Research Memorandum

No 133

The impact of Public Infrastructure Capital on the Private Sector of The Netherlands

An Application of the Symmetric Generalized McFadden Cost Function

Jan-Egbert Sturm

CPB Netherlands Bureau for Economic Policy Analysis, The Hague, March 1997

CPB Netherlands Bureau for Economic Policy Analysis
Van Stolkweg 14
P.O. Box 80510
2508 GM The Hague, The Netherlands

Telephone +31 70 33 83 380
Telefax +31 70 33 83 350

ISBN 90 563 5081 1

The Impact of Public Infrastructure Capital on the Private Sector of The Netherlands
An Application of the Symmetric Generalized McFadden Cost Function

March 13, 1997

Contents

Abstract

This paper expands the symmetric generalized McFadden cost function by incorporating public capital as an unpaid fixed input, and estimates the new function using Dutch sector data for the post-World War II period. Several elasticities concerning public infrastructure are estimated in order to uncover the productivity effects of public infrastructure. We conclude that especially the sheltered sector of the Dutch economy benefits from infrastructure investment. Experimenting with several variants of the model reveals that this outcome is robust. However, despite these unambiguous results, the relationship between private inputs and public infrastructure is unclear. Their estimated elasticities alter sign during the estimation period.

1 Introduction[1]

In most OECD-countries public capital outlays dramatically decreased since the early 1970s.[2] At approximately the same time productivity growth plummeted almost everywhere, also in the Netherlands (see figure 1). Aschauer (1989) has hypothesized that the decrease in productive government services may be crucial in explaining the general decline in productivity growth. This view is often referred to as 'the public capital hypothesis'. Taking a Cobb-Douglas production function and using annual data for the 1949–1985 period, Aschauer found a strong positive relationship between productivity and the ratio of the public to the private capital stock in the USA. On the basis of his results, a ten percent increase in the public capital stock would raise total factor productivity by almost four percent. Consequently, much of the decline in US productivity that occurred in the 1970s can be explained by lower public investment spending. The implications of these results for policy makers seem to be clear: Public investment should go up to give a boost to the economy. However, the outcomes of Aschauer's study have been challenged by several authors.[3]

The purpose of this paper is to get insight in the possible effects which public capital has had on the exposed and sheltered sectors of the Dutch economy during the post-World War II period. The exposed sector is relatively capital intensive and consists of agriculture, manufacturing and transport, whereas trade, banking and other private services form the sheltered sector. Most studies concentrate on the US. With the exception of Sturm and De Haan (1995), so far hardly any studies are conducted for the Netherlands. Despite the developments of public investment and productivity as shown in figure 1, Sturm and De Haan (1995) did not come up with solid econometric results. As noted by these authors, this is probably due to the over-simplifying production function approach.

Our framework here is based on what we call the cost function approach. One can describe the behaviour of agents (*i.e.* firms) by assuming that they minimize costs. From this cost function we can—under certain regularity conditions—derive a unique production function by applying duality theory.[4] Besides explicitly modelling economic behaviour, one of the main advantages of the cost function approach is that we can use flexible functional forms which hardly enforce any restrictions on the production structure. We have opted for the symmetric generalized McFadden (SGM) cost function, and augmented it with public capital. So far, the only second-order Taylor approximations used in this line of research are the transcendental logarithmic (translog) and the generalized

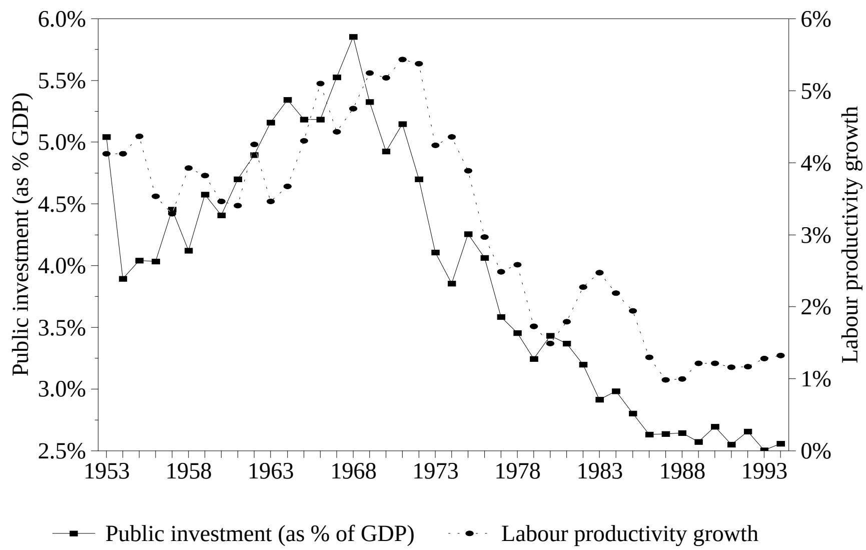
[1]The author gratefully acknowledges support from the CPB Netherlands Bureau for Economic Policy Analysis. The paper is a continuation of Draper and Manders (1996a,b) and benefited from discussions with Peter Broer, Nick Draper, Johan Graafland, Jakob De Haan, Gerard Kuper and Ton Manders. The usual disclaimer applies, however.

[2]See De Haan *et al.* (1996).

[3]See Gramlich (1994) and Sturm *et al.* (1996) for an overview.

[4]See, *e.g.* Diewert (1974).

Figure 1 *Public investment as share of GDP and five-years moving average growth rate of labour productivity in the private sector of the Netherlands, 1953–1993.*



Source: CPB Netherlands Bureau for Economic Policy Analysis.

Leontief function.[5] As shown by Diewert and Wales (1987) both functions frequently fail to satisfy the appropriate theoretical curvature conditions, as is confirmed by Sturm and Kuper (1996) who employed a translog specification to test the 'public capital hypothesis'. Using the (modified) SGM cost function, it turns out that imposing the appropriate curvature conditions at one data point imposes the curvature conditions globally without destroying the flexibility property. Imposing curvature conditions on other flexible functional forms, such as, *e.g.* the translog, often results in biased estimates and the loss of its flexibility property.

The modified SGM specification enables us to estimate several elasticities which uncover the productivity effects of public capital. Besides implementing this framework for the total private economy, we will in particular estimate the specification for two sec-

[5]The translog function is used by, *e.g.* Conrad and Seitz (1992, 1994), Dalamagas (1995), Deno (1988), Keeler and Ying (1988), Lynde and Richmond (1992, 1993a, 1993b), Shah (1992) and Sturm and Kuper (1996). Berndt and Hansson (1991), Morrison and Schwartz (1992, 1996) and Seitz (1993, 1994) apply the generalized Leontief function.

tors: the exposed and the sheltered sector. We expect both sectors to react differently to a change in the public capital stock because of their distinct characters. The production costs of the total private economy are shown to be significantly reduced by public infrastructure. However, differentiating between the two sectors it appears that the relatively capital intensive exposed sector does not benefit as much from the provision of infrastructure as the sheltered sector of the Dutch economy.

The paper is organized as follows. Section 2 discusses earlier empirical research on the 'public capital hypothesis'. The theoretical framework is set forth in section 3, whereas section 4 describes the database. In section 5 the estimation results will be discussed. Finally, some concluding remarks and suggestions for further research are given in section 6.

2 Literature

Summarizing the economic literature, both Gramlich (1994) and Sturm and De Haan (1995) write that various economists found output elasticities of public capital of around 0.3. However, these large elasticities have in turn generated a raft of criticisms from various authors.[6] Despite the initial findings by Aschauer (1989) and others, it seems that most economists do not support 'the public capital hypothesis'.

Studies in the early literature were largely based on the analysis of a production function, often assumed to be of the Cobb-Douglas form, which allows the signs and magnitudes of marginal products to be estimated, but which requires restrictive assumptions about firm behaviour. Furthermore, questions as to the endogeneity of the variables and therefore the extent to which the production function estimates suffer from a simultaneous equations bias have been raised. Specifically, the right-hand side variables in the various equations estimated by Aschauer (1989) include measures of labour input and utilization, and strong arguments have been made that in this type of context such variables should be treated as endogenous. Ordinary least squares (OLS) regressions will therefore produce biased and inconsistent parameter estimates.

These problems do not arise when a cost function approach is used, because input shares or factor-demand equations—both directly derived from the cost function—can be incorporated in the regression analysis.[7] Therefore, the dual framework yields estimating equations that have endogenous dependent variables. In the cost function approach, inputs are no longer exogenous to the level of output. Instead, the input prices and the level of output are exogenous to the minimization of the cost of output.[8]

Using flexible functional forms ensures that hardly any restrictions on the production

[6]See, *e.g.* Hulten and Schwab (1991) and Munnell (1992)

[7]See Sturm *et al.* (1996) for a survey of the pros and cons of the different empirical approaches used in researching the impact of public capital.

[8]Therefore, the problem of possible endogeneity of variables remains, but does not concern the same variables as in the production function approach.

Table 1 *Literature using a cost function approach to investigate the 'public capital hypothesis'.*

Study	Cost function
Berndt and Hansson (1991)	generalized Leontief
Conrad and Seitz (1992)	translog
Conrad and Seitz (1994)	translog
Dalamagas (1995)	translog
Keeler and Ying (1988)	translog
Lynde and Richmond (1992)	translog
Lynde and Richmond (1993b)	translog
Morrison and Schwartz (1992)	generalized Leontief
Morrison and Schwartz (1996)	generalized Leontief
Nadiri and Mamuneas (1994a)	generalized Cobb–Douglas
Nadiri and Mamuneas (1994b)	generalized Cobb–Douglas
Seitz (1993)	generalized Leontief
Seitz (1994)	generalized Leontief
Shah (1992)	translog
Sturm and Kuper (1996)	translog

structure are enforced. For example, a priori restrictions placed upon substitutability of production factors—as often encountered in the production function approach—do not apply anymore. In the early literature only the total effect of public capital on output has been estimated. These studies ignored the fact that public capital might affect the input factors differently, *i.e.* the effects of public capital may not be neutral with respect to private input decisions. After all it seems very plausible that, *e.g.* a larger stock of infrastructure raises the demand for private capital more than the demand for labour. By using a flexible functional form, the total effect of public capital on the private sector can now be divided into the different effects of public capital on the various input factors.

These considerations led several economists to apply the so-called cost function approach to test the 'public capital hypothesis'. Table 1 gives an overview of the published papers using this approach.[9]

Most studies conclude that public and private capital are complements which supports the hypothesis that public capital might enhance the productivity of private capital.[10] The relationship between labour and public capital is less clear. Whereas Conrad and Seitz (1994), Lynde and Richmond (1992) and Seitz (1993, 1994) find a substitutive relationship, Conrad and Seitz (1992), Deno (1988), Nadiri and Mamuneas (1994a) and

[9] For a more comprehensive overview we refer to Sturm *et al.* (1996).

[10] Conrad and Seitz (1992, 1994), Dalamagas (1995), Deno (1988), Lynde and Richmond (1992), Nadiri and Mamuneas (1994a), Seitz (1993, 1994) and Shah (1992) all find that public and private capital behave as complements.

Shah (1992) report that labour and public capital are complements. Furthermore, most studies clearly reject the hypothesis of constant returns to scale in all inputs including public capital. Exceptions are Conrad and Seitz (1992, 1994), Lynde (1992) and Lynde and Richmond (1992). Conrad and Seitz (1992, 1994) even reject the hypothesis of homogeneity of the production function. However, when these authors impose homogeneity this results in not rejecting the hypothesis of constant returns to scale in all inputs.

All studies conclude that public capital reduces private sector costs. However, their estimated effects are mostly significantly smaller than those reported by Aschauer (1989). Only Deno (1988) and Lynde (1992) come up with a larger impact of public capital on the private sector. The remaining studies roughly estimate less than half the impact that Aschauer (1989) reported, *i.e.* a public capital elasticity of approximately 0.15.

3 The theoretical framework[11]

This section develops our theoretical framework which aims at incorporating public capital into the cost function and therefore into the underlying production function. For expositional purposes the section is subdivided into four subsections. The first subsection will discuss the general cost function framework. The second subsection will go into the elasticity estimates which reveal all economically relevant characteristics. In the third subsection the symmetric generalized McFadden cost function will be discussed and modified by incorporating public capital. Finally, the long-run relationship between production costs and public capital will be incorporated into an error correction model.

3.1 The cost function

Starting-point of our theoretical framework is a variable cost function (C^*) which results from minimizing private variable production cost subject to the production function, $y = f^*(x, t, G)$, where $x \equiv (x_1, x_2, \ldots, x_N)^T$ is the vector of private inputs utilized, t denotes technology, and G the services that render from the public capital stock. The latter two variables form the environmental variables in our model. They are exogenous and enter the production function and thus also the cost function as unpaid fixed inputs.[12] Furthermore, we allow the environment to influence the productivity of specific inputs differently. Given a positive vector of input prices, $p \equiv (p_1, p_2, \ldots, p_N)^T \gg 0_N^T$, the cost function C^* dual to the production function f^* may be defined as follows:

$$C^*(p, y, t, G) \equiv \min_x \left\{ p^T x : f^*(x, t, G) \geq y, x \geq 0_N \right\}. \tag{1}$$

All economically relevant characteristics of the underlying production function can

[11] This section draws upon Diewert and Wales (1987, 1995) and Seitz (1994).

[12] There is, of course, a price paid for the services of the public capital stock through the tax system, but it is assumed that firms do not have direct control over how much capital the government supplies to them, so that we can treat these services as ‘unpaid’ factors of production.

be summarized with this cost function if six conditions are satisfied. These conditions are:

$$
\begin{aligned}
C^*(\lambda p, y, t, G) &= \lambda C^*(p, y, t, G), \forall \lambda \geq 0, && (2)\\
C^*(p, y, t, G) &> 0, \forall p > 0_N, \forall y > 0, && (3)\\
\nabla_p C^*(p, y, t, G) &\geq 0_N, && (4)\\
\nabla^2_{pp} C^*(p, y, t, G) &= \text{negative semidefinite}, && (5)\\
\nabla_G C^*(p, y, t, G) &\leq 0, && (6)\\
\nabla^2_{GG} C^*(p, y, t, G) &\geq 0, && (7)
\end{aligned}
$$

where ∇_i denotes the column vector of the first order partial derivatives with respect to the components of i, and ∇^2_{ij} denotes the matrix of second-order partial derivatives with respect to the components of i and j.

The first condition of linear homogeneity in prices is a restatement of the familiar principle that only relative prices matter to economically optimizing agents. Or, as long as input prices only vary proportionally, the cost-minimizing choice of inputs will not vary. The nonnegativity condition (3) simply says that producing a positive output at zero cost is impossible, whereas equation (4) indicates that increasing any input price must not decrease cost. The concavity condition (5) assures that we are minimizing—instead of maximizing—cost. The final two conditions assure that public capital cannot increase the costs of the private sector (equation (6)) and that the marginal benefits of each additional unit of public capital does not increase (equation (7)). The free disposal assumption (6) means that production cost cannot rise as a consequence of an increase in public capital, because otherwise firms would simply not use the additional public capital in their production process.

3.2 Elasticities

Using a flexible cost function it is possible to reveal all economically relevant characteristics of the underlying production function.[13] Several interesting elasticities can be derived from a flexible cost function. For instance, the cost elasticities of all inputs—including public capital—can be calculated as:

$$
\begin{aligned}
\varepsilon_{Cj} &= \frac{\partial \ln C^*}{\partial \ln j} = \frac{\partial C^*}{\partial j}\frac{j}{C^*}, \quad j = p_1, \ldots, p_N, y, G,\\
\varepsilon_{Ct} &= \frac{\partial \ln C^*}{\partial t}.
\end{aligned} \tag{8}
$$

Because we will use a second-order flexible cost function, we can even go a step further and calculate several price and demand elasticities. To do so we first have to apply

[13] See appendix A for an elaboration on flexibility.

Shephard's Lemma to the cost function, $C(p, y, t, G)$, which yields the cost minimizing conditional factor-demand equations for the private inputs:

$$\nabla_p C(p, y, t, G) = x^* = x(p, y, t, G). \tag{9}$$

The price and demand elasticities can now be calculated by:

$$\begin{aligned} \varepsilon_{ij} &= \frac{\partial \ln x_i^*}{\partial \ln j} = \frac{\partial x_i^*}{\partial j}\frac{j}{x_i^*} = \frac{\partial^2 C}{\partial p_i \partial j}\frac{j}{x_i^*}, \quad & j = p_1, \ldots, p_N, y, G, \\ \varepsilon_{it} &= \frac{\partial \ln x_i^*}{\partial t}, & i = 1, \ldots, N. \end{aligned} \tag{10}$$

If the sign of such an elasticity for $j = y, G$ is positive than factor j and the i^{th} private input are complements. For $j = p_1, \ldots, p_N$ a positive sign indicates that the two inputs are substitutes.

Differentiating the cost function with respect to G yields the shadow price, p_G^s, associated with public capital:

$$p_G^s = -\frac{\partial C(p, y, t, G)}{\partial G}, \tag{11}$$

which denotes the change in private production cost caused by one additional unit of public capital, G. Differentiating equation (11) with respect to the variable t yields insight into the impact of public capital on total factor productivity. If $\partial p_G^s / \partial t$ is greater than, equal to or less than zero, then public capital supports, does not affect, or discourages technological progress.

Using the conditional factor-demand equations (9), production costs can be rewritten as:

$$C = p^T x^*. \tag{12}$$

Applying Shephard's Lemma to equation (12) yields:

$$p_G^s = -p^T \nabla_G x^*, \tag{13}$$

which decomposes the cost changes associated with an increase in G into adjustment effects on the private inputs. $\partial x_i^* / \partial G$ denotes the response of the demand for private input x_i, $i = 1, \ldots, N$, to an increase in public capital, G. Equation (13) 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, *i.e.* $\partial x_i^* / \partial G < 0, \forall i = 1, \ldots, N$. However, if one of the private inputs is complementary to the public input, cost savings arise only if the substitution effects outweigh the complementary effect.

The final step is to establish a link between the 'production function approach' and our 'cost function approach'. In order to do this we have to go back to the cost minimization problem and solve the Lagrangian:

$$\pounds(p, y, t, G) = p^T x + \lambda [y - f(x, t, G)]. \tag{14}$$

Note that in the optimum λ equals marginal cost, $\partial C^* / \partial y$. Differentiating with respect to public capital yields:

$$-p_G^s = \frac{\partial \pounds}{\partial G} = -\lambda \frac{\partial f}{\partial G} = -\frac{\partial C^*}{\partial y} \frac{\partial f}{\partial G}, \tag{15}$$

in the optimum, which is at minimum cost. Therefore the following property holds:

$$\frac{\partial f(x, t, G)}{\partial G} \frac{G}{y} = \frac{p_G^s}{\partial C^* / \partial y} \frac{G}{y}. \tag{16}$$

The relation in equation (16) provides a link between the 'production function approach' and the 'cost function approach' and can be used to compare results derived from these two quite different approaches. Note that in case the cost function is linear homogenous in output, the above equation states that the absolute value of the cost elasticity of public capital equals the absolute values of the output elasticity of public capital.

3.3 The modified symmetric generalized McFadden cost function

Now we are ready to define the modified symmetric generalized McFadden (SGM) cost function C.[14] The term 'modified' stems from the fact that we allow for a fixed input, *i.e.* public capital G.[15] Consider the following functional form for the cost function:

$$\begin{aligned} C(p, y, t, G) \equiv g(p)y \quad & + b_{ii}^T py + b_i^T p + b_{it}^T pty + b_{iG}^T pGy \\ & + b_{yy} \beta^T py^2 + b_t \alpha^T pt + b_{tt} \gamma^T pt^2 y \\ & + b_G \delta^T pG + b_{GG} \eta^T pG^2 y + b_{tG} \tau^T ptGy, \end{aligned} \tag{17}$$

where the function $g(p)$ is defined by

$$g(p) \equiv \tfrac{1}{2} \frac{p^T Sp}{\theta^T p}, \tag{18}$$

where $\theta \equiv (\theta_1, \ldots \theta_N)^T \geq 0_N^T$, $b_{ii} \equiv (b_{11}, b_{22}, \ldots, b_{NN})^T$, $b_i \equiv (b_1, \ldots, b_N)^T$, $b_{it} \equiv (b_{1t}, \ldots, b_{Nt})^T$, $b_{iG} \equiv (b_{1G}, \ldots, b_{NG})^T$, $b_{yy}, b_t, b_{tt}, b_G, b_{GG}, b_{tG}$, $\alpha \equiv (\alpha_1, \ldots, \alpha_N)^T$, $\beta \equiv (\beta_1, \ldots, \beta_N)^T$, $\gamma \equiv (\gamma_1, \ldots, \gamma_N)^T$, $\delta \equiv (\delta_1, \ldots, \delta_N)^T$, $\eta \equiv (\eta_1, \ldots, \eta_N)^T$, and $\tau \equiv (\tau_1, \ldots, \tau_N)^T$ are the parameters of our model. To generate elasticities which are invariant to scale changes in the units of measurement, the econometrician has to set

[14] The functional form is a (modest) generalization of a functional form due to McFadden (1978, p. 279), in which $g(p)$ is defined to be symmetric. See Diewert and Wales (1987, p. 51–54) for details. Recent applications of this specification can be found in Rask (1995), Coelli (1996) and Terrell (1996).

[15] Rask (1995) also modifies the orginal SGM proposed by Diewert and Wales (1987) to allow for fixed factors of production. However, the function he defines is not second-order flexible in the fixed inputs.

$\theta_i = \bar{x}_i$ for $i = 1, \ldots, N$.[16] The $7N$ number of parameters, α, β, γ, δ, η, τ, and θ are arbitrarily selected by the econometrician. Since these values may be selected arbitrarily, it means that we are considering a whole family of flexible functional forms rather than just one form. If we choose $\alpha_i = \beta_i = \gamma_i = \delta_i = \eta_i = \tau_i = \theta_i = \bar{x}_i$ for $i = 1, \ldots, N$, where $\bar{x}_i$ is the average amount of input i used over the sample period, then again the elasticities generated by our estimated cost function will be invariant to scale changes. Alternatively, if there are ample degrees of freedom, the econometrician may set $b_{yy} = b_t = b_{tt} = b_G = b_{GG} = b_{tG} = 1$ and estimate α, β, γ, δ, η, and τ. In this case the cost function becomes third-order flexible in y, t and G, and therefore the factor-demand equations are second-order flexible in y, t and G. Finally, S is an $N \times N$ symmetric negative semidefinite matrix that satisfies the N extra restrictions $Sp = 0$ for some $p \gg 0_N$.

Note that C is linear homogeneous in p and that its factor-demand functions are linear in the unknown parameters. By differentiating equation (17) with respect to input prices, and then employing Shephard's Lemma, it is easy to show that the factor-demand equations are:[17]

$$x^* = \frac{Sp}{\theta^T p} - \tfrac{1}{2}\theta \frac{p^T Sp}{\left(\theta^T p\right)^2} \quad \begin{aligned} &+b_{ii} y + b_i + b_{it} t y + b_{iG} G y \\ &+b_{yy} \beta y^2 + b_t \alpha t + b_{tt} \gamma t^2 y \\ &+b_G \delta G + b_{GG} \eta G^2 y + b_{tG} \tau t G y, \end{aligned} \tag{19}$$

where $x^* \equiv \left(x_1^*, \ldots, x_N^*\right)^T$.

It can easily be verified that the concavity restrictions (5) for all $p \gg 0_N$, $y > 0$, $t > 0$, $G > 0$ are satisfied if and only if the S matrix is negative semidefinite. Thus if our estimated S matrix turns out to be negative semidefinite, the C will be globally concave. If furthermore $\nabla_{GG} C\left(p, y, t, G\right) = 2 b_{GG} \eta^T p y \geq 0$ for all $p \gg 0_N$, $y > 0$, $t > 0$, $G > 0$ we may call C globally curvature correct.

Using this functional form Diewert and Wales (1987) show that it is easy to impose the concavity in factor prices. Following a technique due to Wiley *et al.* (1973, p. 318), they reparametrize the S matrix by replacing it by minus the product of a lower triangular matrix of dimension $N \times N$, A say, times its transpose, A^T, *i.e.*

$$S = -AA^T, \tag{20}$$

where $A = \left[a_{ij}\right]$ and $a_{ij} = 0$ for $i < j$, $i, j = 1, \ldots, N$. It must be emphasized that using this technique to impose negative semidefiniteness on S does not destroy the flexibility of the modified SGM functional form.

It should be noted that it is relatively easy to impose several restrictions on the modified SGM defined by (17) and (18). For instance, in order to make C linear homogenous

---

[16] See Diewert and Wales (1987).

[17] See, *e.g.* Diewert (1974).

in output y (so that the dual production function exhibits constant returns to scale in the private inputs), we need only impose the following $N + 3$ additional linear restrictions on the b parameters:

$$b_t = b_{yy} = b_G = 0, \quad b_i = 0_N, \quad j = 1, \ldots, N. \tag{21}$$

3.4 The error correction specification

Equation (19) represents the long-run relation. It is unlikely that factor demand equals the long-run equilibrium in every time period because of habits persistence, adjustment costs, incorrect expectations and misinterpreted real price changes. Therefore, we introduce a first-order error correction model:

$$\Delta x = \Gamma \Delta x^* + \Lambda \left[x^* - x\right]_{-1}, \tag{22}$$

where x^* stand for the long-run factor-demand equations as given by equation (19), whereas Γ and Λ represent parameter matrices. The first matrix estimates the impact effects of short-run changes, whereas the second is the error correction term, which determines the dynamic behaviour.[18] We opted for this simple error correction model, because our main interest lies in estimating the long-run relationship.

4 The Dutch data

In the empirical analysis we will distinguish two and sometimes three production factors controlled by the private sector ($N = 2$, or $N = 3$): Labour (L)—which we will later on subdivide in low-skilled labour (L^l) and high-skilled labour (L^h)—and capital (K). The technology and the services that stem from the stock of public capital are two environmental variables which might influence the cost minimization problem the firms face and will be approximated by time (t) and the stock of public capital (G), respectively.[19]

Accordingly, factor demand is a function of factor prices, output, time, public capital and the parameters of the cost function. Therefore, we need data on prices and quantities of all factor inputs, and quantities of the public capital stock and output. Because our analysis will concentrate on the sheltered and the exposed sectors of the Dutch economy, we need all data—except of course public capital—at the sectoral level.[20] Unless mentioned otherwise the data are extracted from the databases kept by the CPB Netherlands Bureau for Economic Policy Analysis, which are based on the Dutch National Ac-

[18] Using this specification we assume that impact effects of price and production changes are equal.

[19] In this line of research most studies approximate the state of technical knowledge by a time trend. Nadiri and Mamuneas (1994a, 1994b) are the only ones who also take public Research and Development (R&D) capital into account.

[20] As noted in the introduction, the exposed sector contains of agriculture, manufacturing and transport, whereas trade, banking and other private market services form the sheltered sector.

counts of Statistics Netherlands. Furthermore price indices equal one in the year 1973. Appendix C lists the data used in the regression analysis.

Low-skilled labour is defined as labour with a primary and extended education. High-skilled labour involves labour with secondary, higher vocational and university education. Statistics Netherlands (1996) provides data on employment and wages by education for the period 1969–1993. As this is a short period, we will start off with using total labour input. All labour variables are adjusted for the number of hours worked. In a final stage we will make the subdivision in labour in order to say some more about the relationship between labour and public capital. Data on total labour cover the 1952–1993 period.

To get a more accurate estimate of the total private capital stock and its price, we build up both measures from stocks and user costs of structures (buildings) and equipment (machinery and equipment). Both the stock of private structures and the stock of private equipment (K^j) are constructed through the perpetual inventory method. To measure their user cost of capital we follow Jorgenson (1986) and assume that it is a function of the interest rate, tax parameters and the investment price index. Once these rental prices and capital service flows are separately measured, we aggregate them to get the total stock of private capital and the aggregate rental price of private capital by employing the familiar Tornqvist discrete approximation to the continuous Divisia index.[21]

We also use the Tornqvist approximation of the Divisia index to aggregate our data over both sectors. In this way we get estimates of the prices and quantities of all private input factors and private output over almost the entire private sector. Only the building sector and the Dutch gas industry are not taken into account.[22] As we will see, using these aggregated data makes it easier to interpret the results on a sectoral level.

The public capital stock is also constructed using the perpetual inventory method. In the empirical analysis we will concentrate on the stock of public ground, roads and waterways, which we will henceforth label infrastructure.[23] However, sometimes we will also refer to what we call the total public capital stock, which is the sum of five types of public capital: Buildings; ground, roads and waterways; machinery; road transport equipment; and other transport equipment.[24] As in the definition of Statistics Netherlands public firms like, *e.g.* the Dutch railway company (‘*Nederlandse Spoorwegen*’) are not part of the public sector, their capital outlays come under the definition of private investment.[25]

[21]Appendix B goes deeper into the construction of our total private capital stock as well as its price.

[22]Unlike Draper and Manders (1996a,b), the construction sector is left out of the analysis in order to minimize the influence of possible backward linkages, *i.e.* direct impulses on the economy through the demand for labour, raw materials and other capital goods in the construction of the infrastructural work.

[23]A better term would probably be ‘civil engineering works’. However, as in this line of the economic literature the term ‘infrastructure’ has become a convention, we stick to the latter.

[24]Because rental prices of the different public capital stocks are almost impossible to compute, we were not able to use the Tornqvist discrete approximation of the continuous Divisia index to aggregate these stocks.

[25]Consequently, privatisation of these public firms does not influence our data.

Initial capital stocks and depreciation rates are taken from preliminary data on quantities and depreciation rates of the public capital stock which were kindly provided by the Statistics Netherlands.[26] Both infrastructure and the total public capital stock cover the 1949–1993 period.

Many authors adjust the stock of public capital by an index, such as the capacity utilization rate, to reflect their usage by the private sector.[27] Mainly two reasons are advocated for adjusting the stock of public capital. The first argument is that public capital is a collective input which a firm must share with the rest of the economy. Since most types of public capital are subject to congestion, the amount of public capital that one firm may employ will be less than the total amount supplied. The second reason for adjusting the public capital stock is that firms might have some control on the usage of the public capital stock in existence. For instance, a firm may have no influence on the level of highways provided by the government, but it can vary its usage of existing highways by choosing routes. Therefore, there are significant swings in the intensity with which public capital is used. Other authors explicitly "... *refrain from all of these possible adjustment procedures because of their ad hoc character and because 'proper' adjustment makes virtually all results possible.*" (Seitz 1993, p. 230) For the same reason, we will also refrain from adjusting the stock of public capital by some utilization index.

On average, approximately 20 percent of the total capital stock in the Netherlands consists of public capital. However, according to preliminary data of the Statistics Netherlands, almost 80 percent of all infrastructure capital belongs to the public sector. This share has steadily declined from almost 90 percent in the early 1950s to 72 percent in 1990. The private stock of infrastructure is mainly in hands of the exposed sector.[28]

As can be seen in figure 1, there are large fluctuations in the capital outlays of the public sector. Until the early 1970s public investment (in constant prices) increased substantially over the years. After 1971 the reverse happened; in 1987 public investment was almost 40 percent below the 1971 level. Capital spending on infrastructure has the largest share in total public investment. However, the importance of this category has substantially decreased over time. In the 1958–1980 period almost 70 percent of all public investment was in infrastructure, whereas in the 1980–1990 period this reduced to 58 percent. Investment in machinery and transport equipments compensated for this. The share of investment in buildings remained constant over time, covering approximately 25 percent of public capital spending.

[26]The initial infrastructure stock in 1949 was set at approximately 60 billion guilders in 1990 prices. The depreciation rate of infrastructure is taken to be almost two percent.

[27]See, *e.g.* Conrad and Seitz (1994), Deno (1988), Nadiri and Mamuneas (1994), Seitz (1994), Shah (1992).

[28]In 1990 more than 80 percent of all private infrastructure investment was done by the exposed sector.

5 The empirical analysis

In the first part of this section we will summarize the estimation method employed. The regressions results are discussed in the second part.

5.1 The estimation procedure

In the empirical implementation of our theoretical framework of section 3, only the N factor-demand equations defined in (19) which are inserted in the error correction model (22) need to be estimated to obtain estimates for all parameters of the cost function. The cost equation itself does not have to be estimated since it contains no additional information. To keep the error correction model as simple as possible, we assume both Γ and Λ to be diagonal.[29]

We estimate the model for the aggregate, the exposed and the sheltered sectors of the Dutch economy for the 1952–1993 period. In case labour is subdivided into low-skilled and high-skilled we are forced to restrict our attention to the 1969–1993 period. The results presented cover the case in which infrastructure is taken as our public capital measure.[30] Initially, concavity in factor prices (5) is not imposed. However, in case our estimated cost function was not concave at all datapoints, we reestimated the model and imposed the concavity restrictions (20). For all our regressions we have used the software-package *Time Series Processor* Version 4.2, and apply a seemingly unrelated-regression procedure which accommodates cross-equation restrictions and correlations among the disturbances by estimating the model as a system of equations.

The multivariate least squares method used is a generalized least squares method: The disturbances of the model are assumed to be independent across observations but to have a free covariance across equations. The objective function can be written as $Q(b) = e(b)^T \left(V^{-1} \otimes I_T\right) e(b)$, where $e(b)$ is the vector of residuals, V is an estimated covariance matrix of the disturbances, and I_T is the identity matrix of order of the number of observations. V is recomputed from $b(i)$ at each iteration, so (assuming that the disturbances are multivariate normal) the estimator converges to the maximum likelihood estimator (implying that the standard errors are maximum likelihood estimates). The numerical method used is a generalized Gauss-Newton method, in which 'generalized' refers to the fact that the objective function contains a fixed weighting matrix (rather than being a simple sum of squares). The presented standard errors are heteroscedastic-consistent (Robust-White).

We have estimated several models. Because our main interest lies in the effect of infrastructure, we choose to concentrate on models ensuring second-order flexibility of the factor-demand equations in y, t, and G, *i.e.* estimate the α, β, γ, δ, η and τ vectors of parameters instead of the b_{yy}, b_t, b_{tt}, b_G, b_{GG} and b_{tG} parameters (see section 3). Espe-

[29] Without this assumption most off-diagonal elements of both matrices do not significantly differ from zero. As expected, the long-run elasticities are therefore hardly affected by this assumption.

[30] The qualitative conclusions do not change when we use the total public capital stock.

cially attractive is the fact that in this case the effect of public infrastructure on private input factors is modelled somewhat more flexible. The estimated parameters of these models will not be presented because little direct interpretation of these values is possible given the generality of the functional form. Several elasticity estimates summarize all economically relevant information and are therefore used to present the results. First, the elasticities are evaluated in the midpoint of the sample, *i.e.* 1973, and their *t*-statistics are computed assuming that all variables entering the elasticities formulas—except the parameter estimates—are constants. After that, we will look how the elasticities have developed over time.

5.2 The estimation results

We start off with estimating the model without any prior restrictions. Irrespective of the sector, several problems arise. For instance, concavity in factor prices is rejected by the data. To be more precise, one parameter from the *S*-matrix is estimated to be positive, whereas concavity implies that this parameter should be negative. By imposing the concavity restrictions (20) we try to solve this problem. However introducing these nonlinear restrictions into this model makes it impossible to get meaningful parameter estimates, because now the parameter does not converge. Apparently, if this model is used, the data does not allow us to bend the cost function in the right direction: it breaks, forcing us to fix the obstinate parameter to zero. Furthermore, and even more seriously, the total cost elasticity of output is a source of anxiety. Most estimates are well below 0.2, implying incredibly high increasing rates of return. We therefore assume that the cost function is homogeneous in output, *i.e.* we impose the restrictions (21) in the remainder of this paper. This implies that the underlying production function is still allowed to exhibit increasing returns to scale to all inputs, but that we enforce constant returns to scale to the private input factors (CRS). This does not conflict with earlier empirical results in which constant returns to scale over all inputs is usually rejected (see section 2). As already noted in section 3, this implies that the output elasticity of infrastructure equals minus one times the cost elasticity of infrastructure (see equation 16).

Table 2 displays the first outcomes with this restricted cost function in the midpoint of the sample, 1973. First of all, note that the cost elasticity of public infrastructure (ε_{CG}) has the expected negative sign in 1973 for both sectors as well as for the total private sector. However, especially for the total and the sheltered sector, this point estimate is large when compared with previous research (see section 2). A ten percent rise in public infrastructure will—according to the point estimate—decrease the costs of the private sector by almost seven percent. The cost elasticity of infrastructure for the exposed sector of -0.07 is more in line with previous research. However, this elasticity is insignificant. Therefore, these first results suggest that most benefits accrue to the sheltered sector.

The dependence of the sheltered sector on national infrastructure is not very surprising. Our infrastructure stock includes besides highways mainly local infrastructure such

Table 2 *Elasticity estimates in the midpoint of the sample, 1973.*

	Midpoint sample, 1973[a]		
	Total	Sheltered	Exposed
	Elasticities of public infrastructure		
ε_{CG}	-0.676	-1.708	-0.073
	(0.248)	(0.340)	(0.243)
ε_{LG}	-0.565	-1.848	0.494
	(0.360)	(0.438)	(0.433)
ε_{KG}	-0.929	-1.212	-1.041
	(0.128)	(0.220)	(0.183)
$\partial p_G^s / \partial t$	0.092	0.040	0.081
	(0.079)	(0.028)	(0.075)
	Other interesting elasticities		
ε_{Ct}	-0.017	0.022	-0.041
	(0.006)	(0.010)	(0.006)
ε_{Cp_L}	0.697	0.779	0.631
	(0.010)	(0.007)	(0.017)
ε_{Cp_K}	0.303	0.221	0.369
	(0.010)	(0.007)	(0.017)
ε_{Lt}	-0.031	0.021	-0.071
	(0.009)	(0.012)	(0.010)
ε_{Lp_L}	-0.054	-0.042	-0.097
	(0.009)	(0.010)	(0.022)
ε_{Lp_K}	0.054	0.042	0.097
	(0.009)	(0.010)	(0.022)
ε_{Kt}	0.015	0.029	0.011
	(0.003)	(0.004)	(0.004)
ε_{Kp_L}	0.125	0.147	0.165
	(0.019)	(0.034)	(0.032)
ε_{Kp_K}	-0.125	-0.147	-0.165
	(0.019)	(0.034)	(0.032)

[a]The cost function is assumed to be homogeneous in output. The elasticities are evaluated in the midpoint of the sample, 1973. The standard errors in parentheses are heteroscedastic–consistent (Robust–White) and are computed assuming that—apart from the parameter estimates—all variables are constants equal to their values in the midpoint of the sample.

as roads, parking places and sewer systems which are all important environmental variables for sectors like the retail trade and the service industry, which are both part of the sheltered economy. For the exposed sector local infrastructure is not that crucial. By definition the exposed sector depends more on international trade and therefore on only a subset of our infrastructure stock, namely on those components that enhance international trade, such as, *e.g.* highways. Maybe by disaggregating our infrastructure stock into 'internationally-oriented' and more 'locally-oriented' infrastructure, the former would show a more significant impact on the exposed sector. However, data limitations do not allow us to make this distinction. Furthermore, international spill-over effects from, *e.g.*

foreign highway infrastructure might be important for the exposed sector. These spillovers are not captured by our infrastructure variable. Last, but certainly not least, the main part of the private infrastructure stock is owned by the exposed sector. Therefore, the exposed sector does probably not depend as much on the publicly provided part of the total infrastructure stock as the sheltered sector which hardly invests in infrastructure.

As the table shows, the labour elasticity of infrastructure (ε_{LG}) is negative for the total as well as for the sheltered sector.[31] In the exposed sector a complementary relationship between labour and infrastructure seems to exist. Note however, that only the point estimate for the sheltered sector differs significantly from zero. The relationship between private and public capital stocks—as denoted by ε_{KG})—is less ambiguous and approximately the same for all three sectors; there is a significant substitutive relationship between both in the midpoint of our sample. As explained in section 3, at least one of the two private inputs must bear a substitutive relationship and outweigh the possible complementary relationship in order to let infrastructure be cost saving and output augmenting. As the low point estimate of the cost elasticity of public infrastructure in the exposed sector indicates, the substitutive relationship of private capital and public infrastructure barely outweighs the (insignificant) complementary relationship between labour and public infrastructure in that sector. As indicated by the insignificant estimate of $\partial p_G^s/\partial t$, no correlation seems to exist between infrastructure and technological progress.

Let us now pay attention to some of the other interesting elasticities. Most of these other elasticity estimates stay roughly the same for different models. For example, we also estimated some models in which infrastructure was omitted. Although likelihood ratio tests indicated that infrastructure should be included, the estimated elasticities hardly changed. When comparing the models for both sectors, large differences in the effect of technological progress on private costs attract our attention. The exposed sector has definitely been more affected by technological progress than the sheltered sector. One possible explanation for this might be the more open—and therefore more dynamic—character of the exposed sector. In both sectors we find a complementary relationship between technological progress and private capital. However, the relationship between technological progress and labour differs between the sectors: in the exposed sector we find a substitutive relationship, whereas for the sheltered sector there seems to exist a complementary relationship. In the exposed sector the substitutive relationship dominates, resulting in decreasing cost over time. In the sheltered sector, both private inputs behave as complements to technological progress, which results in a theoretically implausible positive cost elasticity of technological progress. The standard price elasticities of both private inputs are all highly significant and have the theoretically correct sign. However, the estimated magnitudes of these elasticities are rather low.

Table 3 shows the estimates of the dynamic parameters as well as some usual statis-

[31]Note that substitutability between the private inputs and infrastructure is calculated for a given output level. Therefore, the negative effect of infrastructure on private factor demand might be counteracted by additional output which is also generated by more infrastructure investment.

Table 3 *The dynamic parameters and some equation statistics.*

1953–1993[a] Equation:	Total private sector ΔL	Total private sector ΔK	Sheltered sector ΔL	Sheltered sector ΔK	Exposed sector ΔL	Exposed sector ΔK
	Dynamic parameters					
π_{ii}	0.38	-0.01	0.34	0.01	0.35	-0.03
	(0.04)	(0.02)	(0.06)	(0.03)	(0.04)	(0.02)
λ_{ii}	0.24	0.21	0.25	0.26	0.23	0.13
	(0.08)	(0.02)	(0.06)	(0.02)	(0.09)	(0.03)
	Equation statistics					
R^2	0.75	0.95	0.71	0.98	0.73	0.86
D–W	1.77	1.76	1.74	1.59	2.17	1.89

[a]The cost function is assumed to be homogeneous in output. The standard error in parentheses are heteroscedastic–consistent (Robust–White).

tics. All dynamic parameters are pretty robust over the sectors. For both equations the error-correction coefficients lie somewhere around the 0.2 and are highly significant. Therefore an actual factor-demand below its long-run level leads to an increase in factor-demand in the next period. As we restricted the off-diagonal elements of the Γ-matrix to zero, these parameters are also the eigenvalues of that matrix, which implies that the dynamic system is definitely stable. Whereas significant short-run effects arise in the labour-demand equations, short-run changes do not have a significant effect on investment decisions of private firms. Apparently, investment decisions are based more on long-term considerations in stead of short-run fluctuations. The reported adjusted R^2's indicate that the model fits the data very well. The Durbin-Watson statistics are—especially for the sheltered sector—somewhat low but do not provide evidence of misspecification.

So far, we have analyzed the model by looking at elasticity estimates in the midpoint of the sample. However, these elasticities may vary over time. Therefore table 4 summarizes the variability of the elasticities by reporting the averages and their corresponding standard deviations over our time-interval. As the bottom part of the table shows, the standard deviations of the elasticities concerning the private inputs and technological progress are generally very low, and their averages correspond to their midpoint estimates reported in table 2. We hoped that the same would be true for the elasticities concerning public infrastructure. Unfortunately, and as the upper part of the table shows, this is clearly not the case. Not only do both factor-demand elasticities with respect to public infrastructure alter sign during our sample period, the cost elasticity of public infrastructure even becomes significantly positive over time which is theoretically unjustifiable (not shown). This leaves little room for interpreting the dynamic behaviour of these elasticities.

In our opinion, it is hard to imagine why especially the cost elasticity of public capital has

Table 4 *The average elasticity estimates over time.*

	1953–1993[a] Total	Sheltered	Exposed
	Elasticities of public infrastructure		
ε_{CG}	0.068	-1.261	1.076
	(0.786)	(0.913)	(1.774)
ε_{LG}	0.260	-1.598	2.054
	(1.171)	(0.807)	(3.007)
ε_{KG}	-0.433	-0.290	-0.662
	(0.517)	(1.189)	(0.474)
$\partial p_G^s/\partial t$	0.136	0.062	0.121
	(0.135)	(0.062)	(0.120)
	Other interesting elasticities		
ε_{Ct}	-0.019	0.010	-0.039
	(0.002)	(0.014)	(0.009)
ε_{Cp_L}	0.689	0.758	0.634
	(0.044)	(0.047)	(0.041)
ε_{Cp_K}	0.311	0.242	0.366
	(0.044)	(0.047)	(0.041)
ε_{Lt}	-0.027	0.016	-0.062
	(0.004)	(0.006)	(0.016)
ε_{Lp_L}	-0.052	-0.053	-0.086
	(0.014)	(0.026)	(0.025)
ε_{Lp_K}	0.052	0.053	0.086
	(0.014)	(0.026)	(0.025)
ε_{Kt}	0.001	0.003	0.001
	(0.013)	(0.040)	(0.009)
ε_{Kp_L}	0.112	0.156	0.146
	(0.013)	(0.051)	(0.024)
ε_{Kp_K}	-0.112	-0.156	-0.146
	(0.013)	(0.051)	(0.024)

[a]The cost function is assumed to be homogeneous in output. The elasticities estimates are averages over the 1953–1993 period. The standard errors in parentheses are computed assuming that the parameter estimates are constants.

changed so dramatically over time. We therefore impose that the 95 percent confidence interval around this elasticity has a maximum band width of approximately 1, *i.e.* the standard deviation of the cost elasticity of public capital over time is bounded by $\frac{1}{4}$. We implemented this prior by adding the following equation to our system:[32]

$$u_t = \bar{\varepsilon}_{CG} + \frac{\partial C^*}{\partial G}\frac{G}{C^*}, \tag{23}$$

where $u_t \sim iid\left(0, \frac{1}{16}\right)$ and which is uncorrelated with the residuals of the factor-demand

[32]See, *e.g.* Jugde *et al.* (1985) for an introduction in estimation methods using stochastic prior information.

equations. Furthermore, $\bar{\varepsilon}_{CG}$ represents a new parameter which equals the average cost elasticity of public infrastructure over time. Note that we do not impose restrictions on the level of this new parameter $\bar{\varepsilon}_{CG}$; only its standard deviation over time is bounded.

Table 5 *Elasticity estimates—using a prior on the bandwith of the cost elasticity of infrastructure—in the midpoint of the sample, 1973 and over time.*

	Midpoint sample, 1973[a] Total	Midpoint sample, 1973[a] Sheltered	Midpoint sample, 1973[a] Exposed	1953–1993[b] Total	1953–1993[b] Sheltered	1953–1993[b] Exposed
	Elasticities of public infrastructure					
ε_{CG}	-0.525	-0.528	-0.364	-0.308	-0.283	-0.201
	(0.120)	(0.098)	(0.126)	(0.114)	(0.143)	(0.086)
ε_{LG}	-0.358	-0.368	0.018	-0.243	-0.363	0.187
	(0.165)	(0.133)	(0.201)	(0.236)	(0.288)	(0.353)
ε_{KG}	-0.930	-1.103	-1.074	-0.526	-0.265	-0.852
	(0.100)	(0.210)	(0.138)	(0.519)	(1.070)	(0.544)
$\partial p_G^s / \partial t$	-0.008	-0.007	0.008	-0.032	-0.020	0.005
	(0.012)	(0.004)	(0.010)	(0.043)	(0.027)	(0.008)
	Other interesting elasticities					
ε_{Ct}	-0.025	-0.008	-0.040	-0.017	-0.009	-0.026
	(0.004)	(0.004)	(0.005)	(0.011)	(0.007)	(0.018)
ε_{Cp_L}	0.707	0.783	0.650	0.687	0.761	0.624
	(0.311)	(0.003)	(0.005)	(0.044)	(0.050)	(0.040)
ε_{Cp_K}	0.293	0.217	0.350	0.313	0.239	0.376
	(0.003)	(0.003)	(0.005)	(0.044)	(0.050)	(0.040)
ε_{Lt}	-0.042	-0.018	-0.069	-0.025	-0.009	-0.044
	(0.006)	(0.004)	(0.008)	(0.016)	(0.008)	(0.028)
ε_{Lp_L}	-0.051	-0.035	-0.086	-0.052	-0.045	-0.087
	(0.007)	(0.009)	(0.015)	(0.014)	(0.022)	(0.025)
ε_{Lp_K}	0.051	0.035	0.086	0.052	0.045	0.087
	(0.007)	(0.009)	(0.015)	(0.014)	(0.022)	(0.025)
ε_{Kt}	0.015	0.027	0.012	0.004	-0.001	0.006
	(0.003)	(0.004)	(0.003)	(0.013)	(0.035)	(0.008)
ε_{Kp_L}	0.122	0.126	0.160	0.110	0.133	0.141
	(0.016)	(0.032)	(0.027)	(0.012)	(0.043)	(0.022)
ε_{Kp_K}	-0.122	-0.126	-0.160	-0.110	-0.133	-0.141
	(0.016)	(0.032)	(0.027)	(0.012)	(0.043)	(0.022)

The cost function is assumed to be homogeneous in output. The cost elasticity of public capital is assumed to lie between a certain bandwith.
[a]The elasticities are evaluated in the midpoint of the sample, 1973. The standard errors in parentheses are heteroscedastic–consistent (Robust–White) and are computed assuming that—apart from the parameter estimates—all variables are constants equal to their values in the midpoint of the sample.
[b]The elasticities estimates are averages over the 1953–1993 period. The standard errors in parentheses are computed assuming that the parameter estimates are constants.

Together with the factor-demand equations in error correction form, as defined by equations (19) and (22), we reestimated the system. The results are presented in table

5. As the right-hand side of that table shows, the standard deviation of the cost elasticity of public infrastructure over time is relatively low compared to our previous results. Of course this is not surprising, because we have enforced this elasticity to stay within a certain band width. However, we did not impose restrictions on the size of this elasticity and its standard deviation at each separate data point. For both sectors and their aggregate, table 5 shows that this cost elasticity is indeed negative and highly significant in the midpoint of our sample. Therefore, public infrastructure plays a significant role in the production process of the private firms. As both tables show, again the effect of public infrastructure on the sheltered sector of the economy is more important than its effect on the exposed sector. On average the cost elasticities of infrastructure for the aggregated, the sheltered and the exposed sectors are respectively -0.31, -0.28 and -0.20, which is—in absolute sense—still somewhat high, but are not out of line with previous research. The dynamic parameters hardly change at all and are therefore not reported.

Figure 2 *The cost elasticity of public capital (ε_{CG}) and his 95% confidence interval for the sheltered and the exposed sector, 1953–1993.*

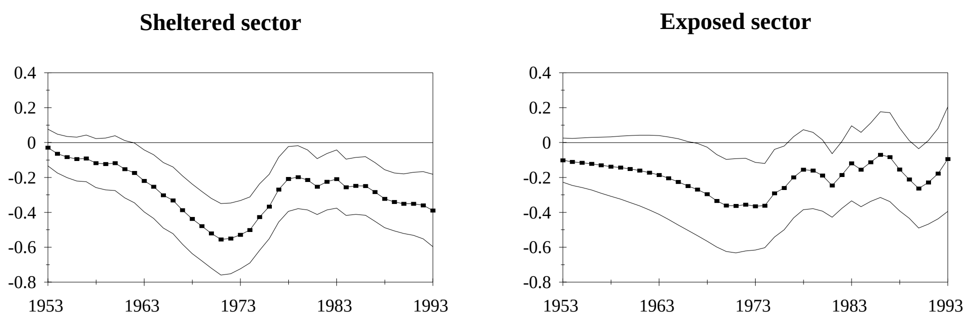


Figure 2 shows the development of the cost elasticity of public infrastructure and its 95 percent confidence interval over time. Clearly the point estimates of the exposed sector are often insignificant whereas this is seldom the case for the sheltered sector. Furthermore, although both parts in figure 2 show that the cost elasticities of public capital develop similarly in both sectors, the elasticity for the sheltered sector shows larger oscillations, indicating that this sector is more vulnerable to changes in the stock of public infrastructure than the exposed sector.

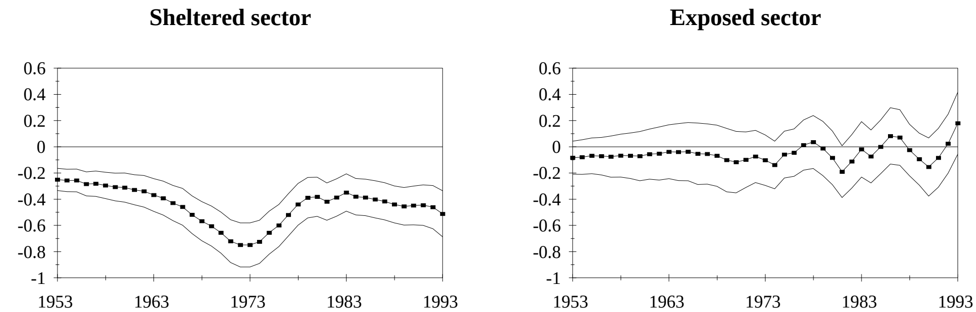
The pattern is clear in both pictures. The build up of infrastructural works after World War II increased the effect of infrastructure on the private sector. Its influence peaks in the early seventies, just a couple of years after government investment has reached its highest overall level (see figure 1). After a lag of approximately two or three years, the cut-backs in public infrastructure expenditure start to affect the private sector; the influence of infrastructure diminishes. After the eighties the curves of the sheltered and the exposed sector show different patterns. Whereas the effect of infrastructure on the exposed sector is becoming more volatile and often insignificant, its influence on the sheltered sector steadily increases. Because public investment did not substantially rise in the early nineties, which suggests that the infrastructural projects in that period were aimed at solving domestically oriented problems, and/or the sheltered sector found a way to use the available infrastructure more efficiently.

Another positive aspect of introducing the prior-equation (23) is that we now find a substitutive relationship between labour and technological progress in the sheltered sector. Despite the use of our prior, all other elasticities roughly stay the same. This also holds for both factor-demand elasticities with respect to infrastructure: still no clear picture emerges from the relationships between the private inputs and infrastructure. As before, in the midpoint private capital and infrastructure behave as substitutes in all sectors. The relationship between labour and public infrastructure is ambiguous. For the exposed sector we again find an insignificant complementary relationship, whereas a significant substitutive relationship prevails in the sheltered sector. However, over time and for all sectors, both elasticities alter sign. For instance, in the first half and in the last two years of our sample private capital of the sheltered sector behaves as a complement to infrastructure, whereas the opposite prevails between 1972 and 1991. The pattern between labour and public infrastructure roughly mirrors the pattern between the two capital stocks. Therefore, despite the fact that most empirical research report a complementary relationship between public and private capital, we come up with very mixed results. As indicated by the insignificant estimate of $\partial p^s_G / \partial t$, still no relationship between infrastructure and technological progress is found.

To test the robustness of the model and to remove some potential autocorrelation problems, we opt for putting a lag on our infrastructure variable. Furthermore, the lumpy character of infrastructure investment implies that the private sector needs some time to adapt to new infrastructure. Noting the pattern of the public investment share and labour productivity growth, as depicted in figure 1, and the reaction lag we observed when discussing figure 2, we choose a two-year lag on our infrastructure variable. An additional advantage of introducing this two-year lag on infrastructure is that it might remove fears concerning the causality between infrastructure and our private variables. The theoretical model underlying our regressions assumes that infrastructure influences the private sector. No room is left open for the private sector to influence the decision-making process that underlie the investments in infrastructure. Generating similar conclusions as before can be seen as indirect proof that our causality assumptions are correct.

The tables evaluating the elasticity estimates in the midpoint of our sample and over time are displayed in appendix D. A comparison of these results with the previous ones reveals that the differences between the two sectors are being amplified. As figure 3 shows, especially the cost elasticity of infrastructure is becoming larger in the sheltered sector, whereas for the exposed sector the estimated effect of infrastructure on costs is becoming insignificant at every datapoint. For the aggregate sector the absolute value of the cost elasticity of infrastructure is in general somewhat larger than for the exposed

Figure 3 *The cost elasticity of public capital (ε_{CG}) and his 95% confidence interval for the sheltered and the exposed sector using a two-year lag on infrastructure, 1953–1993.*



sector but—in contrast with our earlier results—also often estimated to be insignificant. The magnitude of the cost elasticity for both the aggregate as well as the exposed sector—respectively -0.07 and -0.05—are in line with previous research. However, the average cost elasticity of infrastructure for the sheltered sector has become more negative (-0.45). As before, the relationship between public infrastructure and factor-demand is unclear. Therefore, these results do not contradict our previous outcomes. On the contrary, they strengthen our conclusion that especially the sheltered sector is depending on the stock of infrastructure.

To increase the degrees of freedom and to further check whether the effect of infrastructure on both the exposed and the sheltered sector is statistically the same, we constructed a panel dataset covering both sectors. In our first panel regression all parameters are modelled to be sector-specific. As expected, the outcomes resemble our previous results (not shown). In the next step we assume the effect of infrastructure to be the same over both sectors (not shown). A likelihood ratio test indicates that this assumption is strongly rejected by the data. Further panel regressions—restricting other parameters—reveal that it is almost impossible to get reasonable panel data estimates at all and that most restrictions are rejected by the data. Apparently the exposed and the sheltered sector are very dissimilar and should therefore be modelled separately.

Other ways in which we checked the robustness of the outcomes is by changing the initial private capital stocks and their depreciation rates. The conclusions do not alter (not shown). These results strengthen our impression that the findings are very robust.

As already noted, despite the fact that the estimates of the price elasticities are highly significant, their estimates are extremely low. Using a similar specification without infrastructure for the Dutch economy covering the 1972–1993 period, Draper and Manders (1996a) report price elasticities for aggregate labour ranging from -0.02 in the exposed and -0.05 in the sheltered sector which are in line with our own findings. However, by subdividing labour into low-skilled and high-skilled labour their price elasticities rise considerably, but are still well below unity. To check whether the same prevails in our model using infrastructure, and to see whether infrastructure has a different effect on low-skilled versus high-skilled labour, we will now concentrate on the 1969–1993 period for which disaggregated labour data is available. Note that by using this shorter time interval the degrees of freedom are severely reduced. This might result in less precise elasticity estimates.

Before estimating the model using the two labour inputs, we first estimated the same model as before for the 1969–1993 period. As shown in appendix E, the standard elasticity estimates, *i.e.* those without infrastructure, are again pretty robust; none of the significant elasticities alter sign and their magnitudes are still very low and are comparable with our previous results. However, the absolute size of all elasticities of infrastructure definitely increases. For instance, the overall effect of infrastructure on private cost rises considerably. By using the shorter time interval our point estimates of the cost elasticity of infrastructure in the sheltered sector even surpass our previous results which already were high as compared to other research; now the point estimates suggest that a one percent rise in infrastructure decreases cost by approximately one percent. In line with our previous results is the finding that the sheltered sector has benefited more from infrastructure than the exposed sector of the Dutch economy. However, this time we find a significant substitutive relationship between aggregate labour and infrastructure which does not alter sign during our (short) time interval. The relationship between private capital and infrastructure is still unclear.

Keeping these results in mind, we now divide labour into high-skilled and low-skilled labour, and reestimate the expanded model. The results are presented in appendix E and confirm the outcomes of Draper and Manders (1996a,b): the price elasticities of both labour inputs are much higher than the price elasticity of our aggregated labour input. The main difference with the outcomes of Draper and Manders (1996a,b) is that we come up with a complementary relationship between low-skilled labour and private capital, whereas they found a substitutive relationship. High-skilled labour and private capital are substitutes. The overall effect of infrastructure on private cost is approximately the same as when we use the aggregated labour variable over the short time interval; the cost elasticity of public infrastructure is incredibly large. Infrastructure seems to have the opposite effect on low-skilled labour as compared to its effect on high-skilled labour. Whereas a clear substitutive relationship between low-skilled labour and infrastructure prevails, the point estimates of $\varepsilon_{L^h G}$ suggest that high-skilled labour and infrastructure are complements. Note however, that the magnitudes of these factor-demand elasticities with respect to infrastructure are incredibly large. This might indicate a structural break during the 1953–1993 period. However, likelihood ratio tests indicate that including dummy-variables in the models covering the entire sample period does not significantly increase their likelihood functions. Apparently, it is the reduction in degrees of freedom that has large consequences for the precision of the coefficients concerning infrastructure. This is not very surprising, as using a shorter time interval reduces the variability of—and therefore the information contained in—especially our infrastructure stock. Infrastructure then starts to resemble the trend variable and consequently causes multicollinearity problems. This might explain the opposite effect infrastructure has on low-skilled versus high-skilled labour; the amount of high-skilled labour has continuously increased over the 1969–1993 period, whereas the opposite prevails for low-skilled labour.

6 Concluding remarks

After having incorporated a public capital variable in a symmetric generalized McFadden cost function, our empirical analyses yielded some very interesting results. For the post-World War II period in the Netherlands we found a significant influence of infrastructure on output and production costs of the private sector. A ten percent rise in the stock of public infrastructure has reduced the cost of the private economy on average by three percent.[33] This is somewhat high, but still in line with previous research. However, neither labour nor private capital has a very distinct relationship with infrastructure: sometimes private inputs behave as substitutes for public infrastructure, at other times there seems to exist a complementary relationship between them.

Looking at a sectoral level reveals large differences between the exposed and the sheltered sector of the Dutch economy. As a more substitutive relationship between both private inputs and infrastructure exists in the sheltered sector, the cost and output of this sector significantly benefited from increases in infrastructure. In the exposed sector, the quantitatively smaller substitutive and larger complementary effects of infrastructure on both private inputs almost level off, which results in a statistically insignificant cost elasticity of infrastructure. No significant relationship between public infrastructure and technological progress is found in either sector.[34]

Placing a two-year lag on our infrastructure stock amplifies the differences between the sheltered and the exposed sector. Whereas the point estimate of the cost elasticity of infrastructure is insignificant for the exposed sector in every year, it is always highly significant for the sheltered sector. Despite its insignificance, the cost elasticity of infrastructure of the exposed sector (on average -0.05) is in line with previous research. The estimated effect of infrastructure on the costs of the sheltered sector is somewhat large (on average -0.45) as compared to previous research.

[33] In 1993 the cost elasticity of public infrastructure is approximately -0.25. Given the public infrastructure stock and the production costs of the private sector, this implies that an increase of the public infrastructure stock by 1 billion guilders would have decreased the production costs of the private sector by approximately 625 million guilders.

[34] Roughly 20 percent of the cost benefits as computed in footnote 33 of a 1 billion increase in the stock of public infrastructure in 1993 accrues to the exposed sector. The remaining 80 percent are cost reductions of the sheltered sector.

The insignificant effect of infrastructure on output and production cost of the exposed sector can be explained by referring to the fact that only a small part of our infrastructure variable is relevant for that sector. The exposed sector—by definition internationally oriented—is dependent upon those components of the infrastructure stock that enhance international trade. However, highways and other 'internationally-oriented' infrastructure only play a minor role in our infrastructure variable. The sheltered sector benefits mainly from 'locally-oriented' infrastructure, which forms the major part of our infrastructure stock. Furthermore, foreign infrastructure might be expected to be equally important to the exposed sector and is not included as an additional variable. Finally, the exposed sector is probably not that dependent on the publicly provided part of infrastructure as is the sheltered sector, because the exposed sector itself invests in infrastructural works. Nowadays, more than 80 percent of the private infrastructure investment is done by the exposed sector, which means that approximately 25 percent of all infrastructure investments in the Netherlands is conducted by the exposed sector. Therefore, the exposed sector is probably not that dependent upon the publicly provided part of the total infrastructure stock as is the sector which hardly invests in infrastructure, *i.e.* the sheltered sector.

Disaggregating the labour-input variable into low-skilled and high-skilled labour reveals that especially low-skilled labour has a substitutive relationship with infrastructure, whereas high-skilled labour often bears a complementary relationship with infrastructure. However, the point estimates are very imprecise, possibly because of the loss in degrees of freedom as the number of variables increases and the sample size decreases. Furthermore, as multicollinearity problems are raised, it is almost impossible to interpret these findings.

A final word of caution pertains to extrapolating these findings into the future. Even if infrastructure has been highly productive in the past—which is what this study suggests—this does not imply that future investment be similarly productive. The economic advantages associated with future infrastucture may be different from those of past infrastructure. For instance, it could be very beneficial to build a network of highways while expanding this network may yield substantially less benefits. Simply looking at past patterns might tell very little about future effects of public invesment.

Furthermore, as this study has shown, we are a long way from obtaining parameter estimates which are sufficiently precise so as to enable us to plug in values for new infrastructure stock and other variables in an estimated econometric model and obtain reliable estimates of future economic benefits. This may well be due to the heterogeneous character of infrastructure investments. All proposed new infrastructure projects should therefore still be subjected to cost-benefit analysis. Aggregate regression results, as the ones presented in this paper, cannot guide actual investment spending. Cost-benefit analysis may give more reliable estimates of the net benefits of any specific investment project or may be helpful to determine priorities between competing projects.

References

Aschauer, D.A. (1989), "Is public expenditure productive?", *Journal of Monetary Economics*, **23**, 177–200.

Barnett, W.A. (1983), "New indices of money supply and the flexible laurent demand system", *Journal of Business and Economic Statistics*, **1**, 7–23.

Berndt, E.R. and B. Hansson (1991), "Measuring the contribution of public infrastructure capital in Sweden", NBER Working Paper 3842, National Bureau of Economic Research.

Broer, D.P. and W.J. Jansen (1989), "Employment, schooling and productivity growth", *De Economist*, **137**(4), 425–453.

Caves, D.W., L.R. Christensen, and W.E. Diewert (1982), "The economic theory of index numbers and the measurement of input, output, and productivity", *Econometrica*, **50**(6), 1393–1414.

Coelli, T.J. (1996), "Measurement of total factor productivity growth and biases in technological change in Western Australian agriculture", *Journal of Applied Econometrics*, **11**, 77–91.

Conrad, K. and H. Seitz (1992), "The 'public capital hypothesis': the case of Germany", *Recherches Economiques de Louvain*, **58**(3–4), 309–327.

Conrad, K. and H. Seitz (1994), "The economic benefits of public infrastructure", *Applied Economics*, **26**, 303–311.

Dalamagas, B. (1995), "A reconsideration of the public sector's contribution to growth", *Empirical Economics*, **20**, 385–414.

Deno, K.T. (1988), "The effect of public capital on U.S. manufacturing activity: 1970 to 1978", *Southern Economic Journal*, **55**(1), 400–411.

Diewert, W.E. (1974), "Applications of duality theory", in M.D. Intriligator and D.A. Kendrick, editors, *Frontiers of quantitative economics. Volume II*, North-Holland, Amsterdam, 106–120.

Diewert, W.E. (1976), "Exact and superlative index numbers", *Journal of Econometrics*, **4**(4), 115–145.

Diewert, W.E. and T.J. Wales (1987), "Flexible functional forms and global curvature conditions", *Econometrica*, **55**(1), 43–68.

Diewert, W.E. and T.J. Wales (1995), "Flexible functional forms and tests of homogeneous separability", *Journal of Econometrics*, **67**, 259–302.

Draper, N. and T. Manders (1996a), "Why did the demand for Dutch low-skilled workers decline?", *CPB Report, Quarterly Review of CPB Netherlands Bureau for Economic Policy Analysis*, **1**, 29–32.

Draper, N. and T. Manders (1996b), “Structural changes in the demand for labor”, CPB Research Memorandum 128, CPB Netherlands Bureau for Economic Policy Analysis, The Hague.

Gramlich, E.M. (1994), “Infrastructure investment: a review essay”, *Journal of Economic Literature*, **32**, 1176–1196.

Haan, J. de, J.E. Sturm, and B.J. Sikken (1996), “Government capital formation: explaining the decline”, *Weltwirtschaftliches Archiv*, **132**(1), 55–74.

Hulten, C.R. and R.M. Schwab (1991), “Public capital formation and the growth of regional manufacturing industries”, *National Tax Journal*, **44**(4), 121–134.

Jorgenson, D.W. (1986), “Econometric methods for modelling producer behavior”, in Z. Grilliches and M. Intrilligator, editors, *Handbook of econometrics, volume III*, North-Holland, Amsterdam.

Jorgenson, D.W. and Z. Griliches (1967), “The explanation of productivity change”, *Review of Economic Studies*, **34**, 249–282.

Judge, G.G., W.E. Griffiths, R.C. Hill, H. Lütkepohl, and T.-C. Lee (1985), *The theory and practice of econometrics*, 2nd edition, Wiley, New York.

Keeler, T.E. and J.S. Ying (1988), “Measuring the benefits of a large public investment. The case of the U.S. federal-aid highway system”, *Journal of Public Economics*, **36**, 69–85.

Lau, L.J. (1978), “Applications of profit functions”, in M. Fuss and D. McFadden, editors, *Production economics: a dual approach to theory and applications. Volume 1*, North-Holland, Amsterdam, 133–215.

Lynde, C. (1992), “Private profit and public capital”, *Journal of Macroeconomics*, **14**(1), 125–142.

Lynde, C. and J. Richmond (1992), “The role of public capital in production”, *Review of Economics and Statistics*, **74**, 37–45.

Lynde, C. and J. Richmond (1993a), “Public capital and long-run costs in U.K. manufacturing”, *The Economic Journal*, **103**, 880–893.

Lynde, C. and J. Richmond (1993b), “Public capital and total factor productivity”, *International Economic Review*, **34**(2), 401–414.

McFadden, D. (1978), “The general linear profit function”, in M. Fuss and D. McFadden, editors, *Production economics: a dual approach to theory and applications. Volume 1*, North-Holland, Amsterdam, 219–268.

Morrison, C.J. and A.E. Schwartz (1992), “State infrastructure and productive performance”, NBER Working Paper 3981, National Bureau of Economic Research, Cambridge.

Morrison, C.J. and A.E. Schwartz (1996), "Public infrastructure, private input demand, and economic performance in New England manufacturing", *Journal of Business and Economic Statistics*, **14**(1), 91–101.

Munnell, A.H. (1992), "Policy watch: infrastructure investment and economic growth", *Journal of Economic Perspectives*, **6**(4), 189–198.

Nadiri, M.I. and T.P. Mamuneas (1994a), "Infrastructure and public R&D investments, and the growth of factor productivity in US manufacturing industries", NBER Working Paper 4845, National Bureau of Economic Research, New York.

Nadiri, M.I. and T.P. Mamuneas (1994b), "The effects of public infrastructure and R&D capital on the cost structure and performance of U.S. manufacturing industries", *Review of Economics and Statistics*, **76**(1), 22–37.

Rask, K. (1995), "The structure of technology in Brazilian sugarcan production, 1975–87. An application of a modified symmetric generalized McFadden cost function", *Journal of Applied Econometrics*, **10**, 221–232.

Seitz, H. (1993), "A dual economic analysis of the benefits of the public road network", *The Annals of Regional Science*, **27**, 223–239.

Seitz, H. (1994), "Public capital and the demand for private inputs", *Journal of Public Economics*, **54**, 287–307.

Shah, A. (1992), "Dynamics of public infrastructure, industrial productivity and profitability", *Review of Economics and Statistics*, **74**, 28–36.

Statistics Netherlands (1996), *Time series labour accounts 1969–1993: estimations by educational level, provisional data (*in Dutch*: Tijdreeksen arbeidsrekeningen 1969–1993: ramingen van het opleidingsniveau, een tussenstand)*, Statistics Netherlands, Voorburg.

Sturm, J.E. and J. de Haan (1995a), "Is public expenditure really productive? New evidence from the USA and the Netherlands", *Economic Modelling*, **12**(1), 60–72.

Sturm, J.E. and G.H. Kuper (1996), "The dual approach to the public capital hypothesis: the case of the Netherlands", CCSO Series 26, CCSO Centre for Economic Research, Groningen.

Sturm, J.E., G.H. Kuper, and J. de Haan (1996), "Modelling government investment and economic growth on a macro level: a review", CCSO Series 29, CCSO Centre for Economic Research, Groningen [forthcoming in: S. Brakman, H. van Ees and S.K. Kuipers, editors, *Market behaviour and macroeconomic modelling*, MacMillan].

Terrell, D. (1996), "Incorporating monotonicity and concavity conditions in flexible functional forms", *Journal of Applied Econometrics*, **11**, 179–194.

Wiley, D.E., W.H. Schmidt, and W.J. Bramble (1973), "Studies of a class of covariance structure models", *Journal of the American Statistical Association*, **68**, 317–323.

A Second-order flexibility and the number of parameters in the cost function

In this appendix we will elaborate on the linear homogeneity property of C^* in prices. Using this property we will derive the number of free parameters necessary to make our candidate cost function flexible. A functional form is flexible if it can provide a second-order approximation to an arbitrary twice continuously differentiable function that satisfies the regularity conditions defined in equations (2) to (7).[35]

Let $p \gg 0_N$, $y > 0$, $t > 0$, and $G > 0$ and let C^* be twice continuously differentiable with respect to its $N+3$ arguments at (p, y, t, G). Then the linear homogeneity property of C^* in p and Euler's Theorem on homogenous functions implies the following $N + 4$ restrictions on the first and second-order derivatives of C^*:

$$\begin{aligned} p^T \nabla_p C^* (p, y, t, G) &= C^* (p, y, t, G), & \text{(A.1)} \\ p^T \nabla^2_{pp} C^* (p, y, t, G) &= 0^T_N, & \text{(A.2)} \\ p^T \nabla^2_{py} C^* (p, y, t, G) &= \nabla_y C^* (p, y, t, G), & \text{(A.3)} \\ p^T \nabla^2_{pt} C^* (p, y, t, G) &= \nabla_t C^* (p, y, t, G), & \text{(A.4)} \\ p^T \nabla^2_{pG} C^* (p, y, t, G) &= \nabla_G C^* (p, y, t, G). & \text{(A.5)} \end{aligned}$$

The twice continuous differentiability assumption on C^* and Young's Theorem in calculus imply the following $(N + 3)(N + 2)/2$ symmetry restrictions on the second-order derivatives of C^*:

$$\nabla^2 C^* (p, y, t, G) = \left[\nabla^2 C^* (p, y, t, G)\right]^T, \qquad \text{(A.6)}$$

where $\nabla^2 C^*$ denotes the $(N + 3) \times (N + 3)$ matrix of second-order partial derivatives of C^* with respect to all of its $N + 3$ arguments, $(p_1, \ldots, p_N, y, t, G)$.

Therefore a twice continuously differentiable cost function C at the point (p, y, t, G) is flexible if and only if it contains enough free parameters so that the following $1 + (N + 3) + (N + 3)^2$ equations can be satisfied:

$$\begin{aligned} C (p, y, t, G) &= C^* (p, y, t, G), & \text{(A.7)} \\ \nabla C (p, y, t, G) &= \nabla C^* (p, y, t, G), & \text{(A.8)} \\ \nabla^2 C (p, y, t, G) &= \nabla^2 C^* (p, y, t, G). & \text{(A.9)} \end{aligned}$$

Hence the level, all $N + 3$ first-order derivatives and all $(N + 3)^2$ second-order partial derivatives of C and C^* coincide at (p, y, t, G).

[35] Diewert's (1974, p. 113) original definition of flexibility was called a second-order differential approximation by Lau (1978, p. 184). On the equivalence of differential approximations to other concepts of second-order approximations, see Barnett (1983, pp. 19–21).

If we impose linear homogeneity in prices in our candidate function for flexibility C, then C will also satisfy the $(N+4)+(N+3)(N+2)/2$ restrictions (A.1)–(A.6). Hence, in order to be flexible, C must contain at least $N(N+7)/2+6$ free parameters. Therefore the cost function we use contains at least $N(N+7)/2+6$ free parameters.

B The construction of quantities and prices of the private capital stocks

This appendix goes into the construction of the total private capital stock and its price. To get accurate data, we build up both measures from investment data on prices and quantities of structures (buildings) and equipment (machinery and equipment). Both the stock of private structures and the stock of private equipment (K^j) are constructed through the perpetual inventory method, *i.e.* through the accumulation of investments (I^j), assuming a depreciation rate constant over time but varying over type and sector (δ^j):

$$K_t^j = \left(1-\delta^j\right) K_{t-1}^j + I_{t-1}^j, \qquad \text{(B.10)}$$

where j stands for structures or equipment. Both stocks are available from 1952 until 1993. Initial capital stocks and depreciation rates are taken from preliminary data on quantities and depreciations of the private capital stock which were kindly provided by the Statistics Netherlands. The depreciation rate of structures equals two percent for both sectors, whereas the depreciation rate of equipment is set to five percent in the exposed sector and eight percent in the sheltered. In prices of 1990 the initial stock of structures for the exposed sector is set at 250 billion guilders, whereas for the sheltered sector this stock equals almost 100 billion guilders. The initial stocks of equipment equal approximately 70 billion and 14 billion guilders for the exposed and sheltered sectors of the economy respectively.

Measuring the cost of private capital poses a particular problem. One option is to use an interest rate as an approximation. However, the quality of this approximation is probably quit poor. Another option would be to assume that the value of output equals the total costs of production, *i.e.* assume perfect competition and constant returns to scale in the private inputs, as is done by, *e.g.* Draper and Manders (1996a,b). Using such an accounting identity, it is possible to derive the cost of capital from value added, the costs of other inputs and the stock of private capital. However, because the private revenues of public capital are also part of the operating surplus, this approach will not be followed, and a Jorgenson rental price of private capital has been constructed. Following Jorgenson (1986) the user cost of both parts of the private capital stock, *i.e.* structures and equipment, can each be expressed as a function of the interest rate, tax parameters and the investment price index:

$$p_k^j = \frac{\left(1 - wir^j - u * ia^j\right)}{(1-u)} \left[(1-u)\, r + \delta^j + risk^j - \hat{\pi}^j\right] p_{inv}^j, \qquad \text{(B.11)}$$

where j stands for structures or equipment. The corporate tax rate is given by u, and wir^j and ia^j stand for certain fiscal tax reductions. The long-term interest rate on state loans is given by r, δ^j is the depreciation rate, and $risk^j$ is a mark-up for risk, which we set at two percentage points.[36] The price index of investment is given by p^j_{inv} and $\hat{\pi}^j$ is the expected inflation of investment goods. The expected inflation of investment goods is calculated by using the formula

$$\hat{\pi}^j_t = \alpha\hat{\pi}^j_{t-1} + (1-\alpha)\,\pi^j_{t-1}, \tag{B.12}$$

where we picked $\alpha = 0.1$, and where π^j_{t-1} is the realized inflation of investment good j in period $t-1$.[37]

Once these rental prices and capital service flows are measured separately, they must be aggregated to get the total stock of private capital and the aggregate rental price of private capital. We assume that private capital is instantaneously adjustable and employ the familiar Tornqvist discrete approximation to the continuous Divisia index. The Tornqvist approximation of the Divisia index has attractive properties. Diewert (1976) has shown that it can be viewed as an exact index corresponding to a second-order approximation in logarithms to an arbitrary production or cost function.[38] In particular, this index places no prior restrictions on the substitution elasticities among the goods being aggregated. With the Tornqvist approximation, the change in aggregate private capital service flow is a weighted sum of the changes in both asset-specific private capital stocks, where the weights are relative cost shares:

$$\ln\frac{K_t}{K_{t-1}} = \sum_{j=1}^{2}\bar{s}_{j,t}\ln\frac{K^j_t}{K^j_{t-1}}, \qquad \bar{s}^j_t \equiv \frac{1}{2}\left(s^j_t + s^j_{t-1}\right), \quad s^j_t \equiv \frac{p^j_{k,t}K^j_t}{\sum_{j=1}^{2} p^j_{k,t}K^j_t}. \tag{B.13}$$

When the aggregate private capital quantity index is computed using the above equation, the implicit aggregate rental price of private capital can be derived by:

$$p_k = \frac{\sum_{j=1}^{2} p^j_{k,t}K^j_t}{K_t}. \tag{B.14}$$

As emphasized by emphasized by Jorgenson and Griliches (1967), an important feature of aggregate capital growth is that Divisia aggregation can generate very different growth rate results compared with the direct summation or aggregation of capital. For

[36] A lower risk premium sometimes leads to negative capital rental prices.
[37] See Broer and Jansen (1989).
[38] See Caves *et al.* (1982) for further discussion.

example, suppose that the composition of capital changes because investment is growing faster for shorter-lived equipment than for longer-lived structures. As a result, since the depreciation rate for equipment is larger than that for structures it is clear that, *ceteris paribus*, the rental price of equipment will be larger than the rental price of structures (see equation (B.11)). This implies that the growth of equipment investment will be weighted more highly than growth in structures in the Divisia aggregation, and aggregate capital computed using this Divisia index will grow at a larger rate than aggregate capital calculated using direct aggregation. The economic intuition underlying this is that because of the shorter life of equipment, the investor needs to require more services per year from a given dollar of investment in equipment than in structures, *i.e.* a dollar's worth of investment in equipment has higher 'quality' (in terms of service flow per dollar) than a dollar's worth of investment in structures.

C The data

This appendix gives all data used in the final stage of our empirical analysis. All prices equal one in the base year 1973.

Table C.1 *Data aggregate private sector.*

Year[a]	p_Y	Y	p_L	L	P_{L^l}	L^l	P_{L^h}	L^h	P_K	K	G
1950											26.654
1951											27.992
1952	0.462	33.767	0.100	66.468					0.388	9.383	29.393
1953	0.455	35.841	0.104	66.324					0.391	9.372	30.505
1954	0.461	39.720	0.116	68.069					0.400	9.416	32.742
1955	0.488	42.731	0.129	68.954					0.401	9.576	34.254
1956	0.508	44.618	0.143	69.158					0.422	9.879	35.791
1957	0.537	45.799	0.161	68.820					0.481	10.271	37.582
1958	0.542	45.179	0.169	67.962					0.466	10.665	39.395
1959	0.555	47.091	0.175	68.523					0.469	10.875	40.859
1960	0.565	52.140	0.193	70.064					0.516	11.165	42.541
1961	0.574	53.770	0.218	68.322					0.527	11.582	44.369
1962	0.586	56.538	0.237	68.386					0.553	12.072	46.514
1963	0.609	58.701	0.266	67.604					0.564	12.597	48.899
1964	0.649	64.040	0.309	68.181					0.641	13.095	51.625
1965	0.676	68.053	0.351	67.621					0.683	13.656	54.700
1966	0.701	69.794	0.393	67.336					0.768	14.244	57.668
1967	0.719	73.510	0.432	66.554					0.769	14.899	60.699
1968	0.730	79.194	0.477	66.482					0.809	15.583	64.034
1969	0.785	85.904	0.558	65.933	0.569	41.933	0.566	22.856	0.952	16.381	67.836
1970	0.811	92.017	0.643	65.392	0.653	41.030	0.651	23.511	1.017	17.147	71.360
1971	0.858	95.076	0.737	64.714	0.744	40.061	0.744	24.091	0.940	18.123	74.997
1972	0.931	97.873	0.846	62.128	0.850	37.912	0.849	23.947	0.893	18.945	78.981
1973	1.000	104.706	1.000	60.837	1.000	36.622	1.000	24.216	1.000	19.681	82.300
1974	1.075	110.487	1.186	59.652	1.180	35.413	1.182	24.497	1.110	20.581	85.077
1975	1.162	107.105	1.372	57.452	1.358	33.620	1.362	24.328	0.977	21.542	87.574
1976	1.248	114.232	1.512	57.347	1.494	33.058	1.492	25.042	0.980	22.257	90.164
1977	1.301	116.830	1.665	56.540	1.639	32.145	1.635	25.376	0.906	22.869	92.662
1978	1.353	121.242	1.820	55.665	1.774	30.309	1.758	27.050	0.901	23.735	94.701
1979	1.388	125.853	1.962	55.616	1.895	28.955	1.866	29.084	1.020	24.627	96.438
1980	1.433	126.521	2.075	55.868	2.005	27.757	1.928	31.278	1.195	25.545	97.995
1981	1.470	127.560	2.171	54.805	2.102	25.924	1.972	32.708	1.472	26.266	99.582
1982	1.563	127.640	2.298	53.326	2.237	24.478	2.056	32.975	1.418	26.690	100.993
1983	1.615	128.909	2.393	52.070	2.343	23.154	2.110	33.348	1.322	27.059	102.130
1984	1.633	135.062	2.437	51.543	2.408	22.409	2.122	33.786	1.509	27.535	103.162
1985	1.660	138.354	2.584	50.799	2.569	21.661	2.227	33.959	1.522	28.113	104.432
1986	1.709	143.667	2.691	51.512	2.679	21.367	2.301	35.350	1.502	28.908	105.535
1987	1.719	145.883	2.745	52.445	2.739	21.152	2.331	36.912	1.634	29.909	106.445
1988	1.748	151.280	2.770	53.644	2.767	21.000	2.337	38.723	1.960	30.894	107.318
1989	1.779	159.518	2.827	54.560	2.825	20.725	2.371	40.352	2.329	31.812	108.283
1990	1.793	167.465	2.948	55.809	2.976	19.910	2.434	43.253	2.802	32.832	109.031
1991	1.821	172.284	3.088	56.757	3.166	19.705	2.519	44.825	2.879	33.846	109.926
1992	1.850	174.155	3.206	57.765	3.362	19.250	2.571	46.873	2.838	34.868	110.731
1993	1.864	174.512	3.290	57.583	3.452	18.518	2.628	47.752	2.523	35.819	111.588

[a] The aggregate private sector consists of the sheltered and the exposed sectors of the Dutch private economy. All price indices (p_Y, p_L, p_{L^l} and p_{L^h}) and the price of capital (p_K) are normalized to unity in 1973. The real values (in billions of Dutch guilders) of output (Y), total labour (L), low–skilled labour (L^l), high–skilled labour (L^h) and private capital (K) are calculated by dividing their nominal value by their corresponding price series. Public capital is also expressed in 1973 prices.
Source: CPB Netherlands Bureau of Economic Policy Analysis and Statistics Netherlands.

Table C.2 *Data sheltered sector.*

Year[a]	p_Y	Y	p_L	L	P_{L^l}	L^l	P_{L^h}	L^h	P_K	K	G
1950											26.654
1951											27.992
1952	0.355	14.264	0.104	18.660					0.504	2.212	29.393
1953	0.356	15.022	0.108	18.697					0.495	2.169	30.505
1954	0.353	16.641	0.121	19.044					0.493	2.149	32.742
1955	0.395	17.864	0.133	19.431					0.487	2.168	34.254
1956	0.412	18.932	0.147	19.663					0.506	2.230	35.791
1957	0.429	18.914	0.164	19.867					0.573	2.304	37.582
1958	0.446	18.376	0.173	20.025					0.551	2.351	39.395
1959	0.464	19.134	0.178	20.440					0.551	2.362	40.859
1960	0.471	20.085	0.193	21.089					0.602	2.422	42.541
1961	0.491	21.209	0.215	21.014					0.609	2.508	44.369
1962	0.514	22.631	0.230	21.391					0.624	2.634	46.514
1963	0.528	23.956	0.256	21.832					0.633	2.777	48.899
1964	0.578	25.371	0.300	22.380					0.711	2.942	51.625
1965	0.600	27.202	0.338	22.601					0.748	3.126	54.700
1966	0.632	27.805	0.381	22.957					0.833	3.331	57.668
1967	0.653	29.092	0.417	23.406					0.825	3.517	60.699
1968	0.675	30.847	0.467	24.035					0.854	3.729	64.034
1969	0.743	32.903	0.558	24.243	0.573	14.023	0.556	9.854	0.990	4.002	67.836
1970	0.801	35.100	0.647	24.392	0.661	13.953	0.647	10.162	1.056	4.256	71.360
1971	0.852	36.576	0.747	24.389	0.757	13.796	0.747	10.409	0.962	4.582	74.997
1972	0.928	37.511	0.848	23.999	0.854	13.422	0.848	10.486	0.903	4.836	78.981
1973	1.000	40.052	1.000	23.680	1.000	13.092	1.000	10.588	1.000	5.096	82.300
1974	1.097	42.612	1.189	23.438	1.181	12.808	1.189	10.719	1.117	5.393	85.077
1975	1.204	42.617	1.378	22.919	1.359	12.378	1.377	10.715	0.986	5.679	87.574
1976	1.295	45.283	1.528	23.358	1.501	12.351	1.511	11.340	0.990	5.880	90.164
1977	1.380	47.000	1.707	23.334	1.672	12.075	1.673	11.747	0.891	6.125	92.662
1978	1.470	49.091	1.870	23.467	1.803	11.396	1.795	13.004	0.871	6.442	94.701
1979	1.532	51.262	2.016	23.802	1.915	10.805	1.897	14.389	0.990	6.744	96.438
1980	1.624	51.286	2.139	24.099	2.027	10.218	1.962	15.718	1.178	7.080	97.995
1981	1.709	50.379	2.234	23.851	2.114	9.405	2.001	16.682	1.496	7.329	99.582
1982	1.806	50.163	2.364	23.230	2.254	8.891	2.092	16.678	1.466	7.488	100.993
1983	1.906	50.065	2.469	22.848	2.373	8.478	2.157	16.828	1.385	7.606	102.130
1984	1.937	51.688	2.478	23.125	2.400	8.372	2.143	17.363	1.599	7.755	103.162
1985	1.958	53.456	2.648	22.682	2.588	8.007	2.267	17.357	1.640	7.962	104.432
1986	2.012	55.863	2.747	23.307	2.693	8.027	2.336	18.154	1.603	8.258	105.535
1987	2.030	57.395	2.780	24.006	2.735	8.061	2.349	19.027	1.749	8.654	106.445
1988	2.056	59.473	2.804	25.007	2.766	8.183	2.355	20.164	2.095	9.131	107.318
1989	2.100	63.244	2.866	25.816	2.837	8.226	2.392	21.169	2.488	9.589	108.283
1990	2.148	66.550	2.999	26.767	2.972	8.109	2.484	22.616	2.987	10.066	109.031
1991	2.191	68.905	3.138	27.660	3.133	8.064	2.577	23.872	3.068	10.572	109.926
1992	2.269	69.724	3.240	28.463	3.240	7.803	2.640	25.355	3.021	11.130	110.731
1993	2.327	70.374	3.327	28.951	3.335	7.654	2.698	26.240	2.683	11.673	111.588

[a] All price indices (p_Y, p_L, p_{L^l} and p_{L^h}) and the price of capital (p_K) are normalized to unity in 1973. The real values (in billions of Dutch guilders) of output (Y), total labour (L), low–skilled labour (L^l), high–skilled labour (L^h) and private capital (K) are calculated by dividing their nominal value by their corresponding price series. Public capital is also expressed in 1973 prices.
Source: CPB Netherlands Bureau of Economic Policy Analysis and Statistics Netherlands.

Table C.3 *Data exposed sector.*

Year[a]	p_Y	Y	p_L	L	P_{L^l}	L^l	P_{L^h}	L^h	P_K	K	G
1950											26.654
1951											27.992
1952	0.539	19.503	0.098	47.808					0.352	7.171	29.393
1953	0.526	20.820	0.103	47.627					0.360	7.203	30.505
1954	0.539	23.079	0.114	49.025					0.372	7.267	32.742
1955	0.556	24.868	0.127	49.523					0.376	7.408	34.254
1956	0.578	25.687	0.142	49.495					0.398	7.649	35.791
1957	0.612	26.885	0.160	48.953					0.454	7.967	37.582
1958	0.607	26.803	0.168	47.937					0.442	8.314	39.395
1959	0.618	27.957	0.174	48.083					0.446	8.513	40.859
1960	0.623	32.055	0.192	48.975					0.492	8.742	42.541
1961	0.629	32.561	0.219	47.308					0.504	9.074	44.369
1962	0.635	33.906	0.240	46.994					0.533	9.439	46.514
1963	0.664	34.745	0.270	45.772					0.544	9.820	48.899
1964	0.695	38.668	0.314	45.801					0.620	10.154	51.625
1965	0.727	40.851	0.357	45.020					0.663	10.530	54.700
1966	0.747	41.988	0.399	44.378					0.748	10.913	57.668
1967	0.762	44.418	0.440	43.148					0.752	11.382	60.699
1968	0.765	48.346	0.483	42.447					0.795	11.854	64.034
1969	0.811	53.000	0.558	41.690	0.567	27.910	0.573	13.002	0.940	12.379	67.836
1970	0.817	56.917	0.641	41.000	0.648	27.077	0.654	13.349	1.004	12.891	71.360
1971	0.862	58.500	0.732	40.325	0.737	26.265	0.741	13.683	0.933	13.541	74.997
1972	0.932	60.362	0.845	38.129	0.848	24.490	0.850	13.461	0.889	14.110	78.981
1973	1.000	64.654	1.000	37.158	1.000	23.530	1.000	13.628	1.000	14.585	82.300
1974	1.061	67.875	1.184	36.215	1.180	22.605	1.176	13.779	1.107	15.188	85.077
1975	1.134	64.488	1.367	34.533	1.358	21.242	1.349	13.613	0.974	15.862	87.574
1976	1.217	68.948	1.502	33.989	1.489	20.707	1.475	13.702	0.976	16.377	90.164
1977	1.249	69.831	1.636	33.206	1.619	20.070	1.602	13.629	0.912	16.744	92.662
1978	1.273	72.151	1.784	32.198	1.756	18.913	1.724	14.046	0.912	17.293	94.701
1979	1.289	74.591	1.922	31.815	1.883	18.149	1.835	14.695	1.031	17.884	96.438
1980	1.303	75.235	2.027	31.770	1.992	17.539	1.893	15.560	1.201	18.464	97.995
1981	1.314	77.181	2.123	30.955	2.095	16.519	1.942	16.025	1.463	18.937	99.582
1982	1.406	77.477	2.247	30.096	2.228	15.588	2.020	16.297	1.399	19.202	100.993
1983	1.430	78.845	2.334	29.222	2.326	14.676	2.062	16.520	1.297	19.454	102.130
1984	1.445	83.374	2.405	28.419	2.412	14.037	2.099	16.423	1.473	19.779	103.162
1985	1.472	84.898	2.532	28.117	2.558	13.654	2.184	16.602	1.476	20.151	104.432
1986	1.516	87.804	2.644	28.205	2.671	13.340	2.266	17.196	1.462	20.650	105.535
1987	1.517	88.489	2.716	28.440	2.742	13.090	2.311	17.885	1.588	21.254	106.445
1988	1.549	91.806	2.741	28.637	2.767	12.817	2.318	18.560	1.904	21.763	107.318
1989	1.568	96.274	2.792	28.743	2.818	12.500	2.347	19.182	2.260	22.223	108.283
1990	1.560	100.915	2.900	29.041	2.978	11.801	2.378	20.637	2.721	22.767	109.031
1991	1.574	103.379	3.041	29.097	3.188	11.641	2.452	20.953	2.794	23.274	109.926
1992	1.570	104.430	3.174	29.302	3.446	11.447	2.489	21.518	2.753	23.737	110.731
1993	1.551	104.137	3.252	28.632	3.534	10.865	2.543	21.513	2.446	24.146	111.588

[a] All price indices (p_Y, p_L, p_{L^l} and p_{L^h}) and the price of capital (p_K) are normalized to unity in 1973. The real values (in billions of Dutch guilders) of output (Y), total labour (L), low–skilled labour (L^l), high–skilled labour (L^h) and private capital (K) are calculated by dividing their nominal value by their corresponding price series. Public capital is also expressed in 1973 prices.
Source: CPB Netherlands Bureau of Economic Policy Analysis and Statistics Netherlands.

D The regression results using a two-year lag on infrastructure

This appendix displays the elasticity estimates when using a two-year lag on our stock of public infrastructure capital.

Table D.4 *Elasticity estimates—using a two-year lag on infrastructure— in the midpoint of the sample, 1973 and over time.*

	Midpoint sample, 1973[a]			1953–1993[b]		
	Total	Sheltered	Exposed	Total	Sheltered	Exposed
	Elasticities of public infrastructure					
ε_{CG}	-0.196	-0.748	-0.102	-0.078	-0.447	-0.052
	(0.075)	(0.084)	(0.096)	(0.056)	(0.141)	(0.066)
ε_{LG}	0.053	-0.733	0.576	0.111	-0.513	0.687
	(0.099)	(0.107)	(0.150)	(0.210)	(0.281)	(0.494)
ε_{KG}	-0.760	-0.800	-1.168	-0.548	-0.438	-1.117
	(0.110)	(0.141)	(0.231)	(0.557)	(0.884)	(0.639)
$\partial p_G^s / \partial t$	0.033	-0.007	0.040	0.028	-0.024	0.057
	(0.009)	(0.004)	(0.009)	(0.037)	(0.033)	(0.055)
	Other interesting elasticities					
ε_{Ct}	-0.036	0.001	-0.047	-0.024	-0.001	-0.029
	(0.003)	(0.003)	(0.003)	(0.016)	(0.004)	(0.021)
ε_{Cp_L}	0.694	0.774	0.611	0.673	0.750	0.589
	(0.003)	(0.002)	(0.006)	(0.044)	(0.051)	(0.041)
ε_{Cp_K}	0.306	0.226	0.389	0.327	0.250	0.411
	(0.003)	(0.002)	(0.006)	(0.044)	(0.051)	(0.041)
ε_{Lt}	-0.057	-0.007	-0.088	-0.038	-0.003	-0.059
	(0.004)	(0.004)	(0.006)	(0.024)	(0.008)	(0.033)
ε_{Lp_L}	-0.064	-0.042	-0.126	-0.067	-0.055	-0.128
	(0.007)	(0.009)	(0.017)	(0.017)	(0.027)	(0.037)
ε_{Lp_K}	0.064	0.042	0.126	0.067	0.055	0.128
	(0.007)	(0.009)	(0.017)	(0.017)	(0.027)	(0.037)
ε_{Kt}	0.013	0.026	0.018	0.005	0.010	0.015
	(0.003)	(0.003)	(0.007)	(0.014)	(0.026)	(0.008)
ε_{Kp_L}	0.145	0.143	0.198	0.134	0.152	0.180
	(0.015)	(0.031)	(0.025)	(0.015)	(0.047)	(0.029)
ε_{Kp_K}	-0.145	-0.143	-0.198	-0.134	-0.152	-0.180
	(0.015)	(0.031)	(0.025)	(0.015)	(0.047)	(0.029)

The cost function is assumed to be homogeneous in output. A two–year lag is placed on the public infrastructure variable. The cost elasticity of public capital is assumed to lie between a certain bandwith.
[a]The elasticities are evaluated in the midpoint of the sample, 1973. The standard errors in parentheses are heteroscedastic–consistent (Robust–White) and are computed assuming that—apart from the parameter estimates—all variables are constants equal to their values in the midpoint of the sample.
[b]The elasticities estimates are averages over the 1953–1993 period. The standard errors in parentheses are computed assuming that the parameter estimates are constants.

E The regression results using the 1969–1993 period

This appendix displays the elasticity estimates when using the 1969–1993 period. The first table presents the outcomes using our aggregated labour variable. The elasticity estimates when using low-skilled and high-skilled labour are given in the second table.

Table E.5 *Elasticity estimates—using the 1969–1993 sample—in 1973 and over time.*

	1973[a]			1969–1993[b]		
	Total	Sheltered	Exposed	Total	Sheltered	Exposed
	Elasticities of public infrastructure					
ε_{CG}	-1.094	-1.333	-0.994	-1.034	-1.265	-0.943
	(0.160)	(0.210)	(0.170)	(0.059)	(0.069)	(0.046)
ε_{LG}	-1.375	-1.582	-1.240	-1.490	-1.679	-1.253
	(0.207)	(0.263)	(0.198)	(0.395)	(0.391)	(0.240)
ε_{KG}	-0.381	-0.399	-0.479	-0.013	0.044	-0.392
	(0.462)	(0.755)	(0.307)	(0.645)	(1.019)	(0.245)
$\partial p_G^s/\partial t$	-0.032	-0.012	-0.018	-0.141	-0.062	-0.065
	(0.016)	(0.006)	(0.009)	(0.076)	(0.034)	(0.034)
	Other interesting elasticities					
ε_{Ct}	-0.001	0.011	-0.006	-0.005	0.008	-0.012
	(0.005)	(0.007)	(0.005)	(0.002)	(0.002)	(0.004)
ε_{Cp_L}	0.717	0.789	0.676	0.721	0.793	0.669
	(0.003)	(0.005)	(0.003)	(0.051)	(0.046)	(0.059)
ε_{Cp_K}	0.283	0.211	0.324	0.279	0.207	0.331
	(0.003)	(0.005)	(0.003)	(0.051)	(0.046)	(0.059)
ε_{Lt}	-0.003	0.013	-0.013	-0.005	0.009	-0.018
	(0.007)	(0.008)	(0.006)	(0.006)	(0.006)	(0.005)
ε_{Lp_L}	-0.033	-0.033	-0.035	-0.031	-0.028	-0.036
	(0.005)	(0.008)	(0.008)	(0.011)	(0.012)	(0.013)
ε_{Lp_K}	0.033	0.033	0.035	0.031	0.028	0.036
	(0.005)	(0.008)	(0.008)	(0.011)	(0.012)	(0.013)
ε_{Kt}	0.003	0.002	0.008	-0.001	0.008	0.001
	(0.017)	(0.027)	(0.011)	(0.010)	(0.016)	(0.008)
ε_{Kp_L}	0.084	0.125	0.073	0.076	0.101	0.069
	(0.012)	(0.029)	(0.017)	(0.009)	(0.021)	(0.007)
ε_{Kp_K}	-0.084	-0.125	-0.073	-0.076	-0.101	-0.069
	(0.012)	(0.029)	(0.017)	(0.009)	(0.021)	(0.007)

The cost function is assumed to be homogeneous in output. The cost elasticity of public capital is assumed to lie between a certain bandwith.

[a]The elasticities are evaluated in 1973. The standard errors in parentheses are heteroscedastic–consistent (Robust–White) and are computed assuming that—apart from the parameter estimates—all variables are constants equal to their values in the midpoint of the sample.

[b]The elasticities estimates are averages over the 1969–1993 period. The standard errors in parentheses are computed assuming that the parameter estimates are constants.

Table E.6 *Elasticity estimates—using the 1969–1993 sample and low–skilled and high–skilled labour—in 1973 and over time.*

	1973[a]			1969–1993[b]		
	Total	Sheltered	Exposed	Total	Sheltered	Exposed
	Elasticities of public infrastructure					
ε_{CG}	-1.021	-1.644	-0.906	-0.899	-1.513	-0.829
	(0.244)	(0.359)	(0.220)	(0.072)	(0.131)	(0.078)
ε_{L^lG}	-4.007	-4.628	-2.794	-10.244	-9.416	-7.014
	(1.073)	(3.047)	(0.528)	(5.701)	(3.606)	(4.461)
ε_{L^hG}	3.508	1.648	2.367	5.869	2.300	5.094
	(1.905)	(3.988)	(1.335)	(1.808)	(2.330)	(2.402)
ε_{KG}	-1.400	-1.359	-1.086	-1.305	-0.520	-1.225
	(0.456)	(0.933)	(0.318)	(0.956)	(1.691)	(0.262)
$\partial p_G^s/\partial t$	0.062	-0.018	0.036	0.098	-0.033	0.055
	(0.049)	(0.037)	(0.022)	(0.096)	(0.052)	(0.019)
	Other interesting elasticities					
ε_{Ct}	0.000	0.027	-0.006	-0.003	0.019	-0.011
	(0.008)	(0.013)	(0.007)	(0.002)	(0.004)	(0.003)
$\varepsilon_{Cp_{L^l}}$	0.416	0.424	0.422	0.331	0.308	0.351
	(0.003)	(0.005)	(0.002)	(0.082)	(0.091)	(0.076)
$\varepsilon_{Cp_{L^h}}$	0.298	0.366	0.261	0.387	0.485	0.321
	(0.004)	(0.008)	(0.002)	(0.063)	(0.078)	(0.045)
ε_{Cp_K}	0.286	0.209	0.317	0.283	0.207	0.327
	(0.002)	(0.003)	(0.002)	(0.056)	(0.052)	(0.061)
ε_{L^lt}	0.060	0.068	0.020	0.085	0.097	0.030
	(0.041)	(0.117)	(0.020)	(0.022)	(0.048)	(0.021)
$\varepsilon_{L^lp_{L^l}}$	-0.401	-0.770	-0.085	-0.768	-1.404	-0.182
	(0.151)	(0.449)	(0.092)	(0.272)	(0.460)	(0.067)
$\varepsilon_{L^lp_{L^h}}$	0.496	0.918	0.143	0.896	1.603	0.270
	(0.155)	(0.466)	(0.087)	(0.302)	(0.509)	(0.093)
$\varepsilon_{L^lp_K}$	-0.095	-0.149	-0.058	-0.128	-0.199	-0.089
	(0.020)	(0.033)	(0.015)	(0.033)	(0.058)	(0.028)
ε_{L^ht}	-0.112	-0.017	-0.090	-0.092	-0.028	-0.081
	(0.073)	(0.157)	(0.051)	(0.019)	(0.041)	(0.012)
$\varepsilon_{L^hp_{L^l}}$	0.692	1.064	0.231	0.708	0.938	0.274
	(0.217)	(0.550)	(0.141)	(0.081)	(0.121)	(0.047)
$\varepsilon_{L^hp_{L^h}}$	-0.928	-1.321	-0.439	-0.884	-1.112	-0.451
	(0.224)	(0.576)	(0.134)	(0.071)	(0.140)	(0.023)
$\varepsilon_{L^hp_K}$	0.236	0.257	0.207	0.176	0.174	0.177
	(0.029)	(0.050)	(0.025)	(0.042)	(0.056)	(0.026)
ε_{Kt}	0.030	0.020	0.027	0.024	0.026	0.017
	(0.016)	(0.031)	(0.012)	(0.018)	(0.026)	(0.011)
$\varepsilon_{Kp_L^l}$	-0.138	-0.301	-0.077	-0.148	-0.289	-0.093
	(0.029)	(0.067)	(0.020)	(0.038)	(0.072)	(0.024)
$\varepsilon_{Kp_L^h}$	0.246	0.451	0.171	0.239	0.403	0.174
	(0.031)	(0.087)	(0.021)	(0.036)	(0.074)	(0.020)
ε_{Kp_K}	-0.108	-0.149	-0.094	-0.091	-0.114	-0.081
	(0.013)	(0.038)	(0.012)	(0.011)	(0.024)	(0.008)

The cost function is assumed to be homogeneous in output. The cost elasticity of public capital is assumed to lie between a certain bandwith.

[a] The elasticities are evaluated in 1973. The standard errors in parentheses are heteroscedastic–consistent (Robust–White) and are computed assuming that—apart from the parameter estimates—all variables are constants equal to their values in the midpoint of the sample.

[b] The elasticities estimates are averages over the 1969–1993 period. The standard errors in parentheses are computed assuming that the parameter estimates are constants.