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Public Capital and the Demand for Private Inputs

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Abstract

The paper investigates the impact the provision of public capital has on the demand for private capital and labour using a cost function with public capital included as a fixed unpaid factor of production. Special attention is paid to the examination of the influence tax vs. debt financing of public investment might have on the demand for private capital. The model is applied to a panel of 31 2-digit industries of the West German manufacturing industry. It is shown, that private and public capital are complements whereas a substitutive relation emerges for labour and public capital. Decomposing the adjustment of the demand for private labour and capital reveals a stabilizing but steadily decreasing impact of public capital on private inputs.

JEL classification: E6, H3, H4

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1 Introduction: A brief survey of the literature

Recently, a fast growing body of literature is devoted to the investigation of the impact of the provision of public capital, notable public infrastructure, on the performance of the private sector of the economy. There are two good reasons that justify research efforts into this topic: Since around 1975 in most OECD countries a serious decline in the rates of growth in productivity has occurred which caused tremendous research efforts to uncover and explain this productivity slowdown. A series of recently presented papers make the neglect and low growth of public infrastructure investment at least partially responsible for the productivity slowdown. A quite different motive for infrastructure research is to be found in the need to reconstruct the former East European countries. Apart from the poor equippment with public infrastructure capital it is estimated that at least 60% - 70% of their existing public infrastructure facilities - ranging from roads to administrative buildings - are scrapped or completely outdated and need intensive reconstruction at tremendous cost. Thus, information on the contribution of public infrastructure capital to the performance of the private economy is necessary to support and direct the efficient allocation of public investment expenditures. In addition, the problem of the impact of alternative financing schemes on general economic conditions has to be addressed because most countries face tough budgetary restrictions.

Up to the present, in the public finance literature there is a remarkable 'ignorance' with respect to the examination of the role of public goods[1] in the private production process whereas their role as consumption goods are extensively dealt with. Notable exceptions are the work of Arrow and Kurz (1970), and Grossman and Lucas (1974). In their investigation of optimal fiscal policy, the former include the benefits related to the provision of public capital both in the consumption function as well as in the private production function. The paper by Grossman and Lucas extends a standard IS-LM model taking into account that public goods enhance private productivity. However, the role of public capital, or to be more precise, the services rendered thereof, has always been of

[1] The terms 'public capital' and 'public infrastructure' will be used interchangable in section I and II; section III will give more precise definitions.

central focus in the economic development literature under the heading 'social overhead capital' where it is thought to be a 'conditio sine qua non' for economic development, see for example Arnold (1992). Another line of literature in which public capital has been a constant research topic is the regional and urban science. Within this field of economics, investment in public infrastructure is regarded as a vehicle to foster regional growth, see Biehl (1991) for a survey.

In the recently established applied infrastructure research two competing approaches have been proposed. One line of literature takes the 'production function approach' and regresses private input productivity measures or private output on the usual variables including among the regressors data on public capital and check if the latter variable turns out significant. Ratner (1983) has probably been the first who examined such regressions using U. S. data. Within the same framework Aschauer, (1989a, 1989b) estimated the productivity effects of public consumption expenditures as well as of the military and non-military public capital stock. In addition, he estimated rather ad-hoc specified equations for privat investment and the rate of return to private nonfinancial corporate capital in order to examine the crowding out hypothesis and the impact of public capital on the demand for and the profitability of private investment. Aschauer's evidence supports the idea that public non-military capital enhances private productivity and increases the rate of return to private capital and thus crowds in private capital. The latter aspect is also supported by a more recent study presented by Lynde (1992). A competing line of research is constituted by the 'duality approach' which examines the impact of public capital on the private economy by estimating a generalized cost function introducing public capital as a fixed unpaid production factor recovering its productivity effect by applying duality theory. The theoretical basis for this line of research has been established by Diewert (1986). The first empirical study that applied duality theory to measure the economic benefits associated with the provision of public infrastructure, using a restricted profit rather than a cost function, has been presented by Deno (1988). More recent empirical studies use restricted cost function to detect productivity effects of public capital. Berndt and Hansson (1991), using data for Sweden, Conrad and Seitz (1991, 1992), using German data, Morrisson and Schwartz (1992), and Nadiri and Mamuenas (1991) for the U. S. present empirical evidence strongly supporting the productivity effect of public capital. However, negative results

are reported by Holtz-Eakin (1991) for the U. S.

Almost all of the above mentioned infrastructure studies focus their attention on two issues: The estimation of the shadow price of public capital and the examination of the impact public capital has on total factor productivity. The present study examines both aspects only briefly as they are well documented in the papers citied above. We direct our attention on the interrelationship between public capital and the demand for private inputs, especially private capital, shedding new light on the 'crowding out' hypothesis. In section II we use a generalized cost function to examine the impact public capital has on private production cost and the demand for private inputs. Special attention is devoted to the effects of providing public infrastructure capital on the demand for private capital incorporating financing considerations. Section III introduces the econometric implementation of our model and comments on the data used for the present study; empirical results are presented in section IV. Finally, we summarize our conclusions, comment on the shortcomings of our empirical approach and outline prospects for further research.

2 The public capital hypothesis, crowding out and crowding in

Consider the cost function (1) of industry j, j =1,..J:

$$(1) \qquad C_j = C_j(w_j, r_j, t, Y_j, G) \qquad \forall\, j = 1, \ldots J$$

which results from the minimization of the private production cost $C_j = w_j \cdot L_j + r_j \cdot K_j$ subject to the production function $Y_j = f_j(L_j, K_j, t, G)$. w_j is the wage rate, r_j is the user cost of private capital, Y_j is output and the time counter t represents technical change. Public capital, G, appears as an argument in the private cost function (1) as an unpaid[2] fixed input. Differentiating (1) with respect to G yields the shadow price s_j associated with public capital:

$$(2) \qquad s_j = - \frac{\partial C_j(w_j, r_j, t, Y_j, G)}{\partial G}$$

s_j denotes the change in private production cost in industry j if

[2] A rigorous study should consider that firms pay for investing in and running government capital by taxes.

the public capital stock G is expanded by one additional unit. Differentiating equation (2) with respect to the variable t yields insight into the impact public capital has on total factor productivity. If $\partial s_j/\partial t$ is >, = or < 0 than public capital supports, does not affect or disencourages technical progress. Note, that by applying the envelope theorem, one can easily derive the property:

$$f_{j,G} = \frac{s_j}{C_{Y_j}}$$

with $f_{j,G}$ denoting the marginal product of G and $C_Y = \partial C_j/\partial Y_j$ marginal cost. This relation provides a link between the 'production function approach' and the 'duality approach' and can be used to compare results derived from these quite different approaches.[3]

Usually one expects that $s_j \geq 0$, that means that an increase in the provision of public capital either leaves private cost unaffected ($s_j = 0$) or results in cost savings ($s_j > 0$). This expectation implies specific properties of the production function that is primal to the cost function (1) with respect to the substitutionability and/or complementary of the various inputs: Applying Shephard's Lemma to the cost function (1) yields the cost minimizing conditional factor demand functions for private capital and labour, K^*_j and L^*_j:

$$(3a) \qquad \frac{\partial C_j}{\partial r_j} = K_j^* = K_j(w_j, r_j, t, Y_j, G)$$

$$(3b) \qquad \frac{\partial C_j}{\partial w_j} = L_j^* = L_j(w_j, r_j, t, Y_j, G)$$

Using these conditional factor demand functions, production cost can be rewritten as:

$$(4) \qquad C_j = r_j \cdot K_j^* + w_j \cdot L_j^*$$

Applying Shephard's Lemma to (4) yields:

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[3] The proof is quite simple: Let (i) $V(..) = wL + rK + \lambda[Y - f(..)]$ be the Lagrangian to solve the cost minimization problem. Note, that in the optimum λ equals marginal cost, C_Y. Differentiating (i) with respect to G yields $\partial V/\partial G = -\lambda\partial f/\partial G = -s_j = -C_Y\partial f/\partial G$, in the optimum, that is at minimum cost.

$$(5)\ s_j = -r_j \cdot \frac{\partial K_j^*}{\partial G} - w_j \cdot \frac{\partial L_j^*}{\partial G} = - r_j \cdot s_{Kj} - w_j \cdot s_{Lj}$$

which decomposes the cost changes associated with an increase in G into adjustment effects on private labour and capital. s_{Kj} denotes the response of the demand for private capital and s_{Lj} the response of the demand for private labour in industry j to an increase in G. Equation (5) reveals that an increase in the provision of public capital is always cost saving if all private inputs are substitutes with respect to public capital, that is s_{Kj} and $s_{Lj} < 0$. However, if one of the private inputs is complementary to the public input cost saving effects arise only if the substitutive effects upon the other private inputs outweight the complementary effect. The cost of producing the output volume Y_j increase if all private inputs are complementary to G or if complementary effects offset substitutive effects.

The expectation that $\partial C_j/\partial G$ is negative[4], that is that an increase in G reduces private production cost, is based upon a simple analogy to the case when private capital is taken to be fixed in the short run. Assume private labour L, private capital K, and public capital G enter the private production function and that K is fixed in the short run. The resulting short run variable cost function $C = C(w,K,Y,G)$ must have the property $\partial C/\partial K < 0$ because otherwise the cost function C(....) would not be consistent with cost minimizing behavior. Why should firms increase their capital stock if this leads to an increase in cost given w, Y and G? Firms are free to choose the level of K and therefore cost increasing adjustments of K are irrational. But does this carry over to the variable G? Assume that labour and public capital are complements in which case an increase in G increases the cost of producing the output volume Y - given w and K - because more labour is required. As an example consider government investment in public sewage disposal facilities which asks for a more 'bureaucratic' handling of sewage disposal in private firms. Firms cannot escape this cost increase because the level of G is beyond their control. Thus, $\partial C/\partial G > 0$ can be fully in accordance with cost minimizing behavior!

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[4] This expectation seems to be hold throughout the infrastructure literature. Thus, Nadiri and Mamuneas (1991, p, 7) note "..in order for public capital input to have a meaningful context the cost function should be non-increasing in g [the public capital stock]."

Let us examine the response of the demand for private capital to an increase in the provision of public capital in more detail. Totally differentiating the conditional demand function for private capital with respect to public capital G yields a decomposition of the adjustment of the private capital stock caused by additional investment into public capital:

$$(6) \quad \frac{dK_j}{dG} = K'_{j,w}\frac{dw_j}{dG} + K'_{j,r}\frac{dr_j}{dG} + K'_{j,Y}\frac{dY_j}{dG} + K'_{j,G}.$$

From economic theory one would expect that $K'_{j,w} > 0$, $K'_{j,r} < 0$, $K'_{j,Y} > 0$[5] and $K'_{j,G} > (<) 0$ for private capital to be complementary (substitutive) with public capital. Because dt/dG is as a matter of course zero the term $K'_{j,t}\cdot(dt/dG)$ vanishes; $K'_{j,t}$ is $< (>) 0$ as technical progress is capital saving (using). In deriving equation (6) we assumed that the exogenous variables Z = w,r,Y depend on other exogenous variables $x_1,x_2,..,$ which we do not consider explicitly, and possibly also upon G, that is, $Z = Z(x_1,x_2,..,G)$.

dY_j/dG shows how the output of industry j is directly affected by an increase in demand for government capital and $K'_{j,Y}\cdot(dY_j/dG)$ is the associated response of the capital stock in industry j. This effect is probably strongest in the construction industry because about 80% of government investment outlays are in buildings and other construction, especially roads and bridges. We assume that there is no direct response of the wage rate in industry j, that is $dw_j/dG = 0$ and direct our attention on the two remaining effects which are of far greater interest. dr_j/dG indicates the response of the user cost of private capital in industry j to an increase in government investment. The user cost of capital is given by, see Jorgenson (1963):[6]

$$(7) \quad r_j = PI_j\left(R_B + \delta_j - \frac{dPI_j}{dt} \right)$$

δ_j is the depreciation rate, PI_j is the price index of private capital goods in industry j and R_B is the interest rate. Assuming δ_j and PI_j to be unaffected by government investment reduces the response of the user cost of capital to $dr_j/dG = PI_j\cdot(dR_B/dG)$.

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[5] K'_v denotes the partial derivative of the demand for private capital with respect to the variable v.

[6] At the present stage of research, no taxes are incorporated in the user cost of capital. This problem will be dealt with in future research.

According to the standard neoclassical model (lump sum) tax financed government expenditures leave the interest rate unaffected whereas deficit financed public expenditures result in an increase in interest rates.[7] Thus the total effect $K'_{j,r} \cdot PI_j \cdot (dR_B/dG)$ is either zero - in the case of tax financing - or negative - in the case of deficit spending - in which case we get the usual 'crowding out' effect. Arguing within a standard IS-LM model with interest rate and income dependent private investment, increasing the public capital stock either by tax or debt financing directly affects the private capital stock according to $K'_{j,Y} \cdot (dY_j/dG)$. However, if this investment is deficit financed the positive response is at least partially offset by the crowding out effect which makes dK_j/dG smaller in the case of deficit spending.

In order to concentrate on the core of the problem under dispute we surpress the potential effect of public investment on income, wage, technical progress and the price of private capital goods in which case equation (6) boils down to:

$$(6') \qquad \frac{dK_j}{dG} = K'_{j,r} \cdot PI \cdot \frac{dR_B}{dG} + K'_{j,G}.$$

The traditional public economics literature considers only the first effect, that is the possibility of private capital to be crowded out by additional deficit financed government investment. In the standard model of budget deficits, see Barro (1989), a budget deficit leads to an increase in the real interest rate which crowds out private investment resulting in a smaller stock of private productive capital. However, this hypothesis is strongly challenged by the Ricardian equivalence theorem according to which tax payers anticipate future increases in taxes to pay for the public debt. Because the present value of the future tax payment equals the current budget deficit, tax payers are indifferent about tax and deficit financing of current additional public expenditure. Consequently, present saving is adjusted regardless of the financing decision of the government and therefore the interest rate is unaffected by deficit spending. Barro (1989) in surveying the

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[7] Note that if $dR_B/dG > 0$ the term $K^* dr_j/dG$ would have to be appended to equation (5), which is a direct cost increasing effect (affecting the existing capital stock), whereas $K'_{j,r} dr_j/dG$ is an indirect effect (affecting net investment demand only).

empirical evidence concludes that most findings are in support of the Ricardian equivalence theorem, that is that government deficits leave interest rates unaffected. This result refers not only to the U. S. economy. Evans (1987) presents results with the same implications for the six largest OECD countries. The countries covered by Evans include also West Germany. We updated Evans' data and reestimated one of his equations and arrived at the same conclusions, that is, lack of empirical evidence on a positive correlation between government deficits and interest reates.[8] Despite the fact that the public, politicans and many economists believe that budget deficits raise nominal interest rates, arguments in favour of this hypothesis are both on theoretical as well as on empirical reasons rather poor, that is dR_B/dG is virtually zero.

Consequently, the effect of public investment expenditures depend crucially on the question wether public capital is a substitute for or complementary to private capital. Tatom (1991) distinguishes between direct and indirect effects of public capital on the performance of the private economy. *Directly*, public infrastructure capital provides important intermediate services to private firms, that is, like increasing private inputs an increase in the provision of public capital leads to an increase in private output. Technically speaking, the L_j-K_j isoquant in the production function $Y_j = f(L_j,K_j,t,G)$ shifts inward if G is increased. *Indirect* effects arise because an increase in public infrastructure capital provides an incentive for private firms to increase the demand for private capital because a larger stock of public capital raises the rate of return on private capital. This line of reasoning, subsumed under the heading 'public capital hypothesis', suggests that public and private capital are complementary, that is, $K'_{j,G} > 0$ and

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[8] We reestimated Evans' model by running the regression stated in footnote 5 and tabulated in table 8 of Evans' text. Equation (6) of Evans' text could not be estimated because we did not have consistent data on the six-month Eurocurrency interest rate available for the complete observation period. Evans estimates cover the period 74.II - 85.IV, whereas our estimate ranges from 74.I - 89.IV resulting in (figures in parentheses are t-values):

$$i_t - i_{t-1} = 1.695\ UG_t - 0.651\ UD_t - 0.138\ UM_t$$
$$\qquad\qquad (2.1) \qquad (0.5) \qquad (1.7)$$

(We use the notation of Evans). According to the crowding out hypothesis, the coefficient on the nominal budget deficit variable, UD_t, should be significantly positive, whereas we as well as Evans estimate an insignificant negative coefficient!

consequently $dK_j/dG > 0$.

Even if the crowding out effect is working, that is additional public investment expenditures raise interest rates, dK_j/dG can be positive if public and private capital are complements and this complementary effect outweights the crowding out effect resulting in a net crowding in of private investment. Otherwise the crowding out effect would at least be partially compensated. However, if both types of capital are substitutes, dK_j/dG is always negative in which case one might speak of a technologically induced crowding out of private capital.

A relation similar to (6) holds for the demand of labour:

$$(8) \quad \frac{dL_j}{dG} = L'_{j,w}\frac{dw_j}{dG} + L'_{j,r}\frac{dr_j}{dG} + L'_{j,Y}\frac{dY_j}{dG} + L'_{j,G}.$$

From economic theory one would expect that $L'_{j,w} < 0$, $L'_{j,r} > 0$, $K'_{j,Y} > 0$ and for private labour to be complementary (substitutive) with public capital we have $L'_{j,G} > (<) 0$. The above dicussion with respect to the effect of public capital on the demand for private capital also applies to the demand of labour and thus we need not repeat the arguments.

In order to reach final conclusions with respect to the impact debt or tax financed additional public investment expenditures have on the economy one has to turn to empirical research because it is rather speculative to say something a priori about the various effects involved, that means we have to derive an empirical equivalent to equations (6) and (8).

3 Data description and econometric specification

For estimation, we apply our econometric model to a panel of 31 2-digit industries[9] of the manufacturing sector of the West German economy using annual data for the period 1970 - 1989. In order to eliminate effects that might arise from the granting of subsidies and the payment of indirect taxes, we used real (at 1980 prices) net value added instead of real gross value added to measure industry

[9] These 31 industries cover the total manufacturing industry with the exception of the mineral oil refining industry. Due to profit transfer via transfer prices this industry has a negative net value added throughout most of the observation period.

output Y_j. Labour input is measured by the total number of working hours of white and blue collar workers. The wage rate has been calculated by dividing the total wage bill by the total number of hours worked. The stock of private capital is measured by the total net capital stock, evaluated at 1980 prices. The user cost of private capital has been calculated using formula (7) stated above. R_B is the interest rate (mid-year values) on bonds, PI_j the price index for private investment goods and δ_j the depreciation rate. As a matter of course, all data - except R_B - have been calculated industry-specific.[10]

Next we turn to the public capital stock data.[11] Table 1 presents summary statistics on the composition of the non-military public capital stock (net, evaluated at 1980 prices) in West Germany by eight different functions for the years 1961, 1970, 1980 and 1989. The categorization of the government capital by function presented in table 1 is rather close to the categorization used by the OECD for reporting government expenditures. 'Traffic, transportation and communication' and 'community services and pollution abatement' account for more that 50% of the total public capital stock. However, the share of the 'traffic, transport and communication' capital stock is stagnating whereas the share of public capital invested in 'community services and pollution' is still growing. Table 1 also reports annual growth rates for the four selected years. The average growth rate of the public capital stock decreased from 6.5% in 1970 to about 1.4% in 1989. The net stock of public capital invested in education has even decreased since 1983 which reflects the fact that since about 1980 virtually no more new schools and universities have been constructed.

Within the 'infrastructure literature' different concepts to measure public capital have been applied. Some researchers use the total stock of public capital, such as for example Nadiri and Mamuenas (1991) and Morrison and Schwartz (1992), whereas others use the concept of the 'core infrastructure', which comprises public capital

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[10] We acknowledge support by Dr. Georg Erber, German Institute of Economic Research (DIW), Berlin, who kindly provided us with the data. For a detailed description of the data used in this study see Erber and Haid (1989).

[11] These data too have been provided by the DIW, which makes annual reports on the structure of government capital within the regular 'Strukturberichterstattung' (Report on the Structure of the [German] Economy).

Table 1: The Stock of Government Capital in West Germany By Function (Net capital stock at 1980 prices).[1)]

	1961	1970	1980	1989
	%-shares (annual growth rates)			
G_1 General Public Services, Public Order and Savety	10.8 (2.98)	7.3 (5.10)	6.3 (3.38)	6.5 (1.75)
G_2 Education	19.8 (7.94)	21.8 (6.52)	21.9 (1.60)	18.8 (-0.06)
G_3 Health	9.4 (3.69)	7.7 (4.16)	7.0 (3.65)	7.5 (2.44)
G_4 Social Security and Welfare	3.8 (3.67)	2.7 (2.19)	2.5 (2.20)	2.5 (1.56)
G_5 Housing and Community Development	1.9 (2.75)	1.3 (5.48)	1.1 (7.48)	1.5 (6.03)
G_6 Community Services and Pollution Abatement	15.0 (6.13)	15.1 (5.97)	15.7 (4.80)	17.1 (2.40)
G_7 Traffic, Transportation and Communication	32.7 (6.85)	40.0 (7.88)	37.5 (3.51)	37.3 (1.42)
G_8 Recreation and Culture, Agriculture, Forestry and Fishing, Other Economic Affairs	6.6 (7.27)	7.1 (6.49)	8.0 (4.63)	8.6 (1.93)
Total Public Capital Stock[2)]	284.1 (6.08)	560.7 (6.50)	890.4 (3.38)	1060.0 (1.41)

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1) Source: German Institute for Economic Research (DIW), Berlin. The first line of figures indicate the share of the various types of public capital on the total public capital stock; the second line with figures in parentheses the growth rate compared to the previous year.

2) Total net capital stock in bill. of DM at 1980 prices.

capital in form of higways, airports, mass transit, electric and gas plants, telecommunications, water supply facilities and sewers, see for example Berndt and Hansson (1991) and Conrad and Seitz (1991, 1992). Aschauer (1989a,b) examines the total military and non-military public capital stock and Deno (1988) considers 3 different kinds of public infrastructure simultaneously placing however severe zero restrictions on the parameter estimates to avoid multi-collinearity problems. Seitz (1992), in a study of the economic effects of the public road network, used physical data on the length of the motorway network measured in km. With respect to the quantification of public capital data there is a remarkable difference between the 'new infrastructure research' and the infrastructure research in the area of regional economics. Whereas the former uses almost exclusively 'monetary' data the latter almost exclusively uses data measured physically such as the length of the motorway network or measures of accessibility of certain types of infrastructure, see for example the survey by Rietveld (1989). We examine two different concepts of the public capital stock: the total public capital stock and a 'core infrastructure' capital stock derived by aggregating the components G_5, G_6 and G_7 documented in table 1.[12]

To implement our model empirically we use a 'Generalized Leontief' cost function which can be considered to be an approximation to any arbitrary cost function. The 'Generalized Leontief' is a flexible functional form and permits, unlike the Cobb-Douglas function wich is usually chosen by researchers using the 'production function approach', both substitutive as well as complementary relations between the inputs involved, see for example Chambers (1988). Thus we specify the cost function to be estimated as:

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[12] In an earlier version of this paper we examined the eight different types of public capital, $G_1,..,G_8$, covered in table 1. However, the G_i series are highly correlated which made the estimation of the cost function (1) with all capital categories included impossible because of multicollinearity problems. Meaningful estimates could only be derived at the expense of imposing rather severe zero restrictions on parameters. In order to cope with the multicollinearity problem we had to take a rather pragmatic approach, that is estimate the cost function (1) for each category of public capital seperately. The earlier version of this paper with results on the eight different categories of public capital is available upon request by the author.

$$(10)\quad C_j = Y_j[\sum_{i=1}^{31}\beta_{wj}D_j w_j + \sum_{i=1}^{31}\beta_{rj}D_j r_j + 2\beta_{wr}(w_j r_j)^{0.5} + \beta_{wY}w_j Y_j^{0.5} + \beta_{rY}r_j Y_j^{0.5} + \beta_{wt}w_j t^{0.5} + \beta_{rt}r_j t^{0.5} + (w_j + r_j)(\beta_Y Y_j + \beta_t t + 2\beta_{Yt}(Y_j t)^{0.5})] + Y_j^{0.5}[\beta_{wG}w_j G^{0.5} + \beta_{rG}r_j G^{0.5} + (w_j + r_j)(\beta_{YG}(Y_j G)^{0.5} + \beta_{tG}(tG)^{0.5})] + (w_j + r_j)\beta_G G + \sum_{i=1}^{31}\gamma_{Cj}D_j$$

Using Shephard's Lemma cost minimizing conditional demand functions for private capital and labour can be derived:

$$(3a')\quad K_j^* = K(w, r, t, Y, G, D_j); \qquad (3b')\quad L_j^* = L(w, r, t, Y, G, D_j)$$

For lack of space equations (3a') and (3b') are not cast into parametric forms; these can easily be recovered from (10). The cost function (10) together with the two input demand functions (3a') and (3b') are estimated using iterative seemingly unrelated regression. Because we are dealing with a panel data set each equation is appended with industry specific dummies, that is, we estimate a system of equations with fixed effect, see for example Hsiao (1986). γ_{Cj}, j = 1,..31, is the industry j specific fixed effect in the cost function, D_j is a dummy variable taking on the value 1.0 in industry j and 0 otherwise. In order to ensure that both the labour as well as the capital demand equations with fixed effects can still be consistently derived from the cost function (10) the coefficients on the the variables w_j and r_j, β_{wj} and β_{rj}, have to be specified industry specific. These parameters enter the factor demand equations as constant terms taking on the role of industry specific fixed effects. Thus our approach is close to that taken by Nadiri and Mamuenas (1991), who use a cross section of 12 U. S. industries, and Morrison and Schwartz (1992), who pooled data on the manufacturing industry of the 48 contiguous U. S. states. However, compared to most of the empirical studies, our cost function does not impose any a priori homogenity restrictions on the parameters of the cost function, especially the property of constant returns to scale. We will test for this assumption, that is examine whether the restrictions $\beta_{wY} = \beta_{rY} = \beta_Y = \beta_{Yt} = \beta_{YG} = 0$ are jointly compatible with the data. We did not impose any zero restrictions on the

parameters in any of our estimates; for both the total as well as the 'core infrastructure' public capital stock the cost function as stated in equation (10) together with the two input demand functions have been estimated.

Before we turn to reporting our results a final question has to be addressed. Most researchers in the infrastructure literature incorporate the public capital stock data - lagged one period - in an adjusted form by multiplying the public capital stock data with the capacity utilization rate of the industry under consideration, see for example Berndt and Hansson (1991). This practice is based on the argument that there is strong empirical evidence, see Nadiri and Mamuneas (1991), that the intensity of the usage of public capital by private fims varies systematically over the business-cycle. We used the public capital stock data in both the unadjusted form as well as the adjusted form, that is by multiplying the infrastructure data with the capacity utilization rate of the industry using both times the data on G with a one period lag. For lack of space we present results only for the capacity adjusted public capital stock data because this model performed much better. However, in passing we will briefly state results derived from the model with the unadjusted data.[13]

4 Empirical Results

Table 2 presents the estimates derived using the total public capital stock data; the results using the core infrastructure do not differ that dramatically and for lack of space we refrain from presenting these results. With the exception of β_{tG} all of the estimated parameters are significant and the goodness-of-fit statistics are rather satisfactory if we take into account that we apply our model to a panel data set[14]. Table 2 also presents

[13] The adjustment of the public capital stock data with the industry specific capacity utilization rate gives more 'structure' to the public capital data. In the unadjusted form, the data varies only over time whereas in the adjusted form we also have variation accross industries.

[14] β_{tG} is insignificant also in the model using the core infrastructure variable. However, in the model with the unadjusted data, β_{tG} is significantly positive both in the model with the total as well as the core infrastructure public capital stock.

Table 2: Results of the panel-estimation for 31 industries over the period 1970 - 1989 using the total stock of public capital.[1)]

β_{jw}	0.03147	(2.0)	β_Y	$-1.341 \cdot 10^{-6}$	(5.1)
β_{jr}	0.25031	(2.0)	β_t	0.00077	(5.5)
β_{wr}	0.00715	(3.4)	β_{Yt}	$2.294 \cdot 10^{-5}$	(4.8)
β_{wY}	0.00050	(3.9)	β_{wG}	0.00923	(4.4)
β_{rY}	0.00234	(5.1)	β_{rG}	0.06236	(5.7)
β_{wt}	-0.01982	(8.8)	β_{tG}	0.00035	(1.7)
β_{rt}	-0.06791	(8.2)	β_{YG}	$-6.897 \cdot 10^{-5}$	(6.9)
β_G	-0.00023	(3.1)			

Cost Equation: $\bar{R}^2 = 0.990$

Labour Demand Equation: $\bar{R}^2 = 0.809$

Capital Demand Equation: $\bar{R}^2 = 0.633$

Log of Likelihood function: -12.757.3

Specification tests:[2)]

LR_D(FG = 93) = 3824,08
LR_G(FG = 5) = 141,42
LR_H(FG = 5) = 256.11

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1) t-ratios in parenthesis.
The total number of observations are t[=20]·n[=31] = 620.
The 'fixed-effects' parameters γ_j are not reported. Note, that β_{jw} and β_{jr} are estimated industry specific. The figures reported are average values.

2) LR indicates Likelihood-Ratio test-statistics, which follow a chi-square with degress of freedom as indicated in parentthesis.
LR_D: Tests the model with fixed-effects against the model without industry-specific dummies.
LR_G: Tests the model inclusive the variable G against the model exclusive of G, with industry-specific dummies specified in each model. This statistic tests for the overall significance of the variable G.
LR_H: Tests the assumption of constant resturns to scale in the cost function.
The associated probability values for all tests are 0.0000.

various specification tests[15]. The likelihood-ratio statistic LR_D tests the significance of the assumed industry-specific fixed-effects. The test-statistic indicates strongly that the model with fixed-effects outperforms a corresponding model that does not include sector-specific dummies. In addition, we calculated the likelihood-ratio statistic LR_G which tests the model including the variable G against the model without the public capital stock variable. With these test statistics we can assess the overall significance of the variable G. As the individual t-test statistics, LR_G supports the hypothesis that the public infrastructure variable enters significantly the cost, labour demand and capital demand equation. Because some researchers impose the assumption of constant returns to scale whereas we did not impose this assumption, we calculated the likelihood-ratio test-statistics LR_H which indicates a strong rejection of this hyphosesis. All tests performed equally well when using the core infrastructure public capital stock as well as the unadjusted public capital stock data.

Now we turn to the inspection of the economic implications of our estimates. The estimated average shadow price of the total public capital stock is 0.00218 that means, increasing G by one DM decreases private cost by 0.00218 DM; for the core infrastructure variable the average shadow price has been estimated to be 0.00364. Public capital and private capital have been estimated to be complementary and public capital and private labour to be substitutes which is in accordance to results reported throughout the literature, with the exception of Nadiri and Mamuenas (1991). The average elasticity of the demand for private capital with respect to the total public capital stock is $\eta_{K,G} = 0.3597$ and for private labour $\eta_{L,G} = -0.1552$. In the core infrastructure model the corresponding elasticities are: $\eta_{K,G} = 0.3613$ and $\eta_{L,G} = -0.1376$. Our estimates are far lower than those reported by other researchers, such as for example by Berndt and Hanson (1991) who estimate $\eta_{K,G} = 0.86$ and $\eta_{L,G} = -0.60$ using a 'core infrastructure' capital stock variable.

We continue the economic interpretation of our results by taking a closer look at the effects of the provision of public capital on the

[15] Because all of the applied tests are nowadays standard in applied econometrics, we refrain from a detailed discussion of these tests and refer the reader to the literature, see for example Greene (1990).

demand for private inputs. To examine the response of the demand for private capital to factor prices, output and public capital we have to cast equation (6) in our theoretical section into a form which makes it possible to assess the quantitative importance of the various effects involved empirically. This we achieve by differentiating (3a') with respect to time casting the resulting equation into elasticity form:

$$(11) \qquad \frac{\frac{dK}{dt}}{K} = \eta_{Kw}\frac{\frac{dw}{dt}}{w} + \eta_{Kr}\frac{\frac{dr}{dt}}{r} + \eta_{Kt}\frac{1}{t} + \eta_{KY}\frac{\frac{dY}{dt}}{Y} + \eta_{KG}\frac{\frac{dG}{dt}}{G}$$
$$= w^e + r^e + t^e + Y^e + G^e$$

with:

$$(12) \qquad \eta_{KZ} = \frac{\partial K^*}{\partial Z} \cdot \frac{Z}{K^*} \qquad for\ Z = w, r, t, Y, G$$

denoting the capital demand elasticities of the varies variables involved. An equation analogous to (11) can also be derived for the demand for labour which for lack of space we refrain from displaying.

Equation (11) is our empirical counterpart to equation (6) in section II. This equation decomposes the observed adjustment of the private capital stock into a wage, w^e, user cost of capital, r^e, output, Y^e, public capital, G^e, and 'technical progress', t^e, effect. Casting equation (6) into an empirical form would have required the estimation of a complete system of equations of the form $Z = Z(x_1, x_2, ., G)$ - with $x_1, x_2, ..$ denoting other exogenous variables - for all variables that are exogenous in our model, that is $Z = w, r, Y$. This is far beyond the scope of the present study. However, by examining the empirical estimates of the factor demand elasticities and the effects evaluated in equation (11) we are able to access the quantitative importance of the various exogenous variables for the adjustment of private capital.

Figures 1 to 4 present the result using the total public capital stock on the decomposition of the adjustment of the demand for private capital and labour as derived from equation (11). Table 3 presents summary statistics of the results obtained from using the total as well as the core infrastructure capital stock. The results differ only slightly and therefore we direct our attention on the effects of the total public capital stock. The effect of technical progress has been calculated by the residual method, that is we

Decomposition Of Private Capital Adjustment: 'Public Capital'-, 'Wage'- And 'Capital Cost'-Effect.

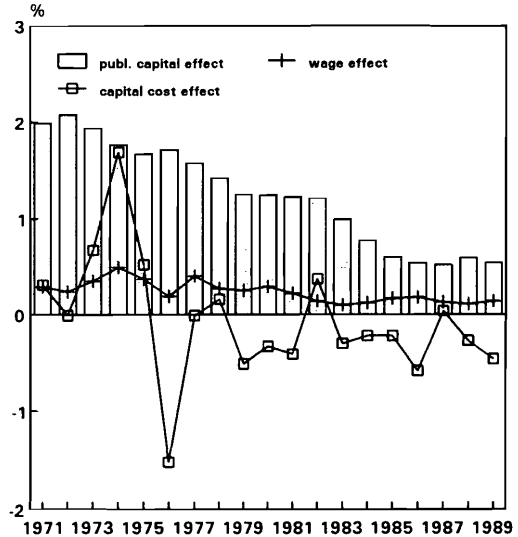

Figure 1

Decomposition Of Private Labour Demand Adjustment: 'Public Capital'-, 'Wage'- And 'Capital Cost'-Effect.

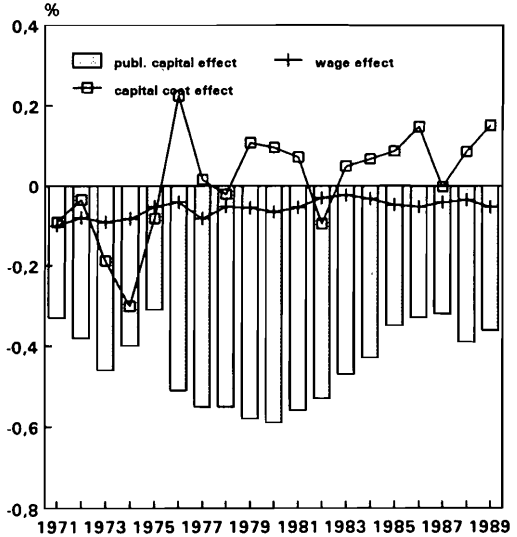

Figure 2

Decomposition Of Private Capital Adjustment: 'Public Capital'- And 'Output'-Effect.

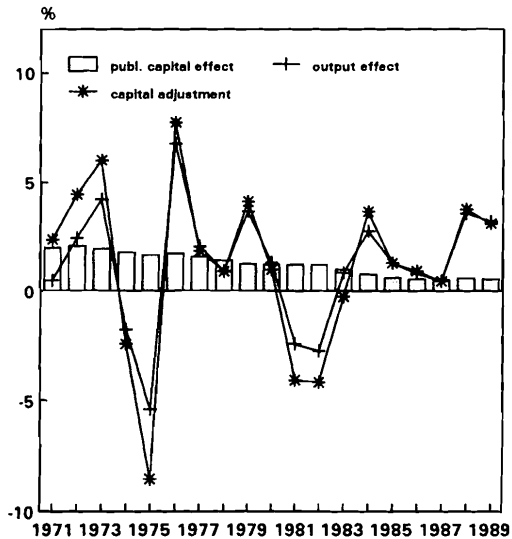

Figure 3

Decomposition Of Private Labour Demand Adjustment: 'Public Capital'- And 'Output'-Effect.

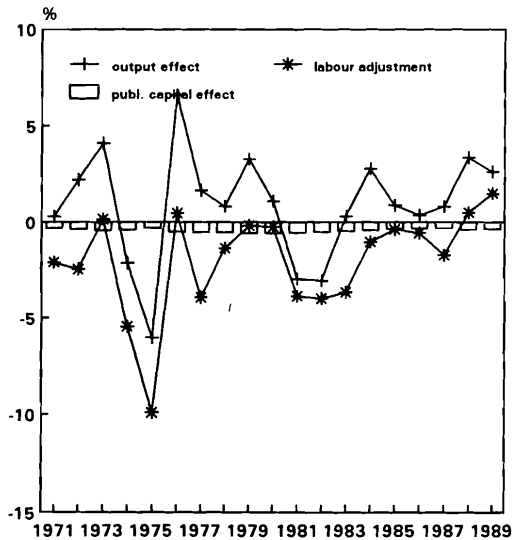

Figure 4

Table 3: Summary statistics of the economic effects on the demand for private capital and labour.[1)]

	Total Public Capital Stock	Core Infrastructure
Capital Demand Equation		
$\eta_{K,w} = -\eta_{K,r}$	0.037	0.037
$\eta_{K,Y}$	0.796	0.798
$\eta_{K,G}$	0.359	0.361
w^e	0.243	0.242
r^e	- 0.058	- 0.057
Y^e	1.178	1.175
G^e	1.271	1.274
t^e	- 1.441	- 1.440
Labour Demand Equation		
$\eta_{L,w} = -\eta_{L,r}$	- 0.093	- 0.093
$\eta_{L,Y}$	0.785	0.777
$\eta_{L,G}$	- 0.155	- 0.138
w^e	- 0.059	- 0.060
r^e	0.040	0.039
Y^e	1.071	1.064
G^e	- 0.450	- 0.394
t^e	- 2.628	- 2.477

1) Reported are the average values for the period 1971 - 1989 across all industries.

solved equation (11) for t^e.[16] First note, that both for labour as well as private capital the contribution of the provision of public capital, G^e, is rather steadily decreasing, see figure 1 and 2, which is mostly due to decreasing growth rates of the public capital stock. Changes in output are the most important determinants of the demand for private factors of production, see figure 3 and 4. The wage effect, w^e, both on private capital as well as labour is also steadily decreasing which might be due to growing legal restrictions associated with the hiring and firing of workers suggesting that labour, more than capital, might be a fixed factor in production. The user cost of capital effect, r^e, is highly volatile accross the business cycle. Its mean *absolute* value is smaller than the average impact public capital has on the demand for private capital and labour. In most years, the effects of changes in the user cost of capital - which are mainly caused by changes in the interest rate and changes in the price of private capital goods - partially offset the positive effect public capital has on private capital formation. However, theoretical considerations (Ricardian equivalence theory) and the evidence collected by Evans (1987), which has been verified by us, as well as the rather small impact the user cost of capital has on the demand for private investment suggests that there is little room for a crowding our effect to work. Figure 5 puts forward another interesting result which might be of practical importance: This figure shows the normalized - that is mean zero and standard deviation equal to one - values of the output, wage, capital cost and government capital effects on the demand for private capital. All effects, except the government capital effect, are highly volatile over the business cycle whereas the government capital effect is rather smooth. This suggests that public investment has a 'stabilizing' or 'smoothing' effect on private investment; however this stabilizing effect has become steadily smaller due to low public capital formation.

Finally, Table 4 summarizes industry specific estimates of output and public capital elasticities on the demand for private capital and labour. The elasticities vary dramatically accross the different industries. The smallest effects of the provision of public capital on the demand for private capital has been found in the road vehicle and in the mechanical engineering industry and the largest effect in the aircraft/spacecraft industry. With respect to labour in many

[16] Thus, t^e absorbs all estimation errors. For this reason we refrain from depicting t^e in figures 1 to 5.

Normalized Series: 'Public Capital'-, 'Wage'-, 'Output'- And 'Capital Cost'- Effects On Private Capital Demand.

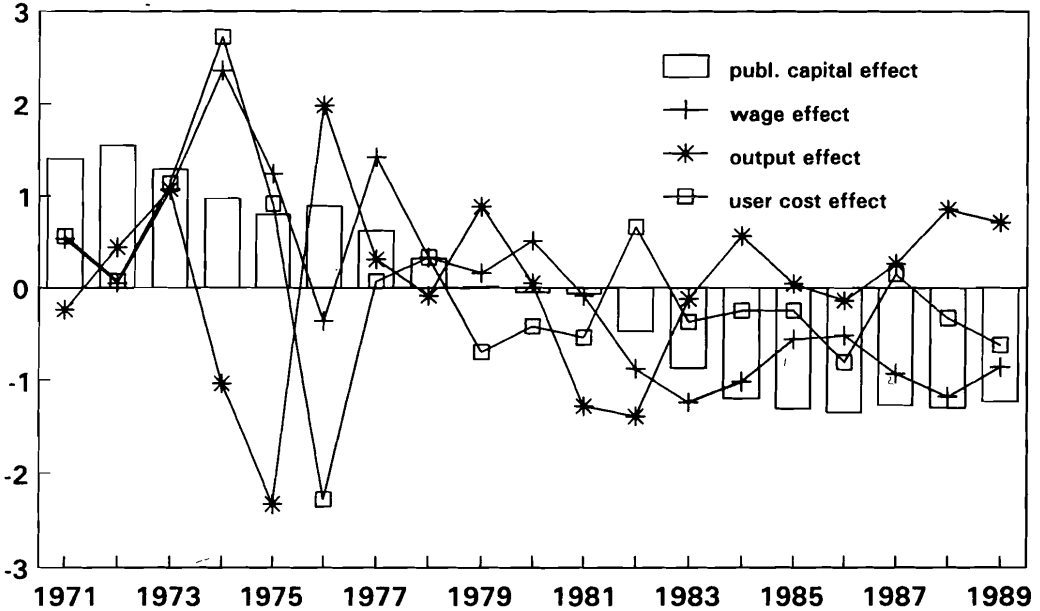

Figure 5

Table 4: Output and Public Capital Elasiticities of the demand for private capital and labour in different industries.

	$\eta_{K,Y}$	$\eta_{K,G}$	$\eta_{L,Y}$	$\eta_{L,G}$
Stones/Earths	0.924	0.169	0.821	-0.155
Iron and Steel	0.922	0.116	0.800	-0.118
Non-ferrous metal	0.801	0.294	0.587	-0.015
Foundries	0.726	0.409	0.732	-0.110
Non-ferrous metal foundries	0.813	0.183	1.171	-0.283
Drawing plants/cold rolling mills	0.527	0.264	0.902	-0.302
Chemical industry	0.816	0.070	0.910	-0.282
Wood working	0.293	0.397	0.815	-0.242
Manufacture of pulp and paper	0.746	0.241	0.667	-0.157
Rubber products	0.753	0.405	0.702	-0.020
Transformation of metals	0.782	0.359	0.727	-0.042
Structural metal products	0.926	0.442	0.838	-0.058
Mechanical engineering	1.055	0.132	0.753	-0.277
Road vehicles	1.124	0.105	0.804	-0.012
Shippbuilding	0.733	0.382	0.884	-0.242
Aircraft/spacecraft	0.830	0.824	0.741	-0.001
Electrical engineering	1.107	0.141	0.655	-0.321
Precision/optical instruments	0.869	0.491	0.741	-0.046
Tools and finished metal goods	0.884	0.235	0.838	-0.132
Office machinery/computers	0.674	0.335	0.565	-0.010
Musical instruments/toys	0.723	0.647	0.770	-0.136
Ceramic goods	0.843	0.638	0.917	-0.297
Glas industry	0.846	0.310	0.662	-0.079
Manufacture of wood products	0.934	0.301	0.846	-0.067
Processing of pulp and paper	0.722	0.320	0.696	-0.052
printing and duplication	1.050	0.292	0.774	-0.087
Plastic products	0.939	0.262	0.800	-0.071
Leather/shoes	1.064	0.654	0.657	-0.121
Textiles	0.627	0.194	0.874	-0.082
Clothing	0.401	0.201	0.841	-0.042
Food/beverages/tobacco	0.857	0.105	0.838	-0.215
Industry Average	0.796	0.359	0.785	-0.155

industries the impact of public capital has been estimated to be very small. The rather large differences of public capital effects across industries suggest that public investmest in not neutral with respect to the industry structure. The estimated marked differences of the impact of public infrastructure on the various sectors of the economy are in accordance with evidence reported in the infrastructure literature within the area of urban and regional economics, see for example Blum (1982) and Biehl (1986).

5 Summary and Conclusions

This study investigated the impact of the provision of public capital on the demand for private capital and labour. In our theorectical discussion we examined the effects of debt vs. tax financing of public investment by applying simple comparative statics on conditional factor demand functions arguing that the effect of additional public investment on private investment demand crucially depends on whether private and public capital are substitutes or complements. We refered to the Ricardian equivalence theorem which raises arguments against a positive correlation between deficit financing and interest rates. Empirical results presented in the literature in support of the Ricardian equivalence theorem as well as own estimates have been shortly dealt with. In the empirical section we presented evidence on the impact of public capital on private production cost as well as on the demand for private factors of production. Our estimates revealed rather small price elasticities of the factor demand functions, leaving only small room for a crowding out effect to work, but rather strong effects of output and less stronger and decreasung effects of the provision of public capital on private labour and capital. Private and public capital have been estimated to be complementary, that is public capital crowds in private capital, and for public capital and private labour a substitutive relation resulted. However, we found rather dramatic differences on the impact of public capital on labour and capital demand accross the 31 2-digit which suggests that government capital formation has a considerable impact on the structure of the private economy.

A severe drawback of the approach presented is that because of the lack of availability of data on material and energy usage in 2-digit industries, we could consider only two private inputs, namely capital and labour. A further methodical shortcoming is that we did not consider a potential simultaneity bias in our estimation because

one should expect that output and factor prices are not exogenous. However, the data set available to us covers only a small set of variables which makes the application of instrumental variables techniques rather problematic if one does not want to rely exclusively on lagged values of the variables in question. Thus, a more richer industry data set should be collected in which also other inputs, such as raw materials and enery, should are covered and which provides data on other industry specific variables to be used as instrumental variables.

Further research should be directed to incorporate the fact that firms pay for the provision of public infrastructure facilities by taxes. Such an extension, both theoretically as well as empirically, could open new avenues for research on the impact of tax vs. deficit financing of public investment expenditures. Another promissing field for future research could be an improved measurement of public intermediate inputs. Most researchers consider only the benefits related to the stock of public capital, but public output like private input is produced by combining labour, capital and intermediates. Thus, to measure the benefits related to public services one would have to find a measure for public output and incorporate this measure into private cost or production functions which could probably be achieved by using hedonic public output concepts.

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