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Public infrastructure capital, scale economies and returns to variety

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Abstract

The recent resurgence of research on infrastructure has basically used simple production and cost functions. The results obtained have given some indications of the relationship between public infrastructure and economic and regional growth, though the direction of this relationship still remains somewhat unclear. Even more recently different ways of approaching this relationship have been developed that involve the construction of economic growth models incorporating public capital as a basic parameter. There are several differently formulated examples in the literature but one is of particular relevance here. Holtz-Eakin and Lovely (1996) sought to model a small, open economy, with two sectors, one producing consumption goods and the other finished manufactured goods. In this economy there are two production inputs - labour and capital - and the basic question posed concerns the likely effects of an increase in public capital. This paper is about the role of public capital in the development of different sectors and regions of the Greek economy. First, the findings for the non-manufacturing sector of the economy are considered. More specifically, the role of the impact of public capital on the regional Gross Domestic Product and its sub-categories are analysed using of quasi-production functions. Second, the manufacturing sector is considered in terms of the Holtz-Eakin and Lovely model. This delineates two channels by which infrastructure affects the secondary sector: one by altering the scale of production (and subsequently the level of total manufacturing output) and the other by affecting the equilibrium number of manufacturing establishments or returns to variety. Empirically, the paper approaches these themes on four different spatial levels.

1 Introduction

The recent resurgence of infrastructure research has basically used production and cost function analytical frameworks. The empirical results obtained by these approaches have given some indications as to the relationship between the public infrastructure and economic and regional growth, even though the direction of this relation still remains somewhat unclear in some cases (see Gramlich's (1994) review essay, Sturm's (1998) book, and the collected volumes edited by Munnell

(1990) and Batten and Karlsson (1996) for a more extensive presentation of the theoretical debate). More recently a different way analysing this relationship has been formulated that basically involves the construction of economic models incorporating public capital as one of their basic parameters.

Several such models have been proposed with the objective of combining infrastructure research with dynamic growth modelling. Barro and Sala-i-Martin have used the production function approach, as well as attempting to model the impact of infrastructure on different economic growth rates. Their overall conclusion was that public capital could well have a positive effect on the growth process (Barro 1990, and Barro and Sala-i-Martin 1992). Similar to these models is that presented by Alogoskoufis and Kalyvitis (1996), the main difference being that these authors did not assume that the economy achieves a new steady growth rate¹ immediately.

Holtz-Eakin and Schwartz (1994), also using a neoclassical growth model for the (48 contiguous) US states, concluded that infrastructure does not play “*an important quantitative role in the explaining the growth patterns of the states*” (p. 20). However, they noted that their results must be viewed with the caveat that the model does not allow for any interaction between public capital and private investment incentives.

All the aforementioned models have shed some light on the mechanisms by which public capital transmits its effects to the economy of the private sector. Some of them are at a totally theoretical level. Others have been used for empirical research. However, it has not been possible to use any of them to analyse the different spatial levels of the Greek economy due to the existing data limitations. Instead, a complete model of a small open economy is has been used here which incorporates public infrastructure capital, and is similar to that presented by Holtz-Eakin and Lovely (1996). Section 2 of this paper offers the theoretical construction and assumptions of the model.

Following this, the next part presents the empirical results for the different sectors and spatial levels of the Greek economy. These results can be classified under two major headings. First, the findings for the non-manufacturing sector of the economy are provided. More specifically the role of the public capital in impacting upon the regional Gross Domestic Product (GDP) and its sub-categories, has been analysed with the use of quasi-production functions.

Secondly, the results for the manufacturing sector of the economy are presented. The Holtz-Eakin and Lovely model delineates two channels by which infrastructure affects the secondary sector: one by altering the scale of production (and subsequently the level of total manufacturing output), and the other by affecting the equilibrium number of manufacturing establishments, perhaps better described by the phrase ‘returns to variety’. There are again four different spatial levels for the empirical investigation of the Greek case. The first refers to a regional panel based on the Greek

¹ For an introductory analysis of the term ‘steady growth rate’ see Jones (1998) or Mankiw (1997).

prefectures, though, at this level there is no sectoral breakdown. The second is that of a sectoral breakdown for Greece as a whole. Third, is the sectoral breakdown for the metropolitan area of Athens. The findings for Athens are then compared to those obtained in the fourth and last level that represents the sectoral breakdown for manufacturing in the Rest of Greece.

The final part of this paper draws some basic conclusions from the empirical analysis based on the modelling. These results are then compared to those of the Holtz-Eakin and Lovely paper for the US economy, and have been also used to put this analysis in perspective. More particularly, the results for the infrastructure's impact on a number of establishments are compared to recent findings and research.

2 Scale economies, returns to variety, and public capital

One of the most important recent models used in public capital research was that constructed by Holtz-Eakin and Lovely (1996). There follows a concise presentation of this model, which has been the basis for the empirical analysis for the Greek case. It has to be noted that the origin of the model can be attributed to the research by Ethier (1979, 1982). The economy of the model is sketched as a small, open one, with two sectors, one producing consumption goods ('wheat' in the Holtz-Eakin and Lovely terminology²) and the other finished manufactured goods ('manufactures' as they call them). In this economy there are two production inputs (factors of production), labour and capital³.

In the model, consumption goods are produced by firms that operate under perfect competition. The perfect competition framework implies constant returns to scale (in the use of the two production inputs). The model ascribes a sector for the production of intermediate goods ('components' as they are termed. These intermediates are necessary for the production of the final goods of the manufacturing sector. It is hypothesised again that the intermediate goods sector is operating under perfect competition.

The two production factors, labour and private capital, can be used either for the production of consumption goods (W), or for the production of 'factor bundles' (m). The latter are used as inputs for the production of the intermediate goods. It is assumed that there is the following transformation function⁴ for the economy (as the quantities of the production factors are given):

$$W = f(m) \tag{1}$$

² Here, some of the terminology is different to that of Holtz-Eakin and Lovely.

³ This model can easily be extended for the case of three production inputs, private capital, labour, and land (see Holtz-Eakin and Lovely (1996), footnote 6).

⁴ The 'transformation function' is a description of the technologically efficient plans (of the particular economy), or, equivalently, this function picks out the maximal vectors of net outputs (Varian 1992). Equation 6.1 may be represented by a production possibilities frontier, which is convex to the origin. This implies that the first derivative of equation 6.1 is $f'(m) < 0$, and the second derivative is $f''(m) \leq 0$ (see, for this point, Holtz-Eakin and Lovely (1996), p. 108, and for the convexity of transformation functions in a multioutput context refer to Chambers (1988), pp. 260-261).

In the Holtz-Eakin and Lovely model consumption goods (wheat) are used as numeraire (p. 108). As consumption goods and factor bundles are produced and sold under conditions of perfect competition, their relative price will be:

$$P_m = -f'(m) \quad (2)$$

This comprises the opportunity cost for the production of factor bundles.

As was mentioned earlier, factor bundles are used for the production of intermediate goods. Intermediate goods, in turn, are used for the production of the final goods of the manufacturing sector, in a manner described by the following production function:

$$M = n^a \left[\sum_{i=1}^n \frac{x_i^b}{n} \right]^{\frac{1}{b}} \quad (3)$$

where x_i is the input of intermediate good i into the production of final goods of the manufacturing sector, M . It is supposed that there are n varieties of intermediate goods in the model economy. Parameter a is a measure of economies of scale with respect to the range of intermediate goods ($a > 1$ denotes increasing returns to variety). Parameter b is a measure of the degree of differentiation between any pair of intermediate goods, as it has been assumed that they are imperfect substitutes⁵. Higher (lower) values of b denote less (more) differentiation among the intermediate goods. Holtz-Eakin and Lovely pointed out that ‘intermediate goods’ (components in their terminology) have been interpreted in different ways in the existing examples of similar economic modelling⁶. In any case, the crucial point is that the final goods production process is dependent on a wide variety of specialised services and goods (see for this point Holtz-Eakin and Lovely 1996, p.109). They assumed that all varieties of intermediate goods have identical production technologies, and argue that “*since each variety enters symmetrically into the production of finished manufactures, in equilibrium an identical quantity, x_0 , will be supplied of each variety*” (ibid.). Under this assumption, equation 3 will become:

$$M = n^a x_0 \quad (4)$$

It is obvious from this last equation that the final goods of the manufacturing sector are linearly homogeneous in input x_0 , and homogeneous to degree a in n . It is assumed that there are many competitive firms which produce final goods using the intermediate factor bundles. For this reason Holtz-Eakin and Lovely (1996, p. 109) argue that “*each of [these firms] takes n as given*” and, more crucially, that the n varieties of intermediate goods can be viewed as an index of the range

⁵ The elasticity of substitution between any pair of intermediate goods is $1/(1-\beta)$.

⁶ See, for instance, Holtz-Eakin and Lovely’s own interpretation (1996), Ethier’s (1982) as specialised intermediate inputs, or Markusen’s (1989) as producer services.

of economic activity in an economy. Higher values for n , in this context, indicate a more dynamic economy.

An increase of the public infrastructure can raise x_0 ⁷. But even in cases where there is no such increase, there is the possibility of an indirect increase of productivity, as there is the possibility that a change of infrastructure capacity can increase the number of n (therefore, the range of economic activity).

There are several other assumptions for the model used here. It is assumed that unlimited quantities of consumption and finished manufactured goods can be traded at P_m price. In the Holtz-Eakin and Lovely model it is assumed that intermediate goods are not tradeable⁸. It is also assumed that the producers of intermediate goods behave as monopolistic competitors (n is adequately large and there is free entry into this sector of the economy).

Each variety of intermediate goods (x) is produced by factor bundles, under the relationship $ax+b$, where $a, b > 0$. A certain part of the necessary factor bundles in the economy, such as road networks, sewage systems, etc, can be provided by the public sector. This will save private resources that would, otherwise, have been directed to the production of this infrastructure.

As Holtz-Eakin and Lovely point out, public infrastructure can decrease either fixed or variable costs, or both. If F is the reduction in fixed costs, and v the reduction in variable costs, then the production of x units of any variety of intermediate goods would require the use of a quantity of factor bundles given by:

$$Q(x) = (a - v)x + b - F \quad (5)$$

The private cost of these factor bundles will be:

$$C_{\beta} = P_m((a - v)x + b - F) \quad (6)$$

The marginal private cost for the intermediate goods producers will be:

$$MPC = P_m(a - v) \quad (7)$$

and the marginal revenue will be⁹:

$$MR = \beta P_c \quad (8)$$

where,

⁷ This case corresponds to the increases in productivity usually considered with production and cost function analyses.

⁸ This assumption is important for spatial analysis. Ethier (1979, 1982) assumed that intermediate goods can be traded. However, Markusen (1991) and Holtz-Eakin and Lovely (1996) presumed that intermediate goods (and services) that contribute to the manufacturing sector are unique to the local economy.

Thus, finished manufactured goods are “assembled from intermediate goods and services produced exclusively in the home jurisdiction” (Holtz-Eakin and Lovely 1996, p.110).

⁹ For the derivation of this marginal revenue, see Holtz-Eakin and Lovely (1996), footnote 9.

P_c is the price of each intermediate good.

This price can be expressed in the terms of the P_m numeraire. As the producers of intermediate goods will equate their marginal cost to their marginal revenue, P_c will be:

$$P_c = \frac{P_m(a-v)}{\beta} \quad [\text{as} \quad P_m(a-v) = \beta P_c] \quad (9)$$

The equation for the profit of each intermediate goods producer will be:

$$p = P_c x_0 - P_m((a-v)x_0 + b - F) \quad (10)$$

In equilibrium there will be free entry and exit of producers, and the profit p will be equal to zero. Equating equation 10 to zero and replacing P_c with the right hand side of equation 9, equation 10 will be:

$$\frac{P_m(a-v)}{\beta} x_0 - P_m((a-v)x_0 + b - F) = 0 \quad (11)$$

Rearranging equation 11 means that:

$$x_0 = \frac{\beta(b-F)}{(1-\beta)(a-v)} \quad (12)$$

Equation 12 can be interpreted as follows. As x_0 is increasing in b , the more a variety of intermediate goods can be substituted from other varieties, the more each firm will produce that particular variety.

In this model the demand for factor bundles comes from the producers of intermediate goods and the public sector (for the creation of the infrastructure stock). There are two extreme possibilities regarding the nature of the public capital. One possibility is for it to be a pure public good. Such goods are not excludable and non-rival, i.e. “*people cannot excluded from consuming them...and one person’s consumption does not reduce the amount available to other consumers*” (Varian 1992, p. 414). Another possibility is for it to be a public sector good that is little different from those produced in the private sector (in this case the goods are ordinary, that is both excludable and rival)¹⁰.

Holtz-Eakin and Lovely, in order to capture the whole range of possibilities (including the two extremes), sketched the total demand for factor bundles as:

$$m = n((a-v)x_0 + b - F) + n^y(vx_0 + F) \quad (13)$$

¹⁰ There can be many in between cases. On such intermediate type are the ‘club’ goods (nonrival, but excludable [see Varian 1992, p. 415]).

In the above equation it is parameter g that denotes the nature of infrastructure. If $g = 0$, v and F are pure public goods. If $g = 1$, v and F are pure private goods.

The supply price of the finished manufactured goods must be equal to P_m (prices are measured in terms of wheat)¹¹. The profits in the sector of the economy where the intermediate goods are assembled into final manufactured goods will be zero. This means that:

$$P_m M = P_c x_0 n \quad (14)$$

The above relationship can be transformed, with the use of equation 4, to become:

$$P_m = n^{1-a} P_c \quad (15)$$

It is apparent from the last equation that an increase in n will have, as a result, an increase in productivity, and subsequently a decrease in the supply price of finished manufactured goods. An increase of P_c , will have the opposite effect - that is it will increase P_m .

Holtz-Eakin and Lovely asked the question, what would be the effects of an increase of public capital¹² in the context of this particular model. The system of basic equations of the model (equations 9, 12, 13, and 15) can be used for the purpose of answering this question.

An increase in public capital would have, as a result, a change in the cost structure of intermediate goods (by changing the preferred levels of output). Equation 16 can be derived from equation 12 by total differentiation:

$$\hat{x}_0 = \frac{-F}{b-F} \hat{F} + \frac{v}{a-v} \hat{v} \equiv -\delta_F \hat{F} + \delta_v \hat{v} \quad (16)$$

where the symbol $\{\hat{\cdot}\}$ denotes proportional changes.

Equation 16 shows that increases in F will reduce x_0 , and increases of v will raise x_0 . Similarly, total differentiation of the other basic equations (equation 9, 13, and 15) provides that:

$$\hat{P}_c = \xi \hat{m} - \delta_v \hat{v} \quad (17)$$

and

$$\hat{m} = \phi_n \hat{n} + \phi_x \hat{x} - \phi_v \hat{v} - \phi_F \hat{F} \quad (18)$$

¹¹ As is usually the norm in economic modelling, a good (in this case wheat) ‘plays’ the role of money, and the prices for the other goods are calculated on the basis of how many units of wheat can be bartered for one unit of the particular good in question.

¹² It has to be noted that Holtz-Eakin and Lovely, in order to clarify the effects of an infrastructure increase, abstracted “from issues of distortionary-tax financing and assumed that government spending is funded by lump-sum taxation of households” (Holtz-Eakin and Lovely 1996, p.111).

$$[\text{where, } \phi_n = \frac{n((a-v)x_0 + b - F) + \gamma n^\gamma (vx_0 + F)}{m} \quad (19)$$

$$\phi_x = \frac{n((a-v)x_0 + n^\gamma vx_0)}{m} \quad (20)$$

$$\phi_v = \frac{(n - n^\gamma)vx_0}{m} \quad (21)$$

$$\phi_F = \frac{(n^\gamma - n)F}{m} \quad (22)]$$

$$\hat{P}_M = (1-a)\hat{n} + \hat{P}_C = 0 \quad (23)$$

Equation 17 shows the changes in the price of intermediate goods as a result of a change of public capital provision (the subsidy to variable costs, v). This equation also shows that P_c is affected by changes in m (factor bundles). Holtz-Eakin and Lovely argued that if resources are withdrawn from the production of consumption goods (the case where $\hat{m} > 0$), then the price of factor bundles will rise. The magnitude of this increase depends on the curvature of the production possibility frontier, \mathbf{x} (see Holtz-Eakin and Lovely, p. 112).

The changes in the demand for factor bundles are given by equation 18. It is clear from this equation that there are three sources of such changes. One results from changes in the number of intermediate goods producers (shown by the first term of the right-hand side of equation 18). Another source is changes of the production level of these producers (shown by the second term). Finally, government purchases can affect the demand for factor bundles (shown by the third and fourth terms).

Equation 23, which closes the system, shows the external price constraint on the supply price of finished manufactured goods. As this equation demonstrates, an increase (decrease) in the number [varieties] of intermediate goods will decrease (increase) the supply price (if $a > 1$). This change must be offset by the positive (negative) effect in the price of the intermediate goods.

Holtz-Eakin and Lovely, using this theoretical model, studied the effects of changes in public capital on the level of output and productivity in equilibrium. They first examined changes in that part of infrastructure that decreases fixed costs (that is, F). If the system of equations 16, 17, 18, and 23 is solved, it is possible to derive the proportionate changes in the price of intermediate goods, the demand for factor bundles, and the number of intermediate goods. These changes are given in equations 24, 25, and 26 respectively:

$$\frac{\hat{P}_c}{\hat{F}} = \frac{(a-1)\xi(\phi_x \delta_F + \phi_F)}{D} > 0 \quad (24)$$

$$\frac{\hat{m}}{\hat{F}} = \frac{(a-1)(\phi_x \delta_F + \phi_F)}{D} > 0 \quad (25)$$

$$\frac{\hat{n}}{\hat{F}} = \frac{\xi(\phi_x \delta_F + \phi_F)}{D} > 0 \quad (26)$$

where $D \equiv \xi\phi_n - (a-1) > 0$.¹³

The provision of public capital attracts production factors into the production process of intermediate goods. This has, as a consequence, an increase in the marginal cost of factor bundles (in terms of consumption goods). The producers of intermediate goods would pass on this cost, *ceteris paribus*, but only to the extent of their market power and in terms of a mark-up percentage). Holtz-Eakin and Lovely observed that “*an increase in component prices must be accompanied by an expansion in varieties if the economy is to retain a competitor in finished manufactures*” (Holtz-Eakin and Lovely 1996, p.113). Due to the mark-up, the intermediate goods industry will have profits at the initial phase of the economy (the phase with n varieties). These profits will generate entry of new firms into the sector producing intermediate goods. As Holtz-Eakin and Lovely argue “*an increase in public infrastructure increases the number of component producers and enhances any external economies of the finished manufactures industry*” (ibid.).

From equation 4 the proportionate change in finished manufactured goods is:

$$\hat{M} = a\hat{n} + \hat{x}_0 \quad (27)$$

An increase in the number of the firms producing intermediate goods does not ensure an expansion of the sector producing manufactured goods. It can also be seen in equation 16 that a public capital increase which reduces the fixed costs (F) will decrease the level of output of the manufacturing sector that is maximising profits. If the solutions for \hat{n} and \hat{x}_0 are substituted in the above equation, the effect of F on the manufacturing sector can be derived as:

$$\frac{\hat{M}}{\hat{F}} = \frac{\xi\delta_G(a\phi_x - \phi_n) + a\xi\phi_F + (a-1)\delta_G}{D} \quad (28)$$

The sign of the numerator of the right-hand side of equation 28 depends on the sign of quantity $a\phi_x - \phi_n$ (as all the other terms are positive). If this quantity is positive then \hat{M} will be positive. This will be the case if:

¹³ This condition is necessary in order to have a positive price-output relation for the manufacturing sector. This assumption restricts the analysis to the concave part of the production frontier for the consumption and manufactured goods (for further analysis, see Holtz-Eakin and Lovely 1996, footnote 11).

$$(a-1) > \frac{1-\beta}{\beta} \quad (29)^{14}$$

As Holtz-Eakin and Lovely helpfully point out “*the left-hand side of this equation is the rate at which the economy realizes returns to variety (see Ethier, 1982) while the right-hand side is a measure of the firms’ market power: the percentage mark-up over marginal cost. If the return to variety dominates the ability of firms to capture the returns to restricting output M will rise. Alternatively, if firms have sufficient market power to enforce greater mark-ups, the contraction of x_0 will dominate and M will fall*” (Holtz-Eakin and Lovely 1996, p.114).

In summary, it can be argued that changes in the provision of public capital can affect the economy in different ways depending, on the one hand, upon market structure, and, on the other, on technological factors.

Holtz-Eakin and Lovely argue that infrastructure changes do not affect the economy only by reducing the fixed costs (F), but also by reducing the variable costs (v). For the study of the effects of the latter they reproduced the aforementioned analysis for v . These effects are given by the following set of equations:

$$\frac{\hat{P}_c}{\hat{v}} = \frac{-(a-1)(\mathbf{x}(\mathbf{f}_x \mathbf{d}_v - \mathbf{f}_v) - \mathbf{d}_v)}{D} \quad (30)$$

$$\frac{\hat{m}}{\hat{v}} = \frac{\phi_n \delta_v - (\phi_x \delta_v - \phi_v)(a-1)}{D} \quad (31)$$

$$\frac{\hat{n}}{\hat{v}} = \frac{-(\xi(\phi_x \delta_v - \phi_v) - \delta_v)}{D} \quad (32)$$

Equation 30, 31, and 32 give the effects of the price of intermediate goods, factor bundles used in the production process of manufactured goods, and the variety of intermediate goods, respectively. It has to be emphasised that all these expressions can be either > 0 , or $= 0$, or < 0 .

Generally speaking, as these equations show, the net effects of the reduction of variable costs, due to an increase of public capital, are not too clear¹⁵. This can be seen in the following equation, which is the counterpart for variable costs of equation 28:

$$\frac{\hat{M}}{\hat{v}} = \frac{a\varepsilon\phi_v + \delta_v - \varepsilon\delta_v(a\phi_v - \phi_n)}{D} \quad (33)$$

¹⁴ For the derivation of this equation, see Holtz-Eakin and Lovely (1996), p.114.

¹⁵ See Holtz-Eakin and Lovely (1996), p 114-115, for an analysis of these ambiguities.

This equation can be either > 0 , or $= 0$, or < 0 . The sufficient condition in order to have

$\hat{M} > 0$ is that $a\phi_x - \phi_n < 0$ ¹⁶.

Holtz-Eakin and Lovely concluded that, in this model's context, the effects of public capital on the manufacturing sector *"are far from direct and clear-cut. Reductions in fixed costs will have far different effects than reduction in variable cost, and the effects of the latter are quite complex"* (Holtz-Eakin and Lovely 1996, p.115).

Similar were their results for the impact of infrastructure on the consumption goods sector. The production of consumption goods would increase (decrease) due to the release (acquirement) of factor bundles from the manufacturing sector. Equations 25 and 31 show that if fixed costs (F) are increased, then the volume of consumption goods will drop. In contrast, an increase of variable costs (v) would have results that are unclear.

3 Infrastructural impacts on the non-manufacturing sector of the Greek economy

As already mentioned, Holtz-Eakin has written extensively on how infrastructure affects the productivity of the private sector (Holtz-Eakin 1992a, 1993a, and Holtz-Eakin and Schwartz 1995). He was also one of the prominent figures in the camp advocating that public capital does not have any significant impact on private output. However, all this body of work was restricted to the investigation of this single potential 'channel' of influence (the direct impact via a production function) between infrastructure and development.

Holtz-Eakin and Lovely (1996) in contrast have used the theoretical model presented in the previous section for the study of potentially alternative channels of influence in the relationship. Namely, they calibrate their model for the examination of infrastructure effects on the consumption goods sector (as the majority of the existing empirical research has studied the effects on the manufacturing sector), as well as on of how public capital affects the range of varieties (the range of intermediate goods). For the study of the latter they used the number of manufacturing establishments as a proxy.

The following analysis tries to utilise the theoretical model of Holtz-Eakin and Lovely for the investigation of such alternative channels in the Greek context, placing special emphasis on the spatial dimension. However, there are significant obstacles in undertaking this task, due to limitations of the available data, both at the regional and the national level.

This section assesses the impact of infrastructure on the non-manufacturing sector, which includes both the primary and tertiary sectors. In the next section the analysis focuses on the

¹⁶ Holtz-Eakin and Lovely (1996) point out that this is exactly the opposite of the sufficient condition for F .

manufacturing sector of the economy and investigates the role of public capital on the increase or decrease of varieties, using the number of establishments as a proxy for the latter.

Even though there is now a small body of work on the results of public capital on the industrial sector of Greek economy (see Dalamagas 1995, Rovolis and Spence 1995, 1997a, 1997b, 1998, Segoura and Christodoulakis 1997) there is a notable absence (here as elsewhere) of research regarding effects on the non-manufacturing sector. The main reason for this is the absence of some key data regarding private capital investment and employment in sectors other than manufacturing. Thus, the application of production function analysis, not to mention the more data demanding cost function approach, seems impossible in this important part of the economy. However, there is an alternative approach, such as the use of quasi-production functions, which can give some indication for the impact of public capital.

Quasi-production functions have already been used in infrastructure research. In fact one of the most significant pieces of research at the regional level - the Biehl report (1986) for the EU - has used this approach extensively. However, here a slightly different implementation of quasi-production functions has been followed (forced upon by the data limitations), which in no small measure follows and develops upon that of Cutanda and Paricio (1994). These authors, interested in the relationship between public capital and regional economic growth in Spain, estimated a function of the type:

$$Y_i = a + b_1 E_i + b_2 I_i + e \quad (35)$$

where Y_i is the per capita regional income, E_i the employment rate in industry, I_i an infrastructure indicator, and e the error term.

One of the problems with the empirical analysis of Cutanda and Paricio is that, due to their data limitations, the time dimension they used is restricted to a specific point in time. It is, effectively, a cross sectional analysis.

Here for Greece, a panel data model is used in order to provide the necessary information for both the time and spatial dimensions. More particularly, data for 49 prefectures of Greece were used for the period 1982 to 1991. The prefectures vector is derived from the official Greek prefectures (NUTS III according to the EU classification). However, the industrial data for employment, which are used in the analysis, imposed several limitations. Thus, as a result, it proved necessary to exclude Lefkada, where there was no industrial activity during the period, and to add the statistics for Kefhalonia to those of the adjacent prefecture of Zakynthos (for a more extensive analysis, see Rovolis and Spence 1997b, 1998). The data for infrastructure have been purged of purely accounting expenditures (represented by Miscellaneous and Administrative Expenditures sub-categories) and what remains is pure investment in the public capital. The various categories of public capital

expenditure have been again classified into the two important components of ‘productive’ and ‘social’ infrastructure. Total infrastructure investment is the sum of these two categories.

Productive infrastructure consists of the categories of Agriculture, Forestry and Fishery, Industry, Energy and Handicrafts, Irrigation, Research and Technology, Special Works (plus those of Athens/Thessaloniki), Transportation (plus those for Railways), Water/Sewage Works, and Prefectural Works/Programmes. Social infrastructure is comprised by Education, Health and Welfare, Housing, Public Administration, and Tourism sub-categories.

The dominant approach for the estimation of the public capital stocks in the infrastructure literature is the *perpetual inventory accounting method*. This approach uses the flow of infrastructure investment for the estimation of stocks, assuming that a percentage of the existing stock has been depreciated. The formula for the estimation of the capital stocks to be used here is:

$$G_t = (1 - \delta)G_{t-1} + I_t$$

where G_t is the end of year public capital stock in year t , δ is the geometric rate of depreciation, and I_t is real investment in public capital during years t . (For more details on this fairly standard method of capital stock construction see for example Holtz-Eakin 1993b).

It is apparent that three pieces of information are necessary for the estimation of public capital stocks. The real investment in infrastructure (I_t) can be approximated by the monetary sums paid by the PIPR. Regarding the geometric rate of depreciation (δ), it was assumed that the rate remained constant for all of the examined period, and that it equals 0.05. This is similar to the depreciation rate used by Bajo-Rubio and Sosvilla-Rivero for the estimation of the Spanish infrastructure stocks (1993, Appendix 1). This figure is arbitrary, but it has been chosen assuming that Greek infrastructure capital is not much different from the Spanish, and that in addition the depreciation rate for fixed assets (buildings) given by the NSSG (see Xenaki 1997) is not dissimilar. Finally, as there were no existing stock estimates at regional level, it was decided to build on the first year of the available data¹⁷.

The output data comprise the regional Gross Domestic Product (GDP). These data were provided by the National Statistical Service of Greece (NSSG) and are supplied with a breakdown into the various sub-categories which comprise the regional GDP. These are Agriculture-Farming-Forestry-Fishery (henceforth Agriculture), Mines, Electricity-Lighting-Water Companies (henceforth Electricity), Constructions, Transportation-Telecommunications (henceforth Transportation), Commerce, Banking-Insurance-Land Estate sectors (henceforth Banking), Housing, Public Administration, Health-Education (henceforth Health), Services (which includes various categories of services), and Manufacturing. As the impact of public capital on the latter has been analysed in detail

¹⁷ This is a common practice in the estimation of capital stocks. See for instance Corrales and Taguas (1991).

elsewhere (see Rovolis and Spence 1997a and 1997b), the following analysis focuses only on the infrastructure effects on the other categories of regional GDP.

It has to be noted that all the quasi-production functions of this section, as well as the analysis regarding the returns of variety for the manufacturing sector (next section), have been formulated with regional specific effects and a time trend. These are least squares dummy variable models (LSDV), (see Greene 1997 for an analysis of this models). This means that the error term of equation 35 should be written as:

$$u_{it} = \mu_i + v_{it} \quad (36)$$

where μ_i is the unobservable regional specific effect, and v_{it} is the remainder disturbance. However, the results for these dummy variables are not reported here due to space limitations. Thus, the panel of data used in this analysis has an N regional dimension, and a T time dimension.

There are three tables of results regarding the effects of public capital on the non-manufacturing sector. Table 1 presents the findings for the total of infrastructure taken as a whole, table 2 examines only the productive part of public capital, and table 3 the social component.

In all these tables a Hausman specification test has been performed. This test can demonstrate if the hypothesis of the exogeneity public capital is valid or not. Usually the question of whether infrastructure investment in a specific geographical area is exogenous or not, is circumvented in empirical work. A potential theoretical justification for this could be that public investment has been decided on by a central state mechanism, without any relation to the regional output. Another reason could be the fact that when the effects of infrastructure on the output of the secondary sector of the economy are examined, the latter can constitute only a rather small part of the regional economy (when the primary and/or the tertiary sectors are the most significant). However, in the case where the whole regional GDP is the dependent variable, there is a strong possibility that GDP disparities are the source of public capital disparities.

The way in which the Hausman specification test is conducted can be found in most econometrics texts¹⁸. In a nutshell, the test principle is that the regressor (of an original regression), which is to be tested for exogeneity, should be used in an auxiliary regression as the dependent variable, in which the other regressors (of the original regression) are the explanatory variables. The residuals of this auxiliary regression are then used as another regressor in the original regression. If the coefficient of the residuals in this augmented regression is statistically significant, then there is a simultaneity problem.

¹⁸ See for instance Berndt 1991, pp. 379-380, or the original paper of Hausman (1976), and Nakamura and Nakamura paper (1981)). For the application of the test in a panel data analysis context, see, for instance, Baltagi 1995, pp. 68-73).

The first column of Table 1, which deals with the total public capital stock, refers to the regional GDP categories, which are the dependent variables for the respective regressions. The second column gives the estimates for the constant term, the third for the labour input (which refers to the employment of the manufacturing sector), the fourth for the infrastructure variable, and the fifth for the time trend. The next three columns give the usual measures of the regressions, the adjusted R square, the error sum squares, and the standard error of the regression, respectively¹⁹. The last column presents, under the *h* heading, the results for the Hausman specification test of the augmented regression (however, the rest of the results refer to the original regression). As mentioned above, the results for the dummy variables are not reported on here. The ‘total’ row gives the results for the sum of regional GDP categories (including total manufacturing). The infrastructure coefficient appears to be small in magnitude (0.036) and statistically insignificant. The *h* statistic shows that the hypothesis of exogeneity for public capital cannot be rejected. Some of the categories of regional GDP seem to have large infrastructure coefficients, which are also statistically significant. These are the Agriculture, Banking, Housing, Public Administration, Services, and to some extent the Health GDP categories. The signs of these coefficients in some cases is negative (Agriculture, Health, and Housing). However, for all the cases where the infrastructure variable appears to be statistically significant the *h* statistic shows that the hypothesis of exogeneity for public capital must be rejected. Thus, the overall conclusion from this table is that the infrastructure variable does not seem to have an impact on regional GDP, and this is inferred from the results for the aggregate GDP category and for the individual sub-categories.

Table 1 The effect of total public capital (G total) on the GDP of the non-manufacturing sectors of Greece, 1982-1991

Equation for per capita regional income (ln)

GDP Category	Constant	lnL	lnG (total)	time trend	Adjust. R2	SSE	SE	h
TOTAL	20.671 (41.217)***	0.031 (2.009)**	0.036 (1.427)	0.017 (5.385)***	0.995	1.832	0.065	0.036 (1.426)
AGR	22.938 (18.171)***	0.073 (1.849)*	-0.154 (-2.404)**	0.024 (3.121)***	0.959	11.606	0.163	-0.154 (-2.400)**
BANK	9.524 (6.655)***	-0.079 (-1.780)*	0.420 (5.801)***	0.029 (3.266)***	0.961	14.917	0.185	0.420 (5.776)***
COMMER	18.209 (23.725)***	0.035 (1.456)	0.048 (1.245)	0.016 (3.294)***	0.989	4.291	0.099	0.048 (1.245)
CONSTR	19.507 (25.886)***	-0.002 (-0.084)	-0.010 (-0.267)	0.029 (6.131)***	0.983	4.136	0.097	-0.010 (-0.267)
HEALTH	19.279 (32.225)***	0.030 (1.635)	-0.057 (-1.877)*	0.063 (17.027)***	0.993	2.607	0.077	-0.057 (-1.878)*
HOUS	24.744 (17.600)***	0.089 (2.024)**	-0.333 (-4.681)***	0.074 (8.442)***	0.960	14.396	0.181	-0.333 (-4.681)***
MINES	36.836 (2.576)**	-0.322 (-0.724)	-0.906 (-1.252)	0.004 (0.043)	0.769	1489.66	1.844	-0.906 (-1.253)
PADMIN	14.916 (11.565)***	0.025 (0.615)	0.190 (2.910)***	0.022 (2.764)***	0.968	12.116	0.166	0.190 (2.913)***

¹⁹ These measures are from the formulation with a constant term and *n-1* dummy variables.

SERV	11.686 (13.855)***	0.041 (1.547)	0.365 (8.556)***	0.003 (0.636)	0.988	5.182	0.109	0.365 (8.545)***
TRANSP	18.336 (44.261)***	0.038 (2.952)***	0.034 (1.639)	0.002 (0.854)	0.997	1.250	0.053	0.034 (1.626)

Note: *t*-statistics in parentheses (and henceforth in all tables)

***Statistically significant at 1% level

**Statistically significant at 5% level

*Statistically significant at 10% level

In tables 2 and 3 the total infrastructure variable has been replaced by its productive and social components. The regional GDP categories, as well as the regression tests remain the same. Table 2 gives a similar picture to that of table 1. The magnitude of the coefficient for public capital, in the regression where the dependent variable is the total regional GDP, is small (0.031) and statistically insignificant. Again the coefficients for public capital are statistically significant, although with different signs, in cases where the GDP sub-categories, Agriculture, Banking, Housing, Public Administration, Services, Health were used as the dependent variable. In all these cases the Hausman specification tests indicated that the infrastructure variable is probably endogenous.

Table 2 The effect of productive public capital (G productive) on the GDP of the non-manufacturing sectors of Greece, 1982-1991

Equation for per capital regional income (ln)

GDP Category	Constant	lnL	lnG (prod)	time trend	Adjust. R2	SSE	SE	h
TOTAL	20.785 (49.519)***	0.032 (2.053)**	0.031 (1.440)	0.017 (5.756)***	0.995	1.832	0.065	0.031 (1.438)
AGR	22.037 (20.818)***	0.069 (1.750)*	-0.108 (-2.016)**	0.021 (2.787)***	0.959	11.651	0.163	-0.108 (-2.013)**
BANK	11.014 (9.185)***	-0.072 (-1.615)	0.346 (5.699)***	0.033 (3.874)***	0.961	14.954	0.185	0.346 (5.680)***
COMMER	18.406 (28.648)***	0.036 (1.500)	0.039 (1.185)	0.016 (3.606)***	0.989	4.292	0.099	0.039 (1.185)
CONSTR	19.551 (31.002)***	-0.002 (-0.080)	-0.013 (-0.393)	0.029 (6.575)***	0.983	4.135	0.097	-0.013 (-0.394)
HEALTH	19.120 (38.193)***	0.030 (1.594)	-0.049 (-1.932)*	0.063 (17.919)***	0.993	2.606	0.077	-0.049 (-1.935)*
HOUS	24.084 (20.555)***	0.084 (1.943)*	-0.302 (-5.079)***	0.074 (9.027)***	0.960	14.276	0.181	-0.302 (-5.078)***
MINES	35.334 (2.953)***	-0.332 (-0.749)	-0.836 (-1.379)	0.008 (0.090)	0.769	1488.53	1.843	-0.836 (-1.379)
PADMIN	15.001 (13.948)***	0.026 (0.653)	0.187 (3.434)***	0.020 (2.619)***	0.969	12.072	0.166	0.187 (3.438)***
SERV	13.767 (19.067)***	0.050 (1.857)*	0.260 (7.116)***	0.012 (2.323)**	0.987	5.421	0.111	0.260 (7.102)***
TRANSP	18.507 (53.344)***	0.039 (3.018)***	0.026 (1.467)	0.003 (1.158)	0.997	1.252	0.053	0.026 (1.455)

***Statistically significant at 1% level

**Statistically significant at 5% level

*Statistically significant at 10% level

The situation is not different when the social part of infrastructure is examined. The results, given in table 3, show that for the total regional GDP the social infrastructure coefficient is small (0.015) and statistically insignificant. Here, only when the categories of Agriculture, Mines, and

Services of regional GDP were used as regressands do the coefficients of social public capital reach high and significant levels. Nevertheless, as in the two previous tables, the Hausman specification test suggests that there is a concern for the problem of public capital endogeneity.

Table 3 The effect of social public capital (G social) on the GDP of the non-manufacturing sectors of Greece, 1982-1991

Equation for per capital regional income (ln)

GDP Category	Constant	lnL	lnG (soc)	time trend	Adjust. R2	SSE	SE	h
TOTAL	21.123 (57.333)***	0.032 (2.030)**	0.015 (0.706)	0.020 (13.978)***	0.995	1.838	0.065	0.015 (0.705)
AGR	22.382 (24.221)***	0.080 (2.029)**	-0.141 (-2.711)***	0.014 (3.759)***	0.959	11.565	0.162	-0.141 (-2.710)***
BANK	18.769 (17.255)***	-0.041 (-0.881)	-0.062 (-1.018)	0.081 (18.906)***	0.958	16.025	0.191	-0.062 (-0.985)
COMMER	19.060 (33.805)***	0.038 (1.556)	0.005 (0.164)	0.021 (9.497)***	0.989	4.306	0.099	0.005 (0.164)
CONSTR	18.679 (33.852)***	-0.008 (-0.318)	0.037 (1.175)	0.026 (11.846)***	0.983	4.124	0.097	0.037 (1.163)
HEALTH	18.298 (41.545)***	0.027 (1.450)	-0.007 (-0.291)	0.057 (32.934)***	0.993	2.627	0.077	-0.007 (-0.278)
HOUS	17.132 (16.239)***	0.056 (1.242)	0.066 (1.109)	0.032 (7.671)***	0.958	15.074	0.186	0.066 (1.110)
MINES	-10.870 (-1.045)	-0.617 (-1.386)	1.747 (2.981)***	-0.188 (-4.594)***	0.773	1465.27	1.829	1.747 (2.984)***
PADMIN	17.829 (18.685)***	0.032 (0.790)	0.045 (0.844)	0.042 (11.176)***	0.968	12.330	0.168	0.045 (0.841)
SERV	14.711 (23.082)***	0.035 (1.300)	0.237 (6.593)***	0.034 (13.551)***	0.987	5.502	0.112	0.237 (6.569)***
TRANSP	19.121 (62.758)***	0.041 (3.175)***	-0.007 (-0.395)	0.007 (5.441)***	0.997	1.257	0.054	-0.007 (-0.394)

***Statistically significant at 1% level

**Statistically significant at 5% level

*Statistically significant at 10% level

The overall conclusion from the analysis of the relationship of the total regional GDP and the total infrastructure is that the latter appears to have no significant impact on the former. This is also true for the productive and social categories of public capital. The breakdown of the regional GDP has not given any indication that infrastructure, in its total, productive, or social form, has a direct productive effect on the private economy whatever the GDP category, if the Hausman specification test results are taken into consideration.

However, it has to be emphasised again that the quasi-production functions utilised here are severely constrained by the data limitations. It is probably the case that the labour input proxy of employment in the manufacturing sector is a poor measure of the employment activity in the specific regional unit in the Greek case. In some Greek prefectures the employment in the primary and tertiary

sector is inversely related to that of secondary employment. For this reason, it could be argued that the aforementioned results could be viewed only as partial evidence.

The theoretical part of the Holtz-Eakin and Lovely model, however, assumes that public infrastructure would not have any significant impact on the non-manufacturing part of the economy. In fact their results for the US economy have corroborated this thesis. Thus, the Greek results presented in this section can be viewed as another confirmation of the model's assumption, with the caveat that the quasi-production functions used here cannot describe accurately this specific part of the Greek economy.

4 Investigating Alternative Channels of Infrastructure Effects at Different Spatial Levels in Greece

The direct impact of public capital on the manufacturing sector of the Greek economy has been extensively analysed in Rovolis and Spence 1997a, 1997b, 1998, at national, regional, sectoral, and urban levels. However, it seems worthwhile to seek for other potential channels by which infrastructure can affect the private economy, perhaps in more subtle ways. The Holtz-Eakin and Lovely (1996) model suggests that there is a variety of such channels at least from a theoretical viewpoint. Their empirical work examined in depth two possible ways by which a change in public capital stock can affect the secondary sector. The first is by altering the scale of production for each manufacturing firm. The second is by influencing the equilibrium number of firms. Thus, their model can help to assess if the public infrastructure affects private manufacturing, either by changing the level or by altering the composition of its productive activity. These issues can be dealt with in turn.

4.1 Public capital's effects on the preferred scale of production

The theoretical model described in section 2 postulates that the number of varieties of intermediate goods in the economy can be used as a measure of the range of economic activity. The greater the number of these varieties the more dynamic is the state of the economy (see equation 4). The empirical counterpart of equation 4 is the following equation,

$$\frac{M}{n} = n^{a-1} x_0 \quad (37)$$

which has been calibrated by Holtz-Eakin and Lovely using as the left hand side variable the output per manufacturing establishment and the right hand side variables are the number of establishments (as proxy of n) and public infrastructure (changes in infrastructure increase x_0 , see section 2) and with the variables in logarithmic form. Thus, equation 37 becomes:

$$\ln\left(\frac{M}{n}\right) = \ln(n^{a-1}) + \ln(x_0) \quad (38)$$

or in working form:

$$\ln \frac{M_{it}}{n_{it}} = (a - 1) \ln n_{it} + \ln G_{it} + t + u_{it} \quad (39)$$

where M_{it} is the Gross Production Value of manufacturing (as a proxy of the finished manufactured goods) in a specific region or sector in time t , n the number of manufacturing establishments (as an index of the range of economic activity), a the degree of homogeneity in equation 37, G_{it} the infrastructure variable, t is a time variable, and e_{it} the error term of the form $e_{it} = \mu_i + v_{it}$, [where μ_i is the unobservable regional or sectoral specific effect, and v_{it} is the remainder disturbance]

A point that begs clarification is the fact that public capital in the above equation appears to be a pure public good. However, as Holtz-Eakin and Lovely (1996, p. 119, footnote 17) argue “*entering public capital in per-firm units would not affect its coefficient. Instead, only the coefficient on the growth of firms (and our estimate of a) would be affected*”.

A similar formulation has been employed for the Greek case. However, here four different datasets were used. The first comprises information on manufacturing (large industry, employing more than 20 persons) for the 49 prefectures. (For a more detailed analysis see Rovolis and Spence 1997a, 1997b, and 1998.) It has to be remembered that these manufacturing data refer to the total of all industrial sectors, no sectoral breakdown being available. The analysis by Holtz-Eakin and Lovely has had the added luxury of regional data together with a sectoral breakdown.

There are, however, three other datasets at hand, which do have a sectoral dimension. The first provides a sectoral breakdown for Greece as a whole. The second has a similar breakdown for the metropolitan area of Athens, and the last refers to the Rest of Greece. The last mentioned is a derivative set of data, as it is the difference between that for the whole of Greece and the Athens panel (again for more details on these datasets see Rovolis and Spence 1997a, 1997b, and 1998). These data, along with the regional panel, allow analysis of the different channels by which public capital can affect manufacturing sector at four different spatial levels.

Gross Production Value (GPV) has been used as a measure for manufacturing output in tables 4 to 7, in which are presented the results for the different datasets. Public capital has been introduced again either as total infrastructure (but excluding Miscellaneous and Administrative expenditures as before) or as a breakdown into productive and social infrastructure (again as defined previously). As in all previous cases where panel data analysis has been used, regional dummies were introduced into the regressions to capture the regional specific effects. This constitutes the Least Squares Dummy Variable model. This model and the organisation of the dummy variables designed to capture the regional effects (and similarly the sectoral effects for the sectoral panels) are described in section 4.4.

Such an approach was also used by Holtz-Eakin and Lovely in their empirical calibration of the model (Holtz-Eakin et al. 1996).

The results for the regional panel, presented in table 4, reveal that public capital has a positive impact on output per firm. This impact is substantial in magnitude (0.383) and is also statistically significant. If total infrastructure is disaggregated into its productive and social components, it appears that the effect of the former is much larger than that of the latter. Productive public capital has a statistically significant coefficient of 0.352, while the respective magnitude for social infrastructure is only 0.041 and statistically insignificant. In all three regressions the variable representing the varieties of production, that is the number of manufacturing establishments, is negative and statistically significant. The respective coefficients for the regressions for total, productive and social infrastructure are -0.662, -0.654, and -0.654 respectively. This implies in turn, an a (as equation 39 shows, the estimated coefficient is actually $a-1$) of 0.338, 0.346, and 0.346 degree of homogeneity respectively.

Table 4 Infrastructure effects on the scale of production: regional panel for total manufacturing, 1982-1991

Dependent Variable: ln of Output (GPV) per Manufacturing Establishment

Constant	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
11.218 (6.608)***	-0.662 (-13.920)***	0.383 (4.475)***			-0.042 (-3.962)***	0.925	21.047	0.219
11.901 (8.461)***	-0.654 (-13.849)***		0.352 (4.918)***		-0.043 (-4.334)***	0.926	20.858	0.218
18.071 (14.124)***	-0.654 (-13.323)***			0.041 (0.576)	0.001 (0.150)	0.922	21.993	0.224

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

The findings for the sectoral panel of manufacturing for Greece as a whole are given in table 5. Public capital appears to be statistically significant in all cases, and to have extremely high coefficients, namely 0.709 for total infrastructure, 0.655 and 0.892 for the productive and social categories respectively. The results for the establishments variable are, in all three regressions of this table, negative and statistically significant. Actually, they are of the same magnitude (at three digit level), that is -0.557, with a degree of homogeneity of 0.443. The infrastructure results certainly imply that some of the industrial sectors are extremely sensitive to changes of public capital.

Table 5 Infrastructure effects on the scale of production: Greece panel for sectors, 1982-1991

Dependent Variable: ln of Output (GPV) per Manufacturing Establishment

Constant	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
1.041 (0.197)	-0.557 (-4.937)***	0.709 (3.382)***			-0.057 (-2.849)***	0.987	2.713	0.124
2.580 (0.534)	-0.557 (-4.937)***		0.655 (3.390)***		-0.057 (-2.851)***	0.987	2.713	0.124
-2.319 (-0.365)	-0.557 (-4.938)***			0.892 (3.345)***	-0.053 (-2.782)***	0.987	2.716	0.124

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

The sectoral results for the metropolitan area of Athens are in sharp contrast to those obtained for the national sectoral panel. As table 6 shows, none of the variables is statistically significant. This is also the case for total, productive and social public capital. Totally different is the picture for the panel as it refers to the manufacturing sectors of the Rest of Greece. Table 7 shows that the Rest of Greece economy appears to have high negative results for the number of manufacturing enterprises variable. These coefficients are -0.505, -0.505, and -0.502 for the regressions with the three types of public capital, implying a degree of homogeneity (α) of 0.495, 0.495, and 0.498 respectively. The coefficient for total infrastructure is high (0.985) and statistically significant. The respective results for the productive and social infrastructure categories are 0.909 and 1.251, again statistically significant at the one percent level.

Table 6 Infrastructure effects on the scale of production: Athens panel for sectors, 1982-1991

Dependent Variable: ln of Output per Manufacturing Establishment

Constant	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
4.205 (0.411)	-0.090 (-0.637)	0.515 (1.186)			-0.014 (-0.425)	9.330	10.099	0.245
2.556 (0.277)	-0.083 (-0.588)		0.596 (1.496)		-0.021 (-0.680)	0.933	10.050	0.245
11.948 (1.155)	-0.100 (-0.708)			0.195 (0.423)	0.010 (0.310)	0.933	10.173	0.246

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 7 Infrastructure effects on the scale of production: Rest of Greece panel for sectors, 1982-1991

Dependent Variable: ln of Output (GPV) per Manufacturing Establishment

Constant	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
-6.041 (-0.963)	-0.505 (-4.648)***	0.985 (3.937)***			-0.082 (-3.421)***	0.983	3.880	0.148
-3.875 (-0.677)	-0.505 (-4.653)***		0.909 (3.941)***		-0.082 (-3.421)***	0.983	3.880	0.148
-10.995 (-1.458)	-0.502 (-4.619)***			1.251 (3.932)***	-0.078 (-3.387)***	0.983	3.881	0.148

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

4.2 The effect of public capital on total manufacturing output

The Holtz-Eakin and Lovely (1996) results relating to output per manufacturing establishment showed that public infrastructure in the United States had only a small, if any, effect on output per firm. In order to pursue this point further, they studied the impact of infrastructure on total manufacturing output, controlling for the private inputs of production and the number of firms. This strategy resulted the following form of equation:

$$Q = \frac{K}{n} + \frac{L}{n} + n + G \quad (40)$$

where Q is total manufacturing output (GPV), K/n is private capital per firm, L/n is labour per firm, n is the number of firms, and G is public infrastructure capital.

Even though in the case of Greece infrastructure capital seems to play a significant role in the determination of the output per manufacturing establishment, it is still useful to extend the analysis in this context as per Holtz-Eakin and Lovely. The results would then corroborate or refute the findings of the previous section. Equation 40 changes for the Greek model to:

$$Q_{it} = \frac{K_{it}}{n_{it}} + \frac{L_{it}}{n_{it}} + n_{it} + G_{it} + t + u_{it} \quad (41)$$

(notation as in previous equations)

Again there are four different levels of spatial analysis. The estimations for the regional panel are given in table 8. The coefficient for total public capital, in the first regression of the table, is positive and statistically significant. Its magnitude is high (0.254), as is also the case for the coefficient of labour. However, the coefficient for private capital is small (0.046) and statistically significant only at ten percent level. The degree of homogeneity a (see section 2) is the magnitude of the estimated coefficient of the manufacturing establishments (this coefficient corresponds directly to a , in contrast to the previous section where the estimated coefficient was $a-1$). Here, a is equal to 0.761 (statistically significant) and is larger than the respective figure obtained in the previous set of regressions. The next two regressions present the results for the breakdown of public capital into productive and social categories respectively. It is interesting that at regional level productive infrastructure seems to account for practically all of the impact of total public capital. The results for this type of infrastructure are almost identical to those for the total. However, it seems that the social component has practically zero impact, as its coefficient is small and statistically insignificant (-0.048).

Table 8 Infrastructure effects on total output: Regional panel for total manufacturing, 1982-1991

Dependent Variable: ln of Total Manufacturing Output (GPV)

Constant	lnK	lnL	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adj. R2	SSE	SE
9.253 (6.650)***	0.046 (1.695)*	0.742 (14.597)***	0.761 (15.677)***	0.254 (3.573)***			-0.026 (-2.982)***	0.990	13.824	0.178
9.401 (8.078)***	0.041 (1.519)	0.742 (14.698)***	0.762 (15.875)***		0.253 (4.256)***		-0.029 (-3.534)***	0.990	13.661	0.177
14.779 (12.843)***	0.062 (2.304)**	0.760 (14.674)***	0.793 (16.072)***			-0.048 (-0.822)	0.005 (0.918)	0.990	14.207	0.181

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

The results for the sectoral panel for the whole of Greece are not essentially much different (table 9). In the regression incorporating total infrastructure the coefficient for private capital appears to be statistically insignificant, that for labour is more or less the same magnitude (0.722 and statistically significant) as for the regional panel, and similarly for the manufacturing establishment variable (0.785 and statistically significant). The estimate for infrastructure is, nevertheless, much

higher in magnitude (0.630 and statistically significant). The same can be said for the findings for the regression utilising productive public capital. Its coefficient is again higher than the respective estimate at regional level (0.583 and statistically significant for the sectoral panel). A crucial difference from the regional analysis can be found if the results for regional and sectoral social infrastructure regressions are compared. At the regional level the coefficient for social public capital is not statistically significant, while when sectors are considered it is both significant and high (0.789) - seemingly more so than is the case for productive infrastructure. The cost function analysis results have shown that social infrastructure does have a positive effect in reducing private costs at the sectoral level. Thus, both the model results and those of the cost analyses suggest that some sectors are highly affected by social public capital. This effect cannot be detected by the regional (prefectural) panel where manufacturing industry as a whole is examined. If there were available sectoral data at regional level, this discrepancy (between sectoral and prefectural results) would be probably solved.

Table 9 Infrastructure effects on total output: Greece panel for sectors, 1982-1991

Dependent Variable: ln of Total Manufacturing Output (GPV)

Constant	lnK	lnL	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adj. R2	SSE	SE
-0.848 (-0.154)	-0.015 (-0.143)	0.722 (5.195)***	0.785 (5.589)***	0.630 (3.183)***			-0.047 (-2.398)**	0.988	2.318	0.115
0.498 (0.098)	-0.014 (-0.140)	0.722 (5.196)***	0.786 (5.592)***		0.583 (3.194)***		-0.047 (-2.402)**	0.988	2.317	0.115
-3.717 (-0.577)	-0.017 (-0.169)	0.723 (5.201)***	0.783 (5.570)***			0.789 (3.139)***	-0.043 (-2.311)**	0.988	2.321	0.115

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Even more interesting is a comparison of the results for the two regional-sectoral panels – those for the metropolitan area of Athens panel (table 10) and the Rest of Greece panel (table 11). The results for Athens, in all three regressions for total, productive and social public capital, generate an insignificant coefficient for public capital. This is in contrast with all other results for the different spatial levels. The estimates for labour approximate roughly similar levels (positive and statistically significant) to the respective results for the regional and other sectoral panels. In contrast, the coefficients for the manufacturing establishments variable are much higher in magnitude than for any other panel. In all three regressions for Athens these estimates are around 1.6, which implies that the number of manufacturing firms generates a greater volume of industrial output. But more important for this research is the finding that, for Athens, infrastructure in all its guises seems to play no role, as in all the regressions its estimates are statistically insignificant. One potential explanation involves the fact that the Athens economy is much more advanced in comparison with that of the rest of Greece. These results seem to corroborate, at first sight, the argument that infrastructure investment has a smaller effect in more advanced economies that already endowed with a sufficient infrastructure capacity (see for instance Holtz-Eakin 1990). Conversely, there is the other possibility that in reality

the industry of the main metropolitan area of the country, in fact, uses the infrastructure stock of whole of Greece.

Table 10 Infrastructure effects on total output: Athens panel for sectors, 1982-1991

Dependent Variable: ln of Total Manufacturing Output (GPV)

Constant	lnK	lnL	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adj. R2	SSE	SE
-7.072 (-0.767)	0.665 (4.414)***	0.781 (4.952)***	1.603 (10.383)***	0.363 (0.963)			-0.019 (-0.637)	0.971	7.450	0.212
-7.326 (-0.874)	0.665 (4.419)***	0.774 (4.892)***	1.604 (10.398)***		0.382 (1.099)		-0.021 (-0.748)	0.971	7.437	0.212
-3.750 (-0.402)	0.663 (4.394)***	0.794 (5.043)***	1.600 (10.349)***			0.231 (0.582)	-0.008 (-0.273)	0.971	7.476	0.212

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

The final table of this set (11) presents the results for the panel that refer to a panel of industrial sectors for the Rest of Greece. The results of this panel appear to determine the respective findings for the sectoral panel for Greece as whole (table 9). The estimates for private capital are statistically insignificant in all three types of regression, while the coefficients for labour and manufacturing establishments are of high magnitude, positive, and significant. The coefficients for public capital, although positive and significant, are of even higher magnitude than the respective estimates for Greece as a Whole. Again here, social infrastructure appears to have a bigger impact than productive public capital.

Table 11 Infrastructure effects on total output: Rest of Greece panel for sectors, 1982-1991

Dependent Variable: ln of Total Manufacturing Output (GPV)

Constant	lnK	lnL	lnEstabl	lnG(total)	lnG(prod)	lnG(social)	time trend	Adj. R2	SSE	SE
-5.944 (-1.041)	0.013 (0.137)	0.852 (6.856)***	0.806 (7.526)***	0.797 (3.694)***			-0.064 (-3.011)***	0.989	2.782	0.126
-4.232 (-0.806)	0.013 (0.136)	0.852 (6.862)***	0.806 (7.526)***		0.738 (3.707)***		-0.063 (-3.018)***	0.989	2.780	0.126
-9.721 (-1.435)	0.012 (0.127)	0.852 (6.845)***	0.807 (7.533)***			1.003 (3.653)***	-0.059 (-2.933)***	0.989	2.786	0.126

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Comparing these panels clearly shows that public capital is significant at the regional (prefectural) level when manufacturing is considered in total. However, while this is also the case for sectors in Greece nationwide and the nation excluding Athens it is most certainly not the case for the metropolitan area of Athens. (Some of these issues will be reconsidered in the conclusion to the thesis.)

4.3 Public capital's effects on the equilibrium number of manufacturing establishment

Another potential way in which public capital can influence the private economy, in the context of the model in hand, is its impact on the (equilibrium) number of manufacturing establishments. The simplest method for the examination of such an effect is via regression. The

dependent variable is the logarithm of the number of manufacturing establishments, and the independent variable is the logarithm of the public infrastructure capital stock. The latter is again introduced as three forms (total, productive, and social) in each of the four spatial levels of reference. Again, the regressions have included a constant term, a time trend, and a set of $(N-1)$ dummy variables capturing the regional or sectoral specific effects (not reported on here due to space limitations). Thus, the working equation becomes:

$$n_{it} = G_{it} + t + u_{it} \quad (42)$$

(notation as in previous equations)

The results of tables 12 to 15 show that there is no direct impact of public capital on the number of establishments, as the public capital coefficients are statistically insignificant in all these regressions. This is true for all spatial levels. However, as Holtz-Eakin and Lovely have argued, there is the danger that such a regression “*fails to control for the resources available to the manufacturing sector*” (1996, p. 120).

Table 12 Infrastructure effects on the equilibrium number of firms (regression based infrastructure and time): Regional panel for total manufacturing, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
-0.978 (-0.574)	0.104 (1.208)			-0.004 (-0.388)	0.976	21.276	0.220
0.448 (0.315)		0.032 (0.445)		0.004 (0.374)	0.976	21.337	0.221
-2.836 (-2.291)**			0.218 (3.168)***	-0.003 (-0.582)	0.977	20.869	0.218

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 13 Infrastructure effects on the equilibrium number of firms (regression based infrastructure and time): Greece panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
7.432 (2.139)**	-0.130 (-0.939)			-0.004 (-0.336)	0.990	1.205	0.082
7.139 (2.255)**		-0.120 (-0.937)		-0.005 (-0.347)	0.990	1.205	0.082
8.053 (1.928)*			-0.164 (-0.929)	-0.005 (-0.412)	0.990	1.205	0.082

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 14 Infrastructure effects on the equilibrium number of firms (regression based infrastructure and time): Athens panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
8.784 (1.584)	-0.212 (-0.897)			-0.029 (-1.619)	0.979	3.027	0.134
9.525		-0.248		-0.025	0.979	3.018	0.134

(1.911)*	(-1.146)	(-1.503)				
5.443		-0.073	-0.039	0.979	3.040	0.134
(0.968)		(-0.290)	(-2.238)**			

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 15 Infrastructure effects on the equilibrium number of firms (regression based infrastructure and time): Rest of Greece panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
4.954 (1.149)	-0.072 (-0.420)			0.009 (0.567)	0.986	1.857	0.102
4.734 (1.205)		-0.064 (-0.405)		0.009 (0.554)	0.986	1.857	0.102
5.795 (1.118)			-0.112 (-0.511)	0.010 (0.665)	0.986	1.856	0.102

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

In order to circumvent this problem, these authors used a regression similar to the previous one, but with the addition of the private inputs of production, private capital, and labour. This method has also been followed here and the results for these augmented regressions are given in tables 16 to 19. The form of this equation becomes:

$$n_{it} = K_{it} + L_{it} + G_{it} + t + u_{it} \quad (43)$$

(notation as in previous equations)

However, even this augmented regression generally fails to produce significant results for the infrastructure variable. The only exceptions are the cases for social capital in the regional panel where a positive relationship holds (table 16) and for productive public capital in the metropolitan area of Athens, where the coefficient is negative (table 18). It has to be noted, nevertheless, that both these coefficients are statistically significant only at the ten percent level. However, perhaps the salient point is that generally the coefficients are negative.

Table 16 Infrastructure effects on the equilibrium number of firms (augmented regression): Regional panel for total manufacturing, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnK	lnL	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
-2.502 (-1.729)*	0.098 (3.510)***	0.536 (11.555)***	-0.054 (-0.730)			0.007 (0.722)	0.983	15.095	0.186
-2.013 (-1.655)*	0.101 (3.631)***	0.536 (11.585)***		-0.083 (-1.326)		0.011 (1.246)	0.983	15.053	0.186
-5.334 (-4.625)***	0.097 (3.559)***	0.519 (11.038)***			0.104 (1.740)*	-0.005 (-0.966)	0.983	15.009	0.185

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 17 Infrastructure effects on the equilibrium number of firms (augmented regression): Greece panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnK	lnL	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
5.286 (1.600)	-0.075 (-1.220)	0.595 (8.384)***	-0.174 (-1.462)			0.008 (0.710)	0.993	0.851	0.070

4.891 (1.599)	-0.075 (-1.220)	0.595 (8.383)***	-0.160 (-1.458)	0.008 (0.701)	0.993	0.851	0.070
6.114 (1.582)	-0.075 (-1.211)	0.595 (8.382)***	-0.219 (-1.452)	0.007 (0.661)	0.993	0.851	0.070

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 18 Infrastructure effects on the equilibrium number of firms (augmented regression): Athens panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnK	lnL	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
1.778 (0.395)	0.205 (2.862)***	0.525 (8.039)***	-0.234 (-1.281)			-0.011 (-0.774)	0.988	1.783	0.103
3.008 (0.739)	0.203 (2.839)***	0.528 (8.113)***		-0.292 (-1.742)*		-0.006 (-0.432)	0.988	1.768	0.103
-2.868 (-0.629)	0.210 (2.917)***	0.521 (7.948)***			-0.040 (-0.208)	-0.026 (-1.830)*	0.987	1.800	0.104

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

Table 19 Infrastructure effects on the equilibrium number of firms (augmented regression): Rest of Greece panel for sectors, 1982-1991

Dependent Variable: ln of Number of Manufacturing Establishments

Constant	lnK	lnL	lnG(total)	lnG(prod)	lnG(social)	time trend	Adjust. R2	SSE	SE
5.147 (1.379)	-0.082 (-1.287)	0.585 (8.504)***	-0.186 (-1.315)			0.022 (1.588)	0.991	1.208	0.083
4.667 (1.360)	-0.081 (-1.283)	0.585 (8.500)***		-0.169 (-1.295)		0.022 (1.570)	0.991	1.208	0.083
6.520 (1.476)	-0.082 (-1.296)	0.585 (8.522)***			-0.254 (-1.418)	0.022 (1.702)*	0.991	1.206	0.083

*** Statistically significant at 1% level, ** Statistically significant at 5% level, * Statistically significant at 10% level

It seems that public infrastructure does not affect the equilibrium number of firms, at least in this model context. There are, however, examples of other research focused on firm entry and exit in Greek industrial sector, in which public capital appears to be a significant factor of firm creation. These results, as well as comments, criticisms and potential extensions of this model are discussed in the next section.

5 Conclusions

The proliferation of empirical research on the effects of public capital investment on the private sector of the economy has provided a substantial body of work. This is based mainly on production function analysis, or alternatively on the duality theory and cost function approach. These approaches can be useful in assessing the role of infrastructure and can be used as a tool for the planning of public investment policies. Having said that, there still remains the problem of an analytical theoretical basis outlining the mechanisms by which public capital generates, or not, these specific effects. A few models by which these mechanisms can be sketched have recently become available. But few of them have been empirically tested for any verification or refutation of their theoretical assumptions.

One exception is the important paper on the US economy by Holtz-Eakin and Lovely (1996). The basic premises of this model have been utilised here for an analysis of the Greek case. The model's empirical calibration distinguishes between two main effects of infrastructure on the economy - the impact on the non-manufacturing part on the one hand and on the manufacturing sector on the other.

However, there are significant differences between the US and the Greek empirical research based on the model. In the former, cross-sectional data were used for four years, whereas in the Greek case the time dimension of the panel data is ten years. Furthermore, there are no available data for the Greek case that permit a proper empirical modelling of the non-manufacturing part of the economy and to circumvent this problem quasi-production functions were used.

The basic equation was calibrated not only for the aggregate measure of the private non-manufacturing sector output, which was the regional GDP, but also for its breakdown to regional sub-categories. Three measures of public infrastructure capital were used, total infrastructure, and its two categories - productive and social public capital. The results showed that there is no significant effect on the total regional GDP, no matter the type of infrastructure proxy in use. There are, however, some sub-categories of regional GDP, for which public capital at first sight seems to have a significant impact. However, for these categories there is the technical problem of the endogeneity of public infrastructure in the equations.

The analysis of the effects of infrastructure on the manufacturing sector of the economy has also been conducted at four different spatial levels. First, a panel of the total (large scale) manufacturing of the Greek prefectures is used; second, there is a sectoral breakdown of the manufacturing for Greece as a whole; third, comes a sectoral breakdown for the metropolitan area of Athens; and finally, the fourth level offers a sectoral breakdown for the Rest of Greece.

The empirical calibration tried to examine the two ways by which the theoretical model assumes that public capital affects the manufacturing sector. The first possibility is that changes of infrastructure provision alter the preferred scale of production for the firms of the manufacturing sector. The empirical counterpart of this possibility was the examination of the impact of public capital and the number of manufacturing establishments on the output per manufacturing establishment. The results showed that total public capital plays a significant positive role at all spatial levels, with the exception of the metropolitan area of Athens. The productive infrastructure coefficients are similarly significant positive, again with the exception of Athens. However, the picture is not clear for the case of social public capital. At the regional level, where the total of manufacturing sectors is considered, social infrastructure appears not to play any important role. The same is true for the sectoral breakdown for the area of Athens. Nevertheless, for the sectoral breakdown for Greece as

a whole, and for the Greece excluding the Athens area, there is a statistically significant impact of high magnitude.

Following Holtz-Eakin and Lovely (1996), the above results were double-checked by a second set of regressions, in which it was assumed that public capital should influence the total manufacturing output via its impact on output per firm and the number of varieties. The results for these latter regressions corroborate those obtained earlier.

The second channel by which infrastructural change affects private manufacturing, in the context of this model is the concomitant changes in the equilibrium number of manufacturing establishments. The direct regression of the number of manufacturing establishments on the public capital variable (either in its total, productive, or social form) has shown that there is no such direct impact, whatever the spatial level. The next step was to augment these regressions with the private inputs of production. Once again the results obtained generally showed that there was little significant impact of the infrastructure variables.

One conclusion that can be drawn from comparing these results for Greece with the findings from the US research is that for the more developed economy infrastructure works more via its effects on the composition of the manufacturing activity, whereas in the Greek case it seems to affect more directly the level of this activity. However, it has to be kept in mind that the US case refers to a huge economy in comparison to the Greek one, and that the US empirical work is based on four cross-sectional surveys articulated into a panel, while the Greek panel has a significantly longer time dimension. In any case, both of these empirical works show that public capital seems to have little if any impact on the non-manufacturing part of the economy. However, the results for the Greek case must be viewed with the caveat that crucial data for this part of the analysis were unavailable, and that it was conducted in a rather indirect way (quasi-production functions).

Finally, it must be noted that the whole analysis was conducted within the analytical framework set by the Holtz-Eakin and Lovely (1996) model. This means that the results are as good as the model's assumptions, and must be viewed in this spirit. For instance, the results for the impact of public capital on the equilibrium number of firms must not be construed as an attempt to evaluate the infrastructural role on new firm creation. There is now an existing body of work on this topic for Greece, and some of this research has incorporated the infrastructure variable into the analysis²⁰. The results of this empirical work have shown that public capital, does indeed play a positive role in new firm creation, with a significant time lag (see Fotopoulos 1998). This implies that the model used here has not allowed for such lagged impact of infrastructure on the equilibrium number of firms.

²⁰ For a summary of the existing bibliography on the topic, see Fotopoulos (1998); for a different perspective on the subject, see also Katseli (1990).

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