: 619-638.

Ferrara, E. L. and M. Marcellino (2000). "TFP, Costs, and Public Infrastructure: An Equivocal Relationship." IGIER **Working Paper No. 176.**

Ghali, K. H. (1998). " Public Investment and Private Capital Formation in a Vector Error-Correction Model of Growth " Applied Economics **30**: 837-844.

Glover, D. R. and J. L. Simon (1975). "The effect of population density on infrastructure: the case of road building." Econ. Dev. Cult. Change **23**: 453--468.

Gramlich, E. M. (1994). "Infrastructure Investment: A Review Essay " Journal of Economic Literature **XXXIII**: 1176-1196.

Hansen, L. (1982). "Large sample properties of generalized method of moments estimators." Econometrica **50**(3): 1029-1054.

Hansen, N. M. (1965). "The structure and determinants of local public investment expenditures." Review of economics and statistics **2**: 150-162.

Hausman, J. (1978). "Specication tests in econometrics." Econometrica **46**(3): 1251-1271.

Infrastructure Canada (2007). Infrastructure and Productivity: A Literature Review. Transport Infrastructure and Communities Portfolio, Government of Canada. Research and Analysis Division Infrastructure.

Irmen, A. and J. Kuehnel (2008). Productive Government Expenditure and Economic Growth. CESifo. **Working paper No. 2314**.

Kamps, C. (2006). " New Estimates of Government Net Capital Stocks for 22 OECD Countries 1960-2001." IMF **Staff Papers 53**: 120-150.

Karadag, M., A. Ozlem Onder, et al. (2005). "Growth of Factor Productivity in the Turkish Manufacturing Industry at Provincial Level." Regional Studies **39,**(2): 213-223.

Kemmerling, A. and A. Stephan (2002). "The Contribution of Local Public Infrastructure to Private Productivity and its Political Economy: Evidence from a Panel of Large German Cities." Public Choice **113**(34): 403-424.

Koopmans, T. C. (1965). On the concept of optimal economic growth,. in (Study Week on the) Econometric Approach to Development Planning. Amsterdam, North-Holland Publishing Co**:** chap. 4. pp. 225-87.

Leamer, E. E., Ed. (1978). Specification Searches: Ad Hoc Inference from Nonexperimental Data. New York, Wiley.

Levine, R. and D. Renelt (1990). "Cross Country Studies of Growth and Policy: Some Methodological, Conceptual, and Statistical Problems." World Bank.

Levine, R. and D. Renelt. (1992). "A Sensitivity Analysis of Cross-Country Growth Regressions." American Economic Review **82**: 942-963.

Levine, R. and S. Zervos (1993). "What We Have Learned About Policy and Growth from Cross-Country Regressions?" American Economic Review, **83**: 427-430.

Looney, R. and P. Frederiksen (1981). "The Regional Impact of Infrastructure Investment in Mexico." Regional Studies **15**(4): 285-296.

Marrocu, E., R. Paci, et al. (2006). Gli effetti del Capitale Pubblico Sulla produttività delle Regioni Italiane. . Federalismo, equità, sviluppo. I risultati delle politiche pubbliche analizzati e misurati dai Conti Pubblici Territoriali. F. Barca, F. Cappiello, L. Ravoni and M. Volpe. Bologna, Il Mulino.

Mas, M., J. Maudos, et al. (1996). "Infrastructures and Productivity in the Spanish Regions." Regional Studies, Taylor and Francis Journals **30**(7): 641-649.

Mastromarco, C. and U. Woitek (2004). "Public Infrastructure investment and efficiency in Italian Regions." www.cide.info/conf/papers/1161.pdf.

Maurizio Di Palma, C. Mazziotta, et al., Eds. (1998). Infrastrutture e sviluppo. Primi risultati: indicatori quantitativi a confronto (1987-95). Quaderni sul Mezzogiorno e le politiche territoriali. Roma, Confindustria.

Mittnik, S. and T. Neumann (2001). "Dynamic Effects of Public Investment: Vector Autoregressive Evidence from Six Industrialized Countries." Empirical Economics **26**: 429-446.

Morrison, C. J. and A. E. Schwartz (1996). "State Infrastructure and Productive Performance." American Economic Review **86**(5): 1095-1111.

Pereira, A. M. (2000). " Is All Public Capital Created Equal?" Review of Economics and Statistics **82**: 513-518.

Pereira, A. M. (2001). "On the Effects of Public Investment on Private Investment: What Crowds In What?" Public Finance Review **29**: 3-25.

Pereira, A. M. and O. R. Sagalés (2006). "Public Infrastructures and Regional Asymmetries in Spain." Department of Economics. College of William and Mary **Working Papers 46**.

Puig-Junoy, J. (2001). "Technical Inefficiency and Public Capital in U.S. States: A Stochastic Frontier Approach." Journal of Regional Science **41**(1): 75-96.

Putnam, R. D., Ed. (1993). Making Democracy Work. Civic Tradictions in Modern Italy Princenton Princenton University Press.

Romp, W. and J. de Haan (2007). "Public Capital and Economic Growth: A Critical Survey " Perspektiven der Wirtschaftspolitik **8**(Special Issue): 6-52.

Sanchez-Robles, B. (1998). "Infrastructure Investment and Growth: Some Empirical Evidence." Contemporary Economic Policy **16**: 98-108.

Sims, C., J. Stock, et al. (1990). "Inference in Linear Time Series Models with Some Unit Roots,." Econometrica **58**: 113-144.

Solow, R. M. (1956). "A Contribution to the Theory of Economic Growth." Quarterly Journal of Economics **70**: 65-94.

Solow, R. M. (1994). "Perspectives on Growth Theory." The Journal of Economic Perspectives **8**(1): pp. 45-54.

Stephan, A. (2002). "Regional Infrastructure Policy and its Impact on Productivity: A Comparison of Germany and France." Wissenschaftszentrum Berlin, CIC Research Unit **Working Paper No. FS IV 0002**.

Sturm, J.-E., J. Jacobs, et al. (1995). "Productivity impacts of infrastructure investment in the Netherlands 1853-1913." University of Groningen. Research Institute SOM (Systems, Organisations and Management) **Research Report 95D3**.

Sturm, J.-E., G. H. Kuper, et al. (1996). "Modelling government investment and economic growth on a macro level: a review." **CCSO Series No. 29**.

Torrisi, G. (2009): "Public Infrastructure: Definition, Classification and Measurement Issues," Economics, Management, and Financial Market. **4** (3).

Wooldridge, J. M., Ed. (2002). Introductory Econometrics A Modern Approach, South-western Publishing Group.

Wylie, P. (1996). "Infrastructure and Canadian Economic Growth" Canadian Journal of Economics **29** (Special Issue): S350-355.

Xiaobo, Z. and S. Fan (2001). "How Productive is Infrastructure? New Approach and Evidence from Rural India." International Food Policy Research Institute **Discussion Paper No. 84**.

Zegeye, A. A. (2000). "U.S. Public Infrastructure and its contribution to private sector productivity. ." U.S. Department of Labor **Bureau of Labor Statistics**(June.).