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Public capital and regional economic growth

Abstract: The paper reviews the literature on the impact of public capital on regional economic growth. It presents the main points of the debate on the role of infrastructure and focuses largely on the empirical research undertaken over the past decade. The paper considers different function forms (production function vs cost function approach) and different econometric specifications (aggregated estimation vs disaggregated estimation). Particular attention is paid to spatial distributions of regional activity as a consequence of the provision of infrastructure.

Keywords: public infastructure, economic growth, spatial distributions of regional economic activity, interregional trade.

JEL codes: H54, O4, R12.

1. Introduction

Since the beginning of the nineties, econometric estimates of the impact of public capital on productivity are the most common method for examining the role that public infrastructure investments play in regional development. Although there is a large range of analytical approaches to forecast the economic impact of infrastructure, for example accessibility approach, input-output approach or SCGE models, but "this is econometrics what economists like to do" (Gramlich 1994, p. 1185)[1].

After the Second World War relatively little consideration was given to the positive long-term effects of public capital. Although many Keynesian economists and politicians in the 1950s believed that active interventions would lead to regional development, the neo-classical growth model, that dominated during the seventies and eighties, predicted regional convergence without public capital. Regional equity considerations became less important in the national policies. Everything

[1] For a more detailed survey of analytical approaches, see Lakshmanan and Anderson (2002) and also Gramlich (1994).

changed in the late 1980s and early 1990s. Infrastructure investments became one of the most frequent topics for econometric research. The explosion of researches on the returns to infrastructure seemed to be connected in some way with a recent trend in the literature: the new growth theory. The new growth theory emphasizes the role of increasing returns to scale in production, which are major sources of economic growth. An intensive investment in knowledge, human capital or infrastructure can be regarded as explanation for the existence of increasing returns (Barro 1990). According to the new or endogenous growth theory, public infrastructure investments therefore might be defended on efficiency grounds.

Moreover, at the beginning of the 1990s, there was a growing consensus among academic researches and political leaders on the need of trade liberalization, both in the USA (NAFTA) and Europe (the Treaty on European Union, signed in Maastricht). One of the main goals of uniting Europe was to establish and develop Trans-European Networks (TEN). The objective of the common network infrastructure in Europe was to strengthen economic, social and territorial cohesion within regions and countries in Europe. Economists showed that since the early 1980s inequalities within regions in the European Union countries have risen (Duro 2001). Political leaders thought that the proper way to stop the process of regional divergence is to develop interregional infrastructure and increase the accessibility of peripheral regions, raising their level of competitiveness. According to politicians, public infrastructure investments therefore might be defended not only on efficiency but also on equity grounds.

All the above mentioned facts were important, but the main reason for debate on the role of public infrastructure in economic growth and public capital productivity was neither trade liberalization nor cohesion projects. The works of Aschauer, especially „Is Public Expenditure Productive?" (Aschauer 1989), drew particular attention to infrastructure.

2. The production function approach

The authors of articles on economic growth before Aschauer, rarely treated infrastructure as an important factor in private production. Production functions were estimated by assuming two conventional factors; labor and private capital. However, Aschauer was not the first author to include public capital as a factor of production. There were a few exceptions. At the beginning of the 1970s Mera estimated productivity of the so called 'social overhead capital' in Japanese regions (Mera 1973). According to Mera, public capital was productive for three main economic sectors and its marginal productivity was comparable with the marginal productivity of private capital. Mera emphasized that during the period of restructuring of the

Japanese economy 1954-1963, the most effective part of infrastructure was transportation and communication 'social capital'[2].

Other notable exceptions of empirical studies, that had considered the role of infrastructure before the late 1980s are these of Ratner (1983) or Eberts (1986) and in Europe Biehl (1986). The results of the above works were not so widely criticized and commented on as these of Aschauer. This is Aschauer who sent a signal to the rest of the economists to develop the methodology and measurement of public capital productivity.

A common specification is that of the well known neoclassical model of the production function. Aschauer and many others have expanded the production function to include public capital as an additional input. Using a frequently applied Cobb-Douglas production function form, the equation looks as follows:

$$Y = AKP^{\alpha} L^{\beta} KG^{\gamma}. \tag{1}$$

Where Y is output, A is the level of technology or Hicks-neutral technical change, KP is the private capital stock, KG is the stock of public capital, L is the labor force, α, β, γ are the elasticities of output with respect to private capital, labor and public capital respectively. After translating the equation into logarithms, the linear function that can be estimated looks as follows:

$$\ln Y = \ln A + \alpha \ln KP + \beta \ln L + \gamma \ln KG. \tag{2}$$

2.1. The Aschauer's approach

In his article Aschauer (1989) estimates the production function for the USA using aggregated national time series data for the 1949 to 1985 period. He also adds a capacity utilization variable CU to control the effects of the business cycle and time counter variable "*t*" to incorporate the influence of disembodied technological progress. Aschauer's results look as follows (1989, p. 183):

$$\begin{aligned} \ln Y - \ln KP = \underset{(10.90)}{-5.60} + \underset{(4.46)}{0.010}\, t + \underset{(3.04)}{0.29}\left(\ln L - \ln KP\right) - \underset{(7.95)}{0.44} \ln KP + \\ + \underset{(9.79)}{0.36} \ln KG + \underset{(11.31)}{0.45} \ln CU. \end{aligned} \tag{3}$$

Where values of t-statistics are in parentheses. Aschauer concludes that there is a very strong and positive relationship between public capital stock in the USA and

[2] Mera (1973) also outlined many methodological problems raised again by the critics of Aschauer.

the level of output (measured as a level of private sector productivity). The estimated elasticity of output with respect to public capital is 0.36. The coefficient is statistically significant. It implies that a 1 percent increase in public capital stock, *ceteris paribus*, leads to an average of a 0.36% percent growth of private sector output per unit of private capital. Aschauer estimates the above production function for different periods. Empirical results show that the elasticity increases to 0.56 during the 1949 to 1967 period. Aschauer concludes that the most productive type of public capital is the so called "core infrastructure" which means transport infrastructure, electrical and gas facilities, water systems and sewers. For example, Aschauer reports results for the trucking industry as follows (1989, p. 188):

$$\ln Y_m - \ln L_m = \underset{(-10.73)}{-7.74} - \underset{(-2.25)}{0.76} \ln L_m - \underset{(2.39)}{0.33} \ln KP_m + \\ + \underset{(5.70)}{0.80} \ln KGH + \underset{(3.56)}{0.61} \ln CU. \quad (4)$$

Where Y_m, L_m, KP_m are output, labor force and private capital in the trucking industry, *KGH* is net stock of public highways. The estimated elasticity of output per employer in the trucking industry with respect to public highways stock is 0.80 at a high degree of statistical significance. The equations (3) and (4) provide some information on returns to scale. The sum of output elasticities of the factor inputs in equations exceeds one. It means that we obtain increasing returns to scale in all inputs. The neoclassical assumption of constant returns to scale across to all factors is rejected. According to Aschauer's estimates of a Cobb-Douglas production function, the rate of return of public infrastructure (marginal product of the public capital, MP_{KG}) reaches nearly 100%. One can obtain the marginal product of public capital by using the real levels of private business output and public capital stock and the following equation:

$$\gamma = \frac{MP_{KG} KG}{Y}. \quad (5)$$

If the rate of return of public capital, as Aschauer claims, is so high or even higher that the marginal product of private capital, one may consider it unusual that private firms complain about imposing taxes to build highways or sewers by the public sector (Gramlich 1994).

Another way in which public capital can lead to economic growth is by raising total factor productivity of all inputs. Aschauer estimates the effect of public capital on total factor productivity. Assuming competitive product and factor markets, when private factors are paid their marginal products, Aschauer's results look as follows (1989, p. 183):

$$TFP = \underset{(-10.01)}{-1.53} + \underset{(35.39)}{0.009} + \underset{(26.33)}{0.39} \left(\ln KG - \left(s_{KP} \ln KP + s_L \ln L \right) \right) + \underset{(18.19)}{0.41} \ln CU. \quad (6)$$

Where *TFP* is total factor productivity, s_{KP}, s_L are shares of private capital and labor respectively. Aschauer finds evidence that a 1 percent increase of public capital stock leads to a 0.39 percent increase of total factor productivity. After the fifties and sixties, when average growth rate of total factor productivity reached 2 percent per annum, *TFP* growth fell in the USA to 0.8 percent in the 1971 to 1985 period. Before Aschauer, the economists explained the decrease in total factor productivity growth by energy prices, research and development, social regulation etc. (Gramlich 1994, p. 1176). According to Aschauer, such a dramatic decrease in productivity was caused by the fall of the level of public investment. The strong positive correlation between public infrastructure and total factor productivity has given rise to the so called "public capital hypothesis" (Seitz 1993). According to this hypothesis the infrastructure raises the marginal product of private capital and is important for private firms' start-ups[3].

At this point it is worth mentioning that the results of the first works at the beginning of the 1990s were quite similar to those of Aschauer. For example, Munnell (1990a) shows that elasticity of average labor productivity with respect to public capital in the USA in the period 1949 to 1987 was between 0.31 and 0.37, which is very near to Aschauer.

Most of the articles examining the role played by public infrastructure investments in the economic growth of the USA were published in the early nineties. At first glance it appears strange that after mid-nineties there are very few examples of econometric estimates of public capital in America. It looks odd in comparison with Europe and other continents, where such econometric studies were and still are very popular. However, one should remember that the nineties and the beginnings of the 21st century were a period of productivity boom in the USA. The main cause of this boom was high labor effectiveness. The stock of public capital in the USA after mid-nineties has not increased rapidly. These facts could make the American economists look for other causes of changes in productivity.

There are many doubts among economists about the results of Aschauer is works. The high rate of return to public capital obtained by Aschauer seems to be particularly implausible. There is a number of logical and econometric problems. Firstly, one should answer what exactly public capital is and what do we know about the measurement of infrastructure.

2.2. What is public capital?

There are some important differences between "infrastructure" and "public capital". It is difficult to define the two concepts. One of the economists claims that: "infra-

[3] Public capital hypothesis is very similar to the conception of "Big Push" put forward in the fifties by Rosenstein-Rodan (1959).

structure is what most people consider it to be" (Button 1998, p. 150). According to Gramlich (1994, p. 1177) one of the possible definitions is to treat infrastructure as large capital intensive natural monopolies, which means for example: transport and communication infrastructure, water and sewage systems and energy supply. This is known as technical infrastructure. Tatom (1993a, p. 391) argues that public educational buildings, hospitals, prisons, courts or police and fire protection constitute part of infrastructure. Therefore, according to Tatom, social infrastructure is equally important. The problem is that many of said types of infrastructure, especially technical infrastructure, are private or built as public-private partnership. It is worth mentioning that the European Union enhances and strengthens the PPPs in infrastructure and such a tool appears to be more and more popular. It seems difficult to distinguish between private infrastructure capital stock and other private capital. For this reason, the OECD countries most frequently use the narrow definition of public capital which focuses on infrastructure owned by the public administration.

According to Mas et al. (2000), Spanish economists, who conducted an ambitious project that resulted in the private and public capital stock series for Spain, the definition of public capital refers only to durable, tangible and reproducible assets. Therefore, the intangible assets or value of land should be excluded from the definition. Capital is divided into three groups: private capital, capital owned by the public administration and the remaining infrastructures. The third group comprises infrastructures owned either by public enterprises or by private firms receiving public support. Toll highways and motorways, airports, railways, autonomous ports are not regarded by Spanish economists as public administration stock. This means that the major part of the infrastructure system does not belong to the narrow definition of public capital.

In every country more or less infrastructure may be considered "public capital". The distinction depends on the structure of ownership. However, a definition of public capital still leaves the problem of how to precisely measure it. The most frequently used procedure in many OECD countries is the Perpetual Inventory Method.

2.3. Measuring public capital stock with Perpetual Inventory Method (PIM)

The PIM derives public capital stock from accumulation of public infrastructure investment series. The public capital statistics carried out in the OECD countries using the PIM show that the public capital stock is obtained by accumulating past purchases of infrastructures over their service lives (Blades 1999). Some basic information needs to be gathered for the PIM. One should know the statistics on gross fixed capital formation, specific deflators, consumption of fixed capital (physical deterioration, obsolescence or damage), average service lives of different infrastructure assets and the mortality functions of these assets. To obtain net capital stock one should estimate gross public capital formation and then subtract accumulated capital consumption from gross capital stock. The proper use of price deflator, correct service lives and mortality function and the choice of depreciation method of public capital may pose difficulties in the research.

First, sector-specific deflator should be available because the use of incorrect price deflator can lead to large errors in public capital stock estimates. It happens because the infrastructure assets, namely buildings or construction works, are unique goods. The solution is to use the model pricing. However there is also a problem with the impact of technological changes of assets on prices (Blades 1999).

Table 1. Service lives for transport infrastructure by four countries

	Spain	USA	Canada	Netherlands
Roads pre 1965	60	60	33	35
Roads post 1965	40	60	33	35
Railways	40	60	52	35
Ports	50	60	37	35
Airports	20	—	33	35

Source: Blades (1999).

Second, precision of estimation of public capital stock depends on the chosen average service lives of assets. The service lives may be obtained from government agencies, expert advice or just from other countries' estimates. One should note that these estimates significantly differ from country to country (Table 1). Since one might expect huge differences between countries, the correctness of international research in the area of public capital productivity is a serious problem. Another problem refers to technological progress that makes the product cycle become shorter. Additional problem that may arise when dealing with service lives of public capital assets is the climate effect that can lead to differences in retirement between parts of the infrastructure of the same type. When thinking of the highway system the examples are: bridges, tunnels and their elements. The further disaggregation of infrastructure appears to be the obvious impossibility. There is usually some kind of simplicity when one function of retirement is used for the whole highway system (Fang 1998).

Third, there is a problem of mortality patterns among different groups of capital. The information on the distribution of retirements around the average service life is very often difficult to obtain. Four types of mortality and survival functions are also discussed: simultaneous exit, linear, delayed linear and bell-shaped (OECD 2001, p. 53). The most frequently used one is Winfrey S-3 survival function. The Winfrey S-3 is one of the bell shaped mortality pattern (Figure 1). In this kind of mortality pattern, the rate of retirement (R) rises gradually after infrastructure investment has

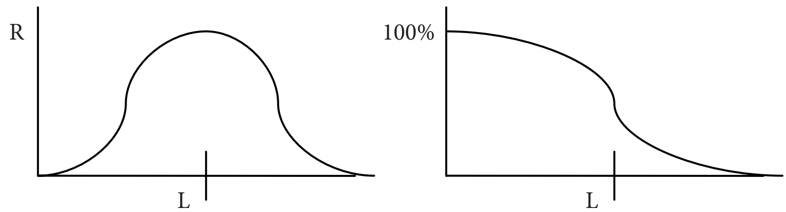

Figure 1. Bell-shaped mortality and survival function
Source: OECD 2001, p. 53

been finished. When an asset is nearing its average service life (*L*), the (*R*) is getting faster. The fastest rate of retirement oscillates around its average service life. After reaching its average service life highways, railways or educational buildings are getting older more slowly. Survival function shows the percentage of infrastructure assets still providing services during the life of the oldest one. According to the mortality function used by the Bureau of Economic Analysis (BEA), the retirement of public capital assets starts at 45 percent of the average service life and ends at 155 percent of the average life (Munnell 1990b, p. 216). Again it seems rather problematic to assume that all infrastructures retire this way.

Fourth, the results of public capital performance measurement depend on the depreciation method chosen. Depreciation shows predicted losses in asset's value over time. There are two methods of depreciation commonly used in the PIM: straight-line and geometric. In the straight-line method, the market value of an asset decreases by the same amount annually. This method is more popular than the geometric one. In the latter, the same rate of decrease per annum is observed. It means that by using the geometric depreciation method one can assume that the value of an asset would never equal zero. The life of an asset is infinite.

The last stage of the PIM procedure is to estimate the net value of public capital stock. As it has already been mentioned above, the net value of an asset equals gross value minus depreciation. Using a straight-line depreciation method, one can obtain net public capital value. It is possible then to use mortality function. Another approach would be to use a geometric depreciation method without retirement pattern (Fang 1998).

One should remember that econometric estimates of infrastructure productivity effects refer usually to net public capital stock. However, neither net nor gross public capital stock series are able to show precisely the effect of infrastructure investment on private sector productivity. On the one hand, the estimates based on the gross public capital stock treat all infrastructures as if they were new. On the other hand, considering net capital stock series, all the existing assets of the same type are amortised in the same way. However, many old assets provide the same quality of services as fast new infrastructures. Another difficulty is that the authors of the works that rely on aggregate time-series data do not pay enough attention to the differences in the intensity with which public capital is used. For companies the stock of public capital is much less important than the amount of services it provides. Therefore it is postulated to adjust public capital series by some appropriate index to reflect the use of public services by various sectors (Satya 2003). It should be also noticed that thanks to intelligent transportation systems and proper management one can ensure better access to transport infrastructure. The same can be obtained thanks to using a more flexible pricing system. By reducing congestion the access to infrastructure can be improved without the need to impose more taxes on new highways or railways. In other words, better management would not be reflected in aggregate capital stock series used in the PIM. All of the above mentioned problems should be taken into account.

2.4. Spurious regression, missing variables and causality

Leaving the problems of inappropriate estimates of public capital stock, several authors have remarked that there are also many econometric problems connected with single-equation regression model used by Aschauer. The macro-econometric problems are: spurious regression, missing variables or the direction of causality.

Most of the early works rely on single-eqution regression of aggregate time-series data. The data series used in the models are often not stationary. They are "drifting" in similar directions over time. One should remember that a long-term relationship with OLS regression requires that the variables used are stationary. The non-stationarity problem omitted by many researches needs to be taken into account. The correlation does not mean causality if we estimate common trends. The estimated correlations may be therefore "spurious". Hulten and Schwab (1993, p. 166) give as an example the "stork and baby" story. There is a strong positive correlation between the number of storks and the number of new-born babies in a particular area. This does not mean that storks bring babies. The concise explanation is that if the weather in the region is fine, the harvest is good, drawing storks to this particular area. On the other hand, better harvest generates bigger income for farmers who are more likely to have more descendants.

A common way to deal with the problem of spurious regression is to first-difference the data (year-to-year changes in the measures of public capital instead of the levels). According to Tatom (1993a) constructing a series of first differences is absolutely necessary for correctness of estimation of non-stationary variables. Detrending the data to induce stationarity gives usually much lower marginal product or rate of return of public capital. Very often reestimating the model after first differentiating the data leads to the conclusion that the effect of public infrastructure on economic growth is insignificantly different from zero. The estimation results may lead to doubts regarding the correctness of the "public capital hypothesis".

Another important issue is the problem of missing variables. The critics of Aschauer have argued that his estimates overstate the impact of infrastructure on productivity by ignoring other factors. Gramlich (1994) claims, that the decrease of public infrastructure expenditures was one of many usual explanatory variables of lower productivity level in the USA after the oil shocks in the seventies. If we include the price of energy into production function, the elasticity of output with respect to public capital falls to 0.13 (Tatom 1991)[4]. The new growth theory also indicates the importance of such production factors as knowledge, human capital or research and development. The estimates of public capital productivity very often lack reference to all these factors. There are also many other factors that probably make production more efficient, but it is extremely difficult to prove it by econometric estimates, eg. computers whose positive impact on output and productivity is often not caught by productivity statistics. One may consider it unusual that in the eighties and the early nineties, when microcomputer revolution in the world began, the USA experienced lower productivity growth.

In addition, there is a problem of the direction of causality. This problem is associated with single equation models. Since the variables of the regression studies are likely to be endogenous, causality may run in both directions. If all infrastructures were a normal good (if demand for infrastructure increased when the income increases) one would expect a higher stock of public capital in richer countries and regions than in the poor ones (Hurst 1994, p. 62). This would happen, because higher incomes would lead to higher demand for vehicles and more "bottlenecks". Moreover, the increased output would also raise public revenues from taxes. This would lead to the increase of public expenditure. If this was the case, Aschauer's public capital hypothesis would have to be rejected. It is just as possible for output growth to cause changes in public capital stock as it is for more infrastructure investments to cause an increase of private sector productivity. According to the critics of Aschauer's approach, if only Aschauer had used in equations (3), (4) and (6) public capital as an endogenous variable (on the left side of the equation) and output as an explanatory one, he would have obtained a strong correlation. It could be assumed that the decline of the US productivity since the beginning of the 1970s was the cause of the decrease in public infrastructure investments (Hulten and Schwab 1993).

Although it is difficult to determine the direction in which the causality runs, a number of studies have applied the Granger causality test to the data. If past values of one variable, refered to as x, are statistically significant in a regression of y on x, x is said to Granger cause y. According to the definition of causality proposed by Granger, public capital causes the changes in private sector productivity if productivity can be better predicted by using lagged values of public capital stock than without them. Tatom (1993b) does a series of lead-lag tests, up to four years earlier,

[4] Gramlich (1994) has criticized that using energy prices would mix production functions and cost functions. He has suggested using energy quantities instead of energy prices.

to examine the direction of causality between public capital and the growth rate of business sector total factor productivity. His conclusion is that in the years of 1949-1991 the Granger test showed strong evidence of reverse causality. It means that the increase in private sector productivity leads to the growth of public capital stock[5].

Fernald (1999) does not agree with the direction of causality that results from Tatom's study. He asks how highways affected the economic performance of the US industries in the 1953-1989 period. According to Fernald, more vehicle intensive industries are the ones that benefit from additional road infrastructure the most. If there exists correlation between the productivity of industries with higher vehicles share and highway infrastructure, then one would expect to find that highways contribute to productivity. However, if one assumes, following Tatom (1993b), that transport infrastructure is an endogenous variable – as the output rate of growth rises, the government is likely to spend more money on public infrastructure. In this case one cannot expect a particular relationship between the productivity of the industries that are more vehicle intensive and public capital spent on highways. However, if elasticity of productivity of the industries with higher vehicles share with respect to public capital is higher than the elasticity in other industries, infrastructure can be regarded as an exogenous variable. Fernald claims that before 1973 the vehicle-intensive industries benefited disproportionately from massive road-building capital of the fifties and sixties. Moreover, the slowdown in productivity after 1973 appears larger in the industries with a lot of vehicles. It was also a time of decline of public expenditure on highways. All of these facts lead to the conclusion similar to the results of the first wave of works on public capital. Moreover, the elasticities of productivity with respect to public capital obtained by Fernald are very similar to these of Aschauer (1989).

The vector autoregression procedure (VAR) allows to overcome the problem of the direction of causality. The multivariate time series approach is frequently used for forecasting systems of interrelated time series. The single-equation framework excludes the dynamic feedbacks among the model variables which are essential to understand the relationship between public infrastructure and economic performance (Pereira and Roca-Sagales 2002). For example, if Cobb-Douglas production function is employed, there is a division between endogenous variables and exogenous variables. In the VAR models all variables are treated equally, as the explanatory variables. The VAR is "atheoretical". The economic theory is lacking comparisons with the structural approach to time series modelling. It can be treated as a drawback of the VAR but the truth is that the economic theory is often not rich enough to identify all the relationships within the economic system. The VAR approach treats every endogenous variable in the system of equations as a function of the lagged values of all the endogenous variables in the system.

[5] If the causality runs from economic exploitation to infrastructure generation, it agrees with the Keynesian approach (Button 1998, p. 151).

The Engle-Granger method can be used for identifying cointegration. Using this method Pereira and Roca-Sagales (1999) showed that public investment is an important factor in aggregate economic growth. They assess regional effects of public capital formation on private sector performance – output, employment and capital. Their results suggest that infrastructure investments crowd in private sector inputs and possitively affect private output. However, rich regions are the main beneficiaries and thus infrastructure is the source of increasing regional asymmetries.

The most common and efficient procedure used to vector autoregression is the multivariate stochastic cointegration tests of Johansen (1994) employed by Lau and Sin (1997). Johansen tests tend to find spurious cointegration more often than Engle-Granger test does. Lau and Sin come to a conclusion that public capital is not as productive as it was shown by Aschauer and many his followers. According to the results obtained by Lau and Sin, the estimated elasticity of output with respect to public capital over the 1925-1989 time period in the USA is only 0.11, smaller than the results of single-eqution regression studies.

3. The spatial disaggregation

The debate on the role of public infrastructure has shown the importance of the level of geographical disaggregation in the estimation of public capital stock. Meeting the need for regional estimates is especially important for choosing a direction for regional policy. It is also recommended because of the network character of infrastructure and the existence of spillover effects (Mas et al. 2000).

3.1. Survey of regional studies

A number of studies have estimated Cobb-Douglas poduction functions for regions within a country. Munnell (1990b) wrote one of the first articles on regional disaggregation of public capital. Munnell's findings are based on pooled cross-section annual time series for 48 US states for the years 1970-1986. Munnell concludes that those states that have invested more in infrastructure tend to have higher output, more private investment and enjoy bigger employment growth. However, output elasticities are not so extraordinarily large relative to these in a controversial paper of Aschauer (1989). Munnell estimates an equation with the state's unemployment rate U that appears as an additional variable. Munnell reports results for "core infrastructure" as follows (1990b, p. 16):

$$\ln Y = \underset{(39.7)}{5.75} + \underset{(43.2)}{0.59} \ln L + \underset{(30.1)}{0.31} \ln KP + \underset{(9.0)}{0.15} \ln KG - \underset{(4.7)}{0.007} \ln U. \qquad (7)$$

The elasticity of output with respect to public capital is 0.15. The above elasticity coefficient was reduced to almost a third compared with the study by Aschauer. Munnell (1990b) specifies not only Cobb-Douglas but also translog functions. She interprets the OLS parameters estimates of the translog model as implying that private capital and labor are strong substitutes, private and public capital are hardly substitutable and public capital and labor are complementary variables (although in the last case the relationship is not statistically significant).

Other studies at the state/regional level gave the evidence for low productivity of public infrastructure. For example Holtz-Eakin and Schwartz (1994) and Hulten and Schwab (1991) estimate the elasticity of output with respect to public capital in the range of 0.00-0.15. Hulten and Schwab (1993, p. 267) compare two US regions – the Snow-Belt and the Sun-Belt[6]. They point out that in the late seventies and early eighties infrastructure investments grew more rapidly in the Sun Belt region, while at the same time higher growth of productivity was observed in the Snow Belt region. The above mentioned facts lead to the conclusion that there is no positive correlation between infrastructure investment and productivity.

Before Aschauer, Eberts (1986) estimated a translog production function with the data from 38 US metropolitan areas over the 1958-1978 period. He concluded that public infrastructure has a positive impact on economic growth, but the estimated output elasticity is a very low 0.03. According to the critics of Aschauer, the reason for such low elasticities of output with respect to public capital is that if one looks very closely, it is less likely to find a significant productivity effect of infrastructure (Hurst 1994). However, the economists, who support the public capital hypothesis, point out that low elasticities are the result of spatial spillovers not being taken into account.

Both supporters and critics of public capital hypothesis suggest that the results of the estimates of the regional impact of infrastructure are qustionable. First, the model should include specific characteristics of the area (region). Second, one should not ignore spatial externalities. Third, the value of past infrastructure investments should be taken into account.

Holtz-Eakin and Schwartz (1994) note that an appropriate model should include region specific characteristics such as land area, weather or location. For example, the lowlands and mountain areas should not be treated in the same way. The stock of public capital needed for the construction of a long mountain tunnel is much higher than building the same length of a lowland highway. The cost of construction differs in each case, although the service delivered is the same. For that reason, the low-cost infrastructure investments undertaken in convenient geographical conditions might seem more productive.

[6] The Snow Belt includes the New England, Middle Atlantic, East North Central, and West North Central Census divisions. The Sun Belt includes the South Atlantic, East South Central, West South Central, Mountain, and Pacific divisions.

Panel data techniques (pooled time-series and cross-section data) should be used to include specific characteristics of the area. One can choose between alternative specifications for intercept α_{it} in the following equation:

$$y_{it} = \alpha_{it} + x_{it}^{'} \beta_i + \varepsilon_{it}. \tag{8}$$

Where y_{it} is the dependent variable, and x_{it} and β_i are k-vectors of non-constant regressors and parameters for i = *1*, *2*, ..., N cross-sectional units, observed for dated periods t = *1*, *2*, ..., T.

If different constants are estimated for each pool member, we have fixed effects. Alternatively, the random effects treat intercepts as random variables across pool members. The random effects model assumes that the intercept is the sum of a common constant α and a time-invariant cross-section specific random variable that is uncorrelated with the residual ε_{it}. In order to choose between the model of fixed effects and model of random effects one can use the Hausmann test. The use of fixed- and random-effects models leads to better results than using traditional OLS estimation. Munnell (1990b) does not estimate fixed or random effects models. Therefore her estimates are subject to an important specification bias. According to Holtz-Eakin and Schwartz (1994), if high elasticities at the regional level are obtained, it means that the method used was inappropriate. They estimate the fixed effects model and show that the elasticity of output with respect to public capital is statistically significant but negative (-0.05). In contrast, by using a random fixed model the effect of infrastructure on regional economic performance appears statistically insignificant.

3.2. Spillover effects of public capital

Externalities are often viewed as an example of market failures. They play an essential role in the theory of economic growth. Infrastructure can be treated as a source of externalities that leads to increasing returns to scale. One should pay particular attention to spatial externalities (or spatial spillovers). Until now the existence of the regional spatial externalities from public infrastructure has received little attention. Regional decomposition of aggregate effects of the public infrastructure provision requires including spatial spillovers in the analysis. By ignoring spatial spillovers one might under- or overstate the impact of public capital on regional economic performance.

The network character of infrastructure refers to energy, water, sewers and transport. The most frequently estimated type of public capital is the highway capital. Highways are a typical example of network infrastructure and can be characterized by network externalities. One should expect the impact of highway capital on output and productivity growth not only in the region where the highway runs but also in many other neighbouring areas.

One might assume that interregional infrastructure is the main source of spatial benefits. According to the new economic geography models, especially the ones that focus on the problems of public policy[7], the development of interregional transport infrastructure is the cause of both generative and distributive effects. Rich regions are the main beneficiaries of the network infrastructure and poor ones are the main losers. Thus one should consider both positive and negative spatial externalities.

The existence of spatial spillovers from public capital investment has been tested in the literature[8]. Holtz-Eakin and Schwartz (1994) define the effective stock of public capital in region *i* – KG_i^E as:

$$KG_i^E = KG_i \prod_{j \neq i}^{N} KG_j^{\delta w_j}. \tag{9}$$

Where KG_i is the observed stock of public capital in region i, w_j is the weight of other region's capital, and the parameter δ measures the effect of the public infrastructure in the first, second and third round neighbouring regions on the effective public capital stock in region i. If δ is significantly greater than zero it can be regarded as a test of the spillover effect.

Boarnet (1996) used a similar method to that employed in the study of Holtz-Eakin and Schwartz (1994). Boarnet examines the possibility of negative spillovers from highway and street capital. He uses data for California counties in the period 1969 to 1988. The estimated function form is then as follows:

$$\ln Y_i = \ln A_i + \alpha \ln KP_i + \beta \ln L_i + \gamma_1 \ln KGH_i + \gamma_2 \ln\left(\sum_{j \neq i}^{N} w_j KGH_j \right) + \varepsilon_i. \tag{10}$$

Where KGH_i is highway and street capital stock in county i, the term $\Sigma w_j KGH_j$ is the weighted sum of highway and street capital stock in all other counties where the infrastructure is supposed to affect the output in county i. Boarnet (1996) gives evidence of indirect economic effects across neighbouring counties. He also raises the problem of defining neighbours. The common border is the traditional meaning of neighbourhood. Boarnet uses two additional measures of the neighbour relationship. The first one is based on population density. The second measure refers to per capita income. Regions with similar population density or in the second case with similar income per capita can be regarded as close neighbours. Boarnet sug-

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[7] See, Baldwin et.al. (2003). The authors analyze the wide range of new economic geography models, focusing on the policy issues.

[8] The problem of spatial spillovers might be solved in the vector auto regressive (VAR) models. The example of this approach is Pereira and Roca-Sagales (2002). The authors point out the existence of spatial spillovers in Spanish regions in the period of 1970 to 1995. They emphasize the importance of the infrastructure situated outside the peripheral Spanish regions for these regions development.

gests that in the presence of negative spillovers the elasticities of output with respect to public capital tend to be smaller.

3.3. Benefits of interregional network

There are some problems arising from retrospective studies. First, the productivity of public capital may depend on the level of past investments in infrastructure. Munnell (1990b) argues that if the construction of a new highway leads to increasing returns to scale, the provision of an additional highway may not. The additional highway system may even result in diminishing returns to scale. Hulten and Schwab (1993, p. 269) reach the same conclusion. They point out that the first infrastructure network gives the largest benefits. The subsequent investments become less and less productive and their positive impact on growth is doubtful. The results of Fernald's (1999) estimates support the above mentioned ideas. Fernald points out that massive road building in the fifties and sixties was exceptionally productive. However, it offered only "a one-time boost" to the productivity. In the long run it did not affect the growth path of productivity. Roads provided after 1973 have not been exceptionally productive.

For these reasons, the retrospective studies are not the best way to forecast the future impact of expanding the infrastructure network. Moreover, the next argument against extrapolation is given by Hulten and Schwab (1993, p. 269). The authors suggest that, due to changes in the structure of the economy, the technical solutions that were sufficient for decades, might not be effective any more. New types of infrastructure are more popular than old ones. For example, railways were replaced by highways and highways are being replaced by air transport and telecommunication infrastructure. However, Rietveld (1989, p. 272) points out that one should not consider infrastructure life cycles in a simplistic way. He gives an example of high speed train network throughout Europe that has changed the image of intercity travel by train.

When considering the productivity gains of the infrastructure network, one may notice that the return on infrastructure investment is a nonlinear one. The rate of return increases in the curved line. First parts of the network are not exceptionally productive. Before the network is completed, connecting additional locations increases the usefulness of the entire network. The most effective is the final section of the road that completes the network. The productivity reaches the highest point when the network is completed. Expanding the network does not lead to additional benefits. An excessive level of infrastructure is undesirable. A simple ilustration of the relationship between the level of the network infrastructure and its productivity gains is given in Figure 2.

Whether the investment is part of a system of interregional infrastructure or intraregional one is extremely relevant. The importance of different consequences of

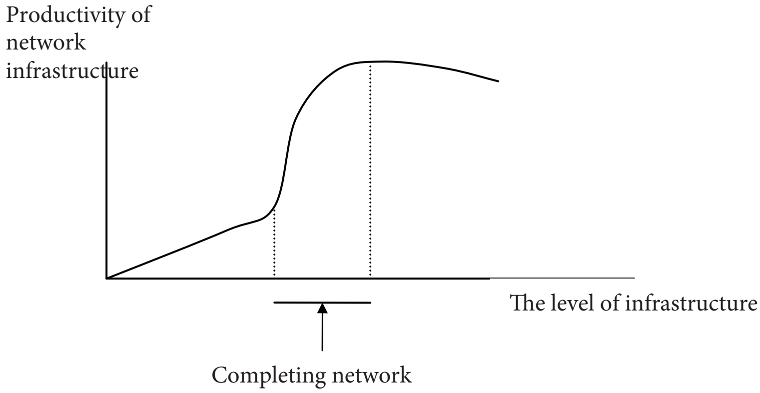

Figure 2. The level of network infrastructure and its productivity
Source: Own preparation

financing the above types of infrastructure is emphasized in new geography models. According to Martin (1998), the importance of the above distinction between types of transport infrastructure refers mainly to the poor, peripheral regions. If public capital is employed in the intraregional infrastructure and decreases the level of the transaction costs inside the poor region, then one could expect that this process attracts the firms and leads to the regional covergence. However, there are some restrictions on how the effects are distributed. Relocation of firms as a consequence of the agglomeration process and benefits from scale could not arise if the initial level of agglomeration in a poor region was very low.

Interregional infrastructure networks are the major ones. This type of infrastructure supports reductions of interregional transaction costs leading to further regional divergence. This is because the firms from a poor region are likely to go to a bigger market in the rich region where they can benefit from the effects of agglomeration and scale. Reduction of interregional transactions costs allows the firms to act in both regions from the richer one. The process of regional divergence is a natural consequence of removing interregional trade barriers by new highway investments. The examples that confirm the above conclusion are the cases of the south of Italy – *mezzogiorno* and East Germany. In both cases the improvement of interregional infrastructure has not decreased regional differences in economic growth. Another example is Galicia, a region located in the northwest corner of Spain. The region suffered for decades from low transport accessibility because of being surrounded by the mountains in the East. Thanks to the Structural Funds and government policy, the interregional transport connections with the rest of the country have improved significantly. However, better interregional transport accessibility could not stop, as in East Germany, the process of emigration from Galicia. During the last two decades of the 20th century the population of Galicia decreased by 120 000 people.

If more than two regions are considered, a decrease of transaction costs of interregional trade would not always lead to the regional divergence. The net effect depends on the geographical location of the regions. If a relatively poor region is located between two rich regions, it can benefit from improvement of interregional transport infrastructure. Baldwin et al. (2003) give the example of Nord-Pas de Calais in the north of France. The improved transport accessibility in the region is a consequence of expanding high speed train (TGV) connections between London, Paris and Brussels. The lowering transaction costs with the metropolitan areas have led to industrial relocation to the Nord-Pas de Calais transport knot. One should point out that the initial level of transaction costs is a very important issue. If that level is already quite low, the improvement of interregional trade via building a highway or a high speed train would not lead to significant changes in development. However, if the change of transaction costs between the poor, peripheral regions and the rich ones is high, then the regional differences might increase (Martin 1998).

4. The cost function approach

There are many drawbacks of the production function models. As Hurst (1994, p. 66) claims, it is difficult to assess whether the level of infrastructure is insufficient or excessive[9]. Another problem arises if one wants to include input prices into production function. Generally, the production function ignores the role of factor prices in the decision making process of a firm. The production function reflects only technological relations. For that reason an alternative, advantegeous approach is frequently used – cost function approach.

The cost function measures the impact of public capital on productivity in terms of cost-saving. In the cost function both inputs and outputs are endogenous variables. Factor prices are exogenous variables. The distinction between exogenous input prices and endogenous input quantities allows to overcome the problem of the direction of causality. Moreover, the cost function allows to determine the effects of infrastructure development through the measured rate of return specified in terms of cost-saving benefits at given production level. The drawback of the cost function approach is that it requires to assume an optimal mix of inputs. The above assumption is questionable at the industry or national level.

The basic aim of the cost function is to examine if the costs of output (cost of labor and cost of private capital) decrease with the higher public capital stock. The function looks as follows:

[9] Aschauer (2000, p. 360) finds that public capital is insufficient only if the marginal product of public capital exceeds the after-tax marginal product of private capital. According to Aschauer, the growth maximizing ratio of public capital to private capital in the USA during the seventies and eighties equals 0.444 for core infrastructure and 0.313 for other infrastructure.

$$C = C(w, r, t, Y, Z), \tag{11}$$

where C – total cost of private output, w – the price of labor, r – the price of private capital[10], t – time, as a proxy for technical change, Y – output, Z – public infrastructure services.

By taking the negative of the partial derivative of the cost function with respect to the public infrastructure services (using Shepard's Lemma) one can derive the shadow price (s_z) of the public capital. The shadow price, as the cost-side equivalent of the marginal product, reflects the reduction in variable costs of production due to an additional infrastructure investment (Morrisson and Schwartz 1996). The shadow price looks as follows:

$$s_Z = -\frac{\partial C(w, r, T, Y, Z)}{\partial Z}. \tag{12}$$

Similarly to the production function, one can derive the elasticities in the cost function approach. The shadow value can be translated into elasticity or "shadow share" measure:

$$\varepsilon_Z = s_Z \frac{Z}{C} = -\frac{\partial \ln C}{\partial \ln Z}. \tag{13}$$

The elasticity shows the percentage change in costs due to a 1-percent change in public infrastructure services. From the firm's perspective, the shadow price is a positive value. The public infrastructure is provided externally. New infrastructure investments are treated as benefits. However, if one takes into account the social rate of return of public infrastructure, the net effect is questionable. The social rate of return equals shadow price minus the social user cost of public capital. The estimation of social user cost is a rather complicated issue. However, Morrison and Schwartz (1996) claim that it is essential by evaluating the net effect of public infrastructure investment on productive performance.

The most frequently used cost functions are translog cost function and generalized Leontief cost function. The latter is used by Morrison and Schwartz (1996). Morrison and Schwartz apply the cost function to state-level data and estimate the effect of public capital on productive performance for US manufacturing in the period 1970-1987. Although infrastructure investments increase the productivity growth (the shadow value in all states exceeds zero) and the stock of public capital was in the research period insufficient, the net effect of increased public spending on infrastructure "may or may not be positive".

Satya (2003) investigates the effects of public infrastructure on the cost structure and productivity in seven private sector industries in Australia in the years 1967-1996.

[10] Morrison and Schwartz (1996) include also the price of energy inputs as an additional variable.

Empirical results show the importance of public infrastructure in this field. However, Satya concludes that the rates of return are much smaller in the cost function when compared with the production function. In the former case the rate of return is 0.25 while in the latter the rate of return is 0.68.

In Europe one of the first attempts of applying the dual cost function approach is an article of Berndt and Hansson (1992). They use annual data from Sweden from 1960 to 1988. Bernst and Hansson point out that although a decrease of public capital after 1974 contributed to the slowdown of productivity growth in the private sector, the impact is quite small. Seitz (1993) analyses the productivity of German highways in the years 1970-1989. His results look as follows: the contribution of public road infrastructure to the economic performance of the private industry is signi-ficiant, public capital and labor are substitutable, public capital and private capital are complementary variables. According to Seitz, the savings in costs related to the provision of public infrastructure varies dramatically across different industries. The highest shadow value is obtained in the chemical industry, mechanical engineering, road vehicles and electrical engineering. Bosca, Escriba and Murgui (2002) find the shadow prices of public capital in all the Spanish regions over the period 1980-1993 positive and significant. According to the Spanish authors, there is still a gap between the observed and optimal public capital stock in Spain.

After conducting an analysis of cost function studies one may conclude that the elasticities obtained in most cost-function studies are lower compared with those received from production function.

5. Short and long-term employment consequences

Public infrastructure has both demand and supply effect. The demand effect is short-term while the supply effect is more medium- and long-term one. The short-term effect of public investments on employment is generally easy to analyse and measure. For that reason this effect dominates in cost-benefit analyses of infrastructure investments. The Keynesian multiplier shows that the increase in public expenditure leads in the short term to the growth of income and employment, especially in the local case. According to Martin (2000, p. 75), the impact of new construction on employment will be stronger in the regions with high unemployment rate.

However, the impact on employment is much more complicated. For example, in one of the US studies concerning the effects of a highway construction program on employment (measured as person-years of full-time employment) are estimated at three points in the economic process (OECD 2002). They are called three rounds of effects. The first round effect means “direct” employment. It occurs when capital expenditures on highway projects lead directly to the creation of new jobs in the highway construction industry and in the other sectors of the economy that supply construction materials and equipment. The second round effect refers to "indirect" employment. It occurs when the beneficial sectors of the first round expand output and employment to fulfil the new demand for construction industry. The second round effect concerns employment gains not only in business services, transportation and warehohousing and wholesale trade but also many jobs in finance, insurance, real estate, chemicals, crude petroleum and natural gas and many others. Finally, the third round effect can be regarded as "induced" employment. It occurs when new employees from the beneficial sectors of the first and second round spend their income and create a higher demand this way. The aggregate output and demand for all goods and services rise. The highway spending multiplier of the first and the second round is 2.34 while the multiplier of all three rounds is 4.77.

It is worth mentioning that the supply effect is considered by economists, especially those dealing with econometrics much more frequently than the demand one (Ratajczak 1999). One should notice that the long-term supply effect of public investment in a poor region may be exactly opposite to the short-term demand effect. The new economic geography points out that the reduction of transaction costs may lead to concentration of firms in the rich regions and regional divergence (Martin 2000).

6. Conclusions

The nineties and the beginnings of the 21st century is a time of a fruitful debate on the effectiveness of public infrastructure networks in Europe. There are many studies in this area, especially in the so called "cohesion countries": Spain, Greece, Ireland and Portugal which have been supported by the Structural Funds. It is important to mention that there have hardly been any empirical studies concerning the productivity effects of public capital in new members of European Union so far. One may consider it unusual due to the fact that many of these countries expand the infrastructure networks and are the main beneficiaries of the structural aid. The survey of the results from empirical studies on the impact of public capital is shown in the Table 2.

The econometric estimates of the impact of public capital on productivity are undoubtfully the most used research method to measure the socio-economic effects of infrastructure. However, since this issue is very complicated, the results of these studies are questionable. The problems that arise from using macroeconomic modelling are as follows:

First, it is difficult to define the quantity of public capital stock. The difficulties concern proper usage of price deflator, correct service lives and mortality function and the choice of depreciation method of public capital.

Second, the econometric problems like spurious regression, missing variables and the direction of the causality may raise doubts about the observed high correlation coefficients in the single-equation models.

Third, the results of aggregate time series do not show the real regional consequences of public infrastructure investment. However, one should point out that difficulties arise also when regional estimates on the impact of infrastructure are taken into account. The appropriate regional model should include specific characteristics of an area (region). One should not ignore spatial externalities. Finally, the level of past infrastructure investments should be taken into account.

Table 2. The survey of the results from empirical studies on the impact of public capital

Country	Authors	Publication year	Level of aggregation and period	Type	Elasticity
USA	Aschauer	1989	National, 1949–1985	Output TFP	0.36 0.39
USA	Munnell	1990	National, 1949–1987	Output	0.31 to 0.37
USA	Fernald	1999	national, 1953–1989	TFP	0.35
USA	Hulten and Schwab	1991	National	Output	0.21
USA	Tatom	1991	National, 1950–1988	Output	0.03, not significiant
USA	Lau and Sin	1997	National, 1925–1989	Output	0.11
USA	Munnell	1990	States, 1970–1986	Output	0.15
USA	Morrison and Schwartz	1996	States, 1970–1987	Cost	0.16
USA	Eberts and Fogarty	1987	Municipalities, (1958–1978)	Output	0.03
Japan	Mera	1973	Regional, 1954–1963	Output	0.20 to 0.40
Sweden	Berndt and Hansson	1992	National, 1964–1988	Output	0.68 to 1.60
Germany	Seitz	1993	National, (1970–1989)	Cost	–0.13 to –0.15
Spain	Pereira and Roca-Sagales	2001	National, 1970–1993	Output	–0.39 to 1.23 0.52 all sectors
Spain	De la Fuente and Vives	1995	Regional (1981–1990)	Output	0.21
Spain	Mas et. al.	1998	Regional, 1964–1993	TFP	0.11
Greece	Mamatzakis	1999	Sectoral, 1959–1990	Cost	–0.02 to –0.78
Greece	Rovolis and Spence	2002	Regional, 1982–1991	Cost	–0.058 to –0.071
Greece	Dalamagas	1995	National, 1950–1992	Output Cost	–1.24 –2.35
Ireland	Kavanagh	1997	National,1958–1990	Output	0.14, not significiant

Source: Own compilation based on Bradley, Morgenroth (2004, p. 38).

Fourth, there are many drawbacks of using production function models. It is difficult to assess whether the level of infrastructure is insufficient or excessive. Another problem is that the production function reflects only technological relations and ignores the role of factor prices in the decision making process of a firm. For that reason, an alternative, advantegeous approach is frequently used – cost function approach.

Fifth, the effects of an increase of public capital stock may differ between the short medium – and the long-term.

Sixth, the retrospective studies are not the best way to justify future expenditures on the infrastructure network. Due to the changes in the economic structure, technical solutions that were sufficient for decades might not be effective any more. For example, railways were replaced by highways and highways are being replaced by air transport and telecommunication infrastructure.

Finally, it should also be noticed that thanks to intelligent transportation systems and proper management, one can ensure better access to transport infrastructure. The same effect can be obtained by using more flexible pricing system. In other words, better management would not be reflected in aggregate capital stock series.

The conclusion of the paper is that public capital has a positive influence on growth when one uses data from the whole economy. However, the relationship between the level of public capital and return to infrastructure investment is non-linear. With respect to a relatively low level of infrastructure services – the provision of public capital improvements is effective. Moreover, taking into account the results of many empirical researches and new economic geography theory, one should add that interregional infrastructure can lead to regional divergence rather than convergence.

The statistical regional database for Poland and other Eastern European states including public capital data at regional levels, should be created. Such a database is needed to help to analyse the possible impact of infrastructure on regional development. Although it will be difficult, it is important as a future direction of research in this area.

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