

Statistics Norway
Research Department

Alexandra Katz and Torstein Bye

Returns to Publicly Owned Transport Infrastructure Investment

A Cost Function/Cost Share Approach for
Norway, 1971-1991

Discussion
Papers

$$+ 2 \sum_{i>j} \sum_{j=1}^n \text{cov}_a(X_i, X_j)$$

$$\text{var}\left(\sum_{i=1}^n a_i X_i\right) = \sum_{i=1}^n a_i^2 \text{var}(X_i) + \sum_{i=1}^n \sum_{j=1}^n a_i a_j \text{cov}(X_i, X_j)$$

$$\text{var}\left(\sum_{i=1}^n a_i X_i\right) = \sum_{i=1}^n a_i^2 \text{var}(X_i) + \sum_{i=1}^n \sum_{j=1}^n a_i a_j \text{cov}(X_i, X_j)$$

Alexandra Katz and Torstein Bye

Returns to Publicly Owned Transport Infrastructure Investment

A Cost Function/Cost Share Approach for
Norway, 1971-1991

Abstract:

An issue of major concern to politicians and policy-makers around the world today is whether transport infrastructure investments, such as those in roads and airports, generate enough economic benefits to justify their very large price tag. Beginning in the mid 1970s, nearly all OECD countries experienced a sustained decline both in public investment and in private sector output. Since infrastructure comprises the vast majority of public capital in these countries, this led many economists to conclude that underinvestment in infrastructure was largely responsible for the low growth rates in output and productivity which were experienced by these countries. In our paper, we discuss the findings in the literature with respect to both econometric and modeling deficiencies. Based on these criticisms, we develop a cost function modeling approach which includes public transport infrastructure capital, perform an econometric analysis and discuss several of our estimates of infrastructure productivity effects. The paper concludes that, in nearly all production sectors (except oil/agriculture), the public transport infrastructure investments made in Norway over the last 20 years significantly reduced private production costs and altered demand for private inputs. However, we find such effects to be statistically insignificant at the aggregate level.

Keywords: Infrastructure, public transport investment, economic growth.

JEL classification: C32, E62, H54, R42.

Acknowledgement: We would like to thank Erling Holmøy for his helpful comments on earlier drafts. Financial support from Norges Forskningsråd through the Society, Environment and Energy program (SAMMEN) is also gratefully acknowledged.

Address: Alexandra Katz, Statistics Norway, Research Department,
P.O.Box 8131 Dep., N-0033 Oslo. E-mail: aka@ssb.no

Torstein Bye, Statistics Norway, Research Department.
E-mail: tab@ssb.no

1 Introduction

An issue of major concern to politicians and policy-makers around the world today is whether transport infrastructure investments, such as those in roads and airports, generate enough economic benefits to justify their very large price tag. Beginning in the mid 1970s, nearly all OECD countries experienced a sustained decline both in public investment and in private sector output. Since infrastructure comprises the vast majority of public capital in these countries, this led many economists (such as Aschauer (1989) and Munnell (1990 a,b)) to conclude that underinvestment in infrastructure was largely responsible for the low growth rates in output and productivity which were experienced by these countries. Our aim in this paper is to investigate how transport infrastructure capital, the majority of which is publicly owned in most countries, enters into the private production process. We hope to find out whether or not there is a clear and discernible link between this particular type of public infrastructure and private production costs in Norway.

One widely used definition of infrastructure is as the real fixed capital stock which is owned by the public sector. This is a rather vague definition, but it permits easy measurement. An alternative, and better definition from a theoretical standpoint, is that infrastructure includes all the various networks of capital intensive natural monopolies, such as highway and utility systems. This is often called the 'core' infrastructure because it is considered most likely to enhance private sector production. While this 'core' definition is more precise than the 'public ownership' one and captures that infrastructure can be both publicly and privately owned, it is notoriously difficult to measure (see Gramlich, 1994). Furthermore, available national accounts data rarely distinguish between private infrastructure capital and other types of private capital. For these reasons, we must follow convention and define transportation infrastructure according to the 'public ownership definition', i.e. as the real fixed public capital stock in air, rail, road, sea, and communication activities.

Even though it is intuitively obvious that production would be impossible without public infrastructure, classical production theory, oddly, has typically ignored this variable, focusing instead on only those variables internal to the firm, like private capital and labor.

Traditionally firms are assumed to choose the optimal amount of private inputs given private input prices, a predetermined level of output, and various exogenous environmental factors - such as technological change. Public transportation infrastructure capital, like technological change, can be thought of as one of those environmental factors which are external to the firm's decision making process yet nonetheless influence its production possibilities, and thus, indirectly, its cost structure.

According to Meade (1952), public capital affects output in two ways. One way is as an environmental variable, as just discussed, which can boost private input productivity. The

other way public capital affects output is more directly as an input which contributes independently to a private firm's production. Public capital can stand in its own right in the production function, even though it is not a 'choice' variable of the firm. (In the simplest case, think of plane plus pilot plus public airport services as producing air travel services.) The important distinction is that public infrastructure capital is different from traditional inputs because it is not purchased by the firm like private inputs are. Instead, changes to the stock are usually determined externally, via the political process. Assuming that the individual firm has no influence in this process, public infrastructure capital should be considered as an exogenous, unpaid factor of production which affects the firm's variable costs.

A review of the literature

A brief review of the literature demonstrates that economists are widely divided over whether or not public infrastructure investment generates economic returns, in terms of higher output or increased productivity. The controversy is not about *if* public capital belongs in the production (or cost) function, but rather *how* the function should be estimated. Important issues to consider are which functional form is appropriate and whether the data used are stationary, i.e. give reliable results.

It should be noted at this point that there is an important distinction between the *stock* of infrastructure capital and the *flow* of services from that stock. It is the amount of *services* which a firm receives from the infrastructure stock which influences a firm's cost structure, rather than the total infrastructure capital network which exists. Unfortunately, it is impossible to accurately measure the amount of infrastructure services which a firm uses. For example, it is hard to measure which parts of a national highway system a firm actually uses, how intensely it uses these routes, and how to account for variations in road quality or congestion levels. The second-best solution, now standard in most of the recent literature, is to multiply the infrastructure capital stock by a capacity utilization index in order to reflect that firms utilize the available infrastructure stock to different degrees, depending on the level of activity in their industry. Thus in boom periods, the firm's demand for public transport infrastructure services will be relatively high, reflecting that the demand for the firm's own products is large, whereas in recessions situation is obviously reversed.

Assuming Cobb Douglas production technology, constant returns to scale over all inputs¹, and using time series data, Aschauer (1989) performs a straightforward least squares regression of total private business economy value-added per unit of private capital on the private labor-capital ratio, the net (of depreciation) public capital (nonmilitary) stock to private capital stock

¹ CRTS over all inputs is tested and accepted by Aschauer.

ratio,² capacity utilization in the manufacturing sector, and on time as a proxy for technological change. Using annual US data from 1949-1985,³ he finds that the elasticity of output with respect to 'core infrastructure', is .24 and is highly significant.⁴ This means that a 1% increase in the public 'core' public infrastructure capital stock would generate a .24% rise in output. The estimated elasticity of output with respect to private capital is .26. Therefore, in Aschauer's model, public 'core' infrastructure capital appears to have almost the same impact on private sector output as private capital does. He concludes that the government should take advantage of this large stimulative effect by increasing public investment in infrastructure. Aschauer's work prompted many other economists to investigate whether the economic returns to infrastructure were really as dramatic as he claimed.

Using a similar approach, Ratner (1983) had earlier estimated an aggregate Cobb Douglas production function, assuming constant returns to scale technology. Ratner's model was slightly different from Aschauer's model, where capacity utilization enters additively to the estimated equation, as an independent variable. In his original study, Ratner finds an elasticity of private US business sector output with respect to public (infrastructure) capital of .06 over the period 1949-1973. Tatom (1991) reestimates Ratner's model using revised levels data for this period and finds that the elasticity of output with respect to public (infrastructure) capital is .28. Tatom argues, however, that Ratner's findings (as well as his own reestimation) are invalid due to the nonstationarity of the data⁵. Therefore, Tatom reestimates the model (for the same period) after first differencing the data, which makes each of the variables stationary (he also includes a term for the price of energy relative to the price of business sector output). Once the variables are first differenced, the impact and statistical significance of public capital fall dramatically. When Tatom uses the first differenced data for just 1949-1973, the public capital coefficient changes sign to negative and becomes statistically insignificant. He also reestimates the model to include the period 1949-1985 and finds that the elasticity of output with respect to public capital still is statistically insignificant. In addition, when Hulten and Schwab (1994) reestimate Aschauer's equations using first differenced data instead of the levels, they also find that the coefficient on public capital becomes statistically insignificant. They note that, "with slightly different statistical

² Here, the stock of public capital is used here as a proxy for the flow of services from public capital since the services are assumed to be proportional to the stock. The capacity utilization index comes in additively.

³ A detailed discussion of the international literature is presented in APPENDIX C.

⁴ Aschauer defines 'core' public infrastructure as highways, mass transit, airports, utility (electric, gas, water) systems, and sewers. So defined, 'core public infrastructure' comprises 55% of the total nonmilitary public capital stock.

⁵ By stationarity, it is meant that the main properties of the variable, such as its mean, variance, and covariance with its lagged variables do not depend on the absolute value of time, but rather on the time *between* periods. For example, after a random shock we would expect the mean of a stationary variable to return to its original long run trend. For a non stationary variable, however, temporary shocks become permanent ones. The problem with macroeconomic time series, in particular, is that they not only usually follow a trend (e.g. the means rise over time), but often even when the trend is removed, they remain non-stationary. For more on time series analysis see, for example, Harvey (1990), Kennedy (1992) and Granger and Newbold (1986).

approaches (i.e. whether or not the data are first differenced), the same data could lead us to conclude that additional investment in infrastructure could have either a dramatic impact or virtually no impact on the private economy." This underscores the main point here, that obtaining non-spurious results hinges on whether stationary data are used.

Economists are not only divided over econometric issues concerning data stationarity, they are also divided on how to model the link between infrastructure public capital and output. Most studies of the effects of infrastructure capital on output use the Cobb Douglas single equation aggregate production function specification. This is probably due to its simplicity, especially with relatively few inputs, and to the fact that current research is often compared to earlier work, which usually employed Cobb Douglas aggregate production functions. Another modeling dilemma concerns whether to use a single equation approach or a simultaneous equation estimation.

The main problem with the Cobb Douglas production function is the relationships that it presupposes between the inputs. The elasticity of substitution between the different inputs are constant and equal to one which means *ex ante* that private capital, public capital and labor are all assumed to be substitutes. By choosing this form, then, one has already decided beforehand that higher investment in public capital leads to higher marginal and average productivity of the other inputs. The Cobb Douglas form, therefore, is too restrictive because it does not leave room for the possibility of complementarity between the inputs.⁶

A related problem with the Cobb Douglas production function is that it presumes that all inputs are variable in the production process at all times.⁷ A more realistic assumption, of course, would be to model only some factors (such as material inputs and labor) as variable in the short run, while inputs such as private and public capital would be fixed. The translog functional form could incorporate these changes.⁸

A drawback of using a single equation estimation relates to the problem of correlation versus causality. Two time series which are dominated by strong, similar trends, like output growth and infrastructure investment, will no doubt be correlated, but this does not necessarily imply that one variable indeed *caused* the other. The problem here is to determine which variables are exogenous and which are endogenous. It is very likely the case, for example, that the production function is part of a system of simultaneous equations and, therefore, that the right hand side variables (inputs in the standard production function estimates, like Aschauer's) like

⁶ Private and public capital are found to be complements in most of the literature, especially in the manufacturing sector. See, for example, Seitz (1994), and Berndt and Hansson (1991).

⁷ The problems with using the Cobb Douglas functional form are discussed in greater detail in Berndt and Hansson (1991).

⁸ The translog cost function was first introduced in Christensen, Jorgenson, and Lau (1973).

labor input and capacity utilization are actually endogenously determined. If so, then OLS yields biased and inconsistent estimates. Since the endogenous variables are jointly determined in a simultaneous equation system, causality is not implied by correlation when looking at just one equation (such as the production function) in isolation. In addition, a single equation approach also seems to be inadequate due to the unique nature of public infrastructure capital and the multi-dimensional way that it affects production.⁹

Taking advantage of duality principles, Lynde and Richmond (1992) look at the effects that public capital has on US private sector (nonfinancial) production costs. Following the 'ownership' definition of infrastructure, they measure public capital as the net stock of nonmilitary fixed government-owned capital. Under perfect competition, the individual firm minimizes private production costs by choosing the optimal level of labor services and private capital services given the level of public capital services which are provided by the government at no cost to the firm¹⁰. Lynde and Richmond use a translog cost function and estimate only the set of cost share equations for the period 1958-1989. They find a negative and significant infrastructure coefficient in the labor cost share equation which implies that an increase in the provision of public capital services leads to a fall in the cost share of labor. When Lynde and Richmond calculate the *overall* effect of public infrastructure capital on the demand for labor (i.e. after also taking the productivity effect into account), they find that labor and public capital are substitutes. They also find that private and public capital are complements. The results also suggest that the marginal product of public capital is falling over the period. That is, an increase in public capital services leads to an increase in its shadow cost share. Nonetheless, they find that the marginal product of public capital was not driven below zero. In short, although Lynde and Richmond take a different methodological approach than Aschauer and Ratner, they also conclude that public capital is a significant determinant of US manufacturing sector costs. They do not, however, discuss the stationarity of their data.

The Norwegian case

In contrast to the analytical studies performed thus far, most of which look at the impact of aggregate public infrastructure investment (i.e. which also includes utilities, sewers, schools, etc) on the manufacturing sector, we are interested in the effects of one particular type of public infrastructure, namely transport infrastructure. This variable is particularly interesting to focus on because it is reasonable to assume, for example, that expenditure on a better highway system will have more of a direct effect on the economy than, say, building a hospital will. Public transport infrastructure capital is also arguably an important type of public infrastructure to study because it accounts for such a large part of the total public

⁹ The deficiencies of single equation models in this context are detailed in Hulten (1993).

¹⁰ See Appendix C.

capital stock and public investment in most OECD countries. In 1991, for instance, Norway's public transportation infrastructure capital stock was NOK 307.3 billion (1991 prices), which was about 45% of the total Norwegian real fixed public capital stock (Statistics Norway, 1994).

Figure 1

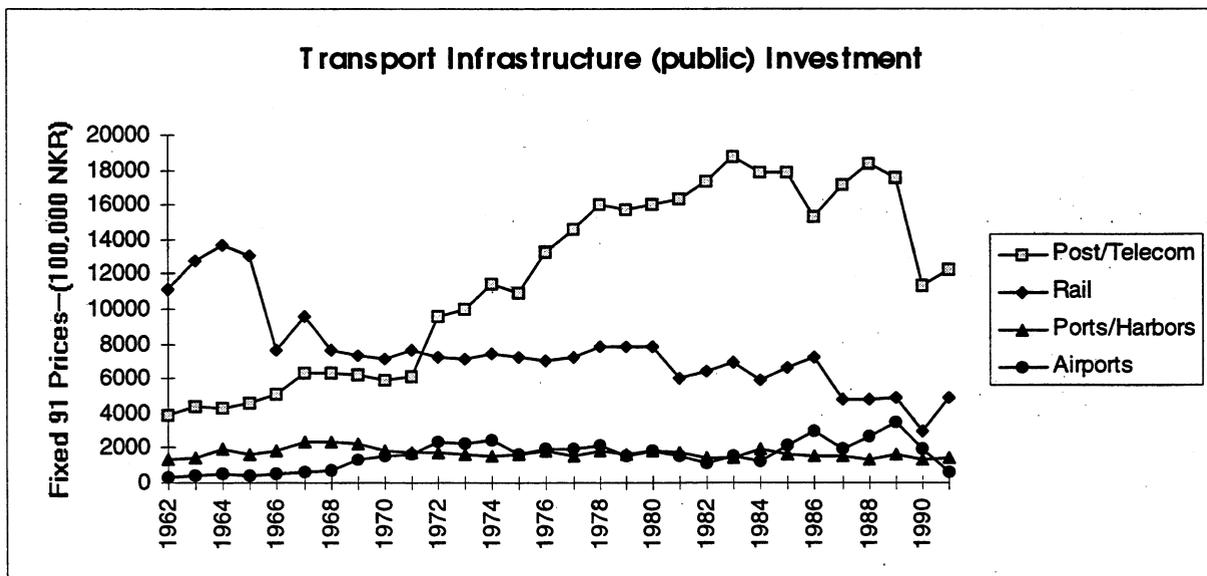
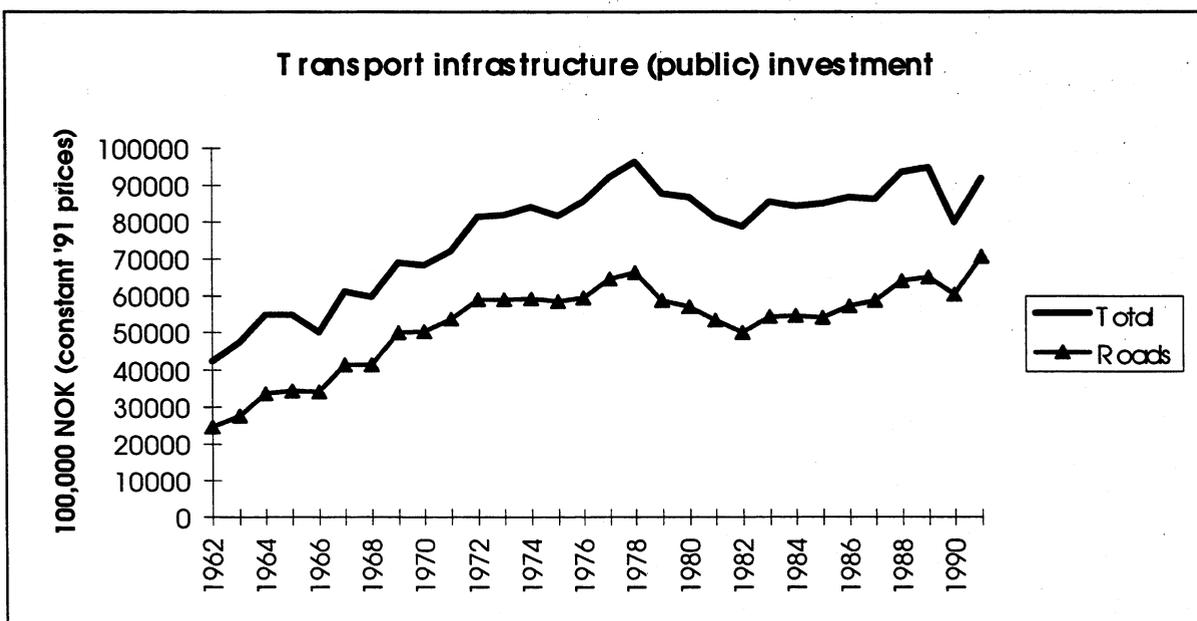
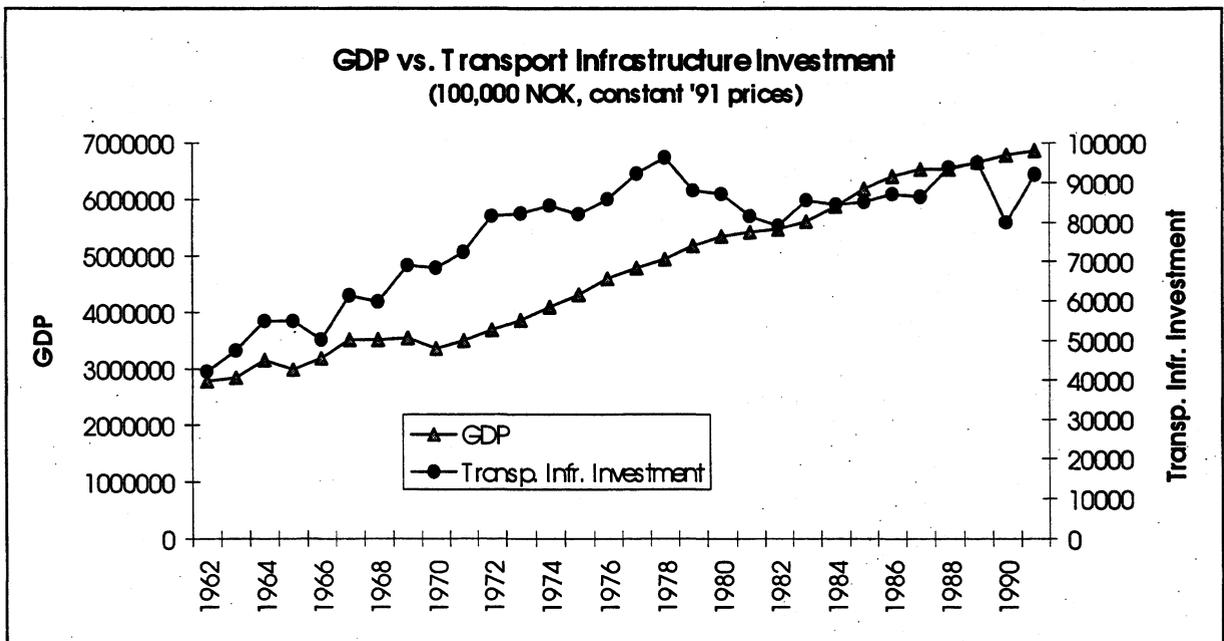


Figure 2



The same year, total investment in Norwegian public transportation infrastructure was NOK 9.2 billion (1991 prices), which was approximately 1.3% of GNP or about 7% of total national gross fixed capital formation (Statistics Norway, 1994). The most dramatic *change* in transport infrastructure investment levels occurred in the post/telecommunications sector, as Figure 1 shows. However, Figure 2 reveals that by far the majority of all public transport infrastructure investment went to the road sector. For instance, road investment accounted for 73% of total public investment in transport infrastructure in 1991. This means that, for Norway, when we analyze the effects of public transport infrastructure investment on the private production process, we are primarily talking about the impact of spending on roads (including tunnels and bridges).

Figure 3



Norway stands out as an interesting case study for two main reasons. First, Norway was one of the only OECD countries which did not experience a sustained decline in its public transport infrastructure investment after 1975 (OECD, 1960-1990). As can be seen in Figure 3, both Norwegian GDP and public transport infrastructure investment rose steadily between 1962 and 1991. This then raises the question: is there a connection between Norway's steadily increasing investment in transport infrastructure and the similarly steady growth in its GDP?

A second interesting feature of Norway is its geography combined with its political objectives as a welfare state. Norway is a long, thin country which contains many small coastal islands and which is criss-crossed by fjords all up and down the coast. There is, therefore, a high demand by rural inhabitants for transport infrastructure, especially for bridges, tunnels, and roads, in these isolated regions.¹¹ While it seems clear that providing a better transportation infrastructure network to these people would increase their welfare, it is less clear whether connecting these regions is justifiable on economic grounds--that is, whether the construction of a better public transport infrastructure network results in a 'payoff' in the form of lower private production costs in the affected regions. Identifying a clear and discernible relationship between such public transport infrastructure investment and private sector cost reduction is, therefore, of clear importance.

Using a cost function/cost share approach, we seek to model the impacts, if any, that public transport infrastructure capital has on Norwegian private sector (variable) costs. We use annual time series data for the period 1971-1991 and examine private production costs at both the aggregate and sectoral level. The paper is further structured as follows: In section 2, the results of our Norwegian estimations, including elasticity estimates, are reported at the aggregate and disaggregate level. Section 3 concludes with some final comments.

2 Estimations

As noted earlier, most studies about the role of public capital in the production process employ the broad 'public ownership' definition of infrastructure capital and focus on the United States economy. We use Norwegian time series data and focus on a particular type of public infrastructure capital-- *transportation* infrastructure (which is represented by *G* in our model). We assume a translog cost function and estimate a set of cost share equations simultaneously, making sure to use stationary data. The production and cost functions contain the same information according to duality principles, but we use the latter specification because it allows us to explicitly include input price effects and their impact on factor utilization.¹² After obtaining results for the aggregate Norwegian economy, we re-run the regressions at the sectoral level, to examine the impact of public transport infrastructure capital on sectoral production.

¹¹ However, this is not necessarily reflected by a high willingness of inhabitants to pay for the services from these types of transport capital.

¹² For a discussion on duality and on measuring infrastructure benefits see Diewert (1986).

2.1 The Translog Aggregate Cost Function and Estimated Cost Share Equations for the Norwegian Economy

Suppose that, in a perfectly competitive market, each industry has a simple, well-behaved (variable) private cost function¹³ which depends on private input prices (p_K, p_L, p_M), gross output level (Y), the amount of public transport infrastructure capital services available (G),¹⁴ and time (as a proxy for technological change). The three private input quantities- services of capital (K), labor (L), and intermediates (M) - are determined conditional on the predetermined (by the government) public input, namely public transport infrastructure capital services, which is available at zero cost to firms in this simple model. G is thus modeled as an exogenous unpaid factor of production which can indirectly influence the cost function by altering the production environment. Total cost is defined by

$$(2.1) \quad C(p_K, p_L, p_M, Y, G, t) = \min_{K, L, M} p_L L + p_K K + p_M M \quad s.t. \quad Y = f(K, L, M, G, t)$$

where $f(\cdot)$ is a production function. We assume that $f_K > 0$, $f_L > 0$, $f_M > 0$, $f_t > 0$ and $f_G \geq 0$.¹⁵

Using Shephard's lemma, the optimal conditional factor demands can be expressed as

$$(2.2a) \quad L^* = \frac{\partial C}{\partial p_L} ,$$

$$(2.2b) \quad K^* = \frac{\partial C}{\partial p_K} ,$$

$$(2.2c) \quad M^* = \frac{\partial C}{\partial p_M} .$$

Recalling that under perfect competition, $\lambda^* = q$ (output price) and using the envelope theorem, the following relations can be shown to hold

$$(2.2d) \quad \frac{\partial C}{\partial y} = q ,$$

$$(2.2e) \quad \frac{\partial C}{\partial G} = -q f_G .$$

13 Properties of the well-behaved cost function $C(\cdot)$ include that it is continuous, twice differentiable, concave in input prices, non-decreasing in output level and linearly homogenous in input prices.

14 Here, the transport service is assumed to be proportional to the stock of transport infrastructure capital multiplied with a capacity utilization index.

15 The $f_G \geq 0$ assumption is equivalent to requiring that the cost function be nonincreasing in G , which is discussed below (free disposal assumption).

By imposing a free disposal assumption, we rule out *a priori* the possibility that increasing the amount of public infrastructure capital can increase costs. Thus, we assume that an increase in G enables the firm to produce a given level of output with fewer labor, private capital, and/or intermediate inputs *ceteris paribus*. This assumption requires that $f_G \geq 0$ (on the production side) or, equivalently, that $C_G \leq 0$ (on the cost side) and which then implies $s_G \leq 0$.

An alternative way of expressing the shadow price of public transport infrastructure capital is in terms of the adjustment costs of labor, private capital, and intermediates:

$$(2.3) \quad \frac{\partial C}{\partial G} = p_L \left(\frac{\partial L^*}{\partial G} \right) + p_K \left(\frac{\partial K^*}{\partial G} \right) + p_M \left(\frac{\partial M^*}{\partial G} \right), \quad \text{which} \leq 0, \text{ by assumption.}$$

This shows that an exogenous change in the *transport* infrastructure capital stock can affect the private production costs by altering both the productivity of and the cost minimizing conditional demands for the private factors.¹⁶ Only if these effects go in the “right” direction (for example, if all private inputs were substitutes with respect to public transport infrastructure capital), will an increase in public capital services unambiguously reduce private production costs. This would obviously be a legitimate argument for increasing infrastructure investment. Ascertaining the production relationships between all of the factors, i.e. whether they are complements or substitutes, is therefore of key importance.

We use a translog cost function of the form

$$(2.4) \quad \begin{aligned} \ln C = & \beta_0 + \sum_i \beta_i \ln p_i + .5 \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \beta_Y \ln Y + .5 \beta_{YY} (\ln Y)^2 + \sum_i \beta_{Yi} \ln p_i \ln Y \\ & + \beta_G \ln G + .5 \beta_{GG} (\ln G)^2 + \sum_i \beta_{iG} \ln p_i \ln G + \beta_{YG} \ln Y \ln G + \beta_t \ln t + .5 \beta_{tt} (\ln t)^2 \\ & + \sum_i \beta_{it} \ln p_i \ln t + \beta_{Yt} \ln Y \ln t + \beta_{Gt} \ln G \ln t \end{aligned} \quad i, j = K, L, M$$

Substituting from (2.2(a-e)), the cost shares can be written as

$$(2.5a) \quad s_L^* = \frac{p_L L^*}{C^*} = \frac{\partial \ln C}{\partial \ln p_L} \geq 0 \quad (\text{cost share of labor}),$$

$$(2.5b) \quad s_K^* = \frac{p_K K^*}{C^*} = \frac{\partial \ln C}{\partial \ln p_K} \geq 0 \quad (\text{cost share of private capital}),$$

¹⁶ For example, increased investment in airports might mean that an air courier firm could deliver its packages faster. Per unit costs would fall, but there might also be an indirect effect on the demand for labor and private capital. The total number of pilot hours worked could fall (less need for overtime) and the planes would perhaps require less frequent repairs. The individual firm therefore, adjusts its private input decisions according to whether each private input substitutes or complements public capital services.

$$(2.5c) \quad s_M^* = \frac{p_M M^*}{C^*} = \frac{\partial \ln C}{\partial \ln p_M} \geq 0 \quad (\text{cost share of intermediates}),$$

$$(2.5d) \quad s_Y^* = \frac{qY}{C^*} = \frac{\partial \ln C}{\partial \ln y} > 0 \quad (\text{cost flexibility}),$$

$$(2.5e) \quad s_G^* = \frac{-qf_G G}{C^*} = \frac{\partial \ln C}{\partial \ln G} \leq 0 \quad (\text{shadow cost share of public capital}).$$

However, because the private factor cost share equations must sum to one only two of the private input share equations are independent

$$(2.6) \quad s_K^* + s_L^* + s_M^* = 1.$$

If $f(\cdot)$ is homogeneous of degree one in K, L, M, G (i.e. constant returns to scale), then it can also be shown by Euler's Theorem, (2.5d), and (2.5e) that

$$(2.7) \quad s_G^* + s_Y^* = 1.$$

Letting the measured equivalents of the cost minimizing cost shares (*) equal S_L, S_K, S_Y and S_G , our set of simultaneous equations is thus comprised of two of the S_L, S_K, S_M equations and either the S_G or S_Y equation. We (arbitrarily) choose to estimate the S_K, S_M and S_Y equations. The unrestricted cost share equations are then

$$(2.8) \quad s_K = \beta_K + \beta_{KK} \ln p_K + \beta_{KL} \ln p_L + \beta_{KM} \ln p_M + \beta_{KY} \ln Y + \beta_{KG} \ln G + \beta_{KT} \ln t,$$

$$(2.9) \quad s_M = \beta_M + \beta_{MK} \ln p_K + \beta_{ML} \ln p_L + \beta_{MM} \ln p_M + \beta_{MY} \ln Y + \beta_{MG} \ln G + \beta_{MT} \ln t,$$

$$(2.10) \quad s_Y = \beta_Y + \beta_{YK} \ln p_K + \beta_{YL} \ln p_L + \beta_{YM} \ln p_M + \beta_{YY} \ln Y + \beta_{YG} \ln G + \beta_{YT} \ln t.$$

The producer's choice of inputs determines the cost level at the same time, and therefore equations (2.4), (2.8), (2.9), and (2.10) comprise a set of simultaneous equations. However, to maximize the degrees of freedom in the regressions, we estimate only the share equations (2.8), (2.9), and (2.10), since they will yield all the parameters in which we are interested. Full Information Maximum Likelihood (FIML) estimation is used.

Conditions and Restrictions

To ensure that the cost function is consistent with economic theory, some conditions must be imposed on the parameters of the share equations. Neo-classical theory maintains that the cost function must be symmetric and linearly homogeneous in input prices. For symmetry to hold, we require $\beta_{ij} = \beta_{ji}$ and $\beta_{iy} = \beta_{yi}$ for $i, j = K, L, M, Y, G$. By Euler's Theorem, the linear homogeneity of the cost function implies that the share equations be homogenous of degree 0

in input prices. The relevant conditions affecting the share equations are then $\beta_{iK} + \beta_{iL} + \beta_{iM} = 0$ for $i=K, L, M, Y, G$. In order for the CRTS restriction to hold, the share equations must be homogeneous of degree 0 in Y and G , (i.e. $\beta_{iY} + \beta_{iG} = 0$ for $i = K, L, M, Y, G$).

The Data

To test for stationarity, we use Augmented Dickey-Fuller (ADF) t-tests to check for unit roots in the levels variables. A unit root here corresponds to a zero coefficient on the lagged levels variable, Z_{t-1} (coefficient β in Test A, Appendix A) and indicates a non stationary data series. The critical values are found in the Dickey-Fuller tables, which cover estimations with a drift and with a drift and time trend.¹⁷ As can be seen in the results table, for none of the levels variables is this β coefficient significantly different from zero.¹⁸ Thus, none of the variables we use are stationary in levels.

We then perform the same tests on the first differences of the variables and report the results under Test B, Appendix A. The coefficient estimates for ΔZ_{t-1} (again called β) are now all significantly different from zero. Therefore, all of the first differenced variables are stationary, $I(1)$, perhaps some with a drift.¹⁹ Since all of the variables are of the same order of integration, we can proceed with the analysis using these first differenced variables and can interpret the estimates in the conventional manner.

In accordance with the literature, the price of private capital is constructed using the user cost of capital formula originally developed by Jorgenson (1963)²⁰

$$(2.11) \quad p_K = p_J(r + \delta) .$$

That is, it equals the price index of new investment (p_J) multiplied by the sum of the interest rate (r) and the physical capital depreciation rate (δ). The interest rate is proxied by the rate of return in the manufacturing sector and equals the operating surplus divided by the real capital stock in that sector. The depreciation rate, δ , is assumed to be .05.²¹ This specification implies that the capital can be resold at the end of each period at no cost, and that corporate taxes are not taken into consideration at this stage of the analysis.

¹⁷ See Table 8.5.2 in Fuller (1976).

¹⁸ The relevant ADF critical t-statistics here at 5% (reported for $n=25$) are approximately -3.6 when the constant and a trend are significant, -3.0 with only a constant, and -1.95 if neither the constant nor the trend are included.

¹⁹ While, admittedly, this may not be the best or only way to make the data stationary, we feel it is better than not taking account of the non-stationarity at all. A better method, beyond the scope of this paper, might be to find cointegrated relationships among the variables.

²⁰ For example, Seitz (1994), Nadiri and Mamuneas (1991), Lynde and Richmond (1992) all use this type of specification for the user cost of capital. An alternative specification based on interest rates which include tax rates is formulated in Biørn (1983). Biørn and Fosby (1980) also discuss the relationship between the capital depreciation structure and the user cost of capital.

²¹ At the next stage of investigation, a unique depreciation rate will be calculated for each sector.

2.2 Aggregate Estimation Results

Regression results (symmetry and homogeneity assumed):

Log Likelihood=229.30

() indicates coefficient restricted a priori

$$(2.12) \quad s_K = -.003 + .117 \ln p_K - .046 \ln p_L - .071 \ln p_M - .146 \ln Y + .114 \ln G + .001 \ln t$$

$$(-.513) \quad () \quad (-4.59) \quad (-3.61) \quad (-4.47) \quad (1.03) \quad (.047)$$

$$R^2 = .662 \quad SER = .192$$

$$(2.13) \quad s_M = .002 - .071 \ln p_K - .093 \ln p_L + .164 \ln p_M + .162 \ln Y - .020 \ln G - .004 \ln t$$

$$(.412) \quad (-3.61) \quad (-4.78) \quad () \quad (3.86) \quad (-.262) \quad (-.220)$$

$$R^2 = .496 \quad SER = .013$$

$$(2.14) \quad s_Y = .002 - .146 \ln p_K - .016 \ln p_L + .162 \ln p_M - .014 \ln Y + .007 \ln G - .009 \ln t$$

$$(.261) \quad (-4.47) \quad () \quad (3.86) \quad (-.014) \quad (.049) \quad (-.285)$$

$$CR^2 = .643 \quad SER = .022$$

Our model yields estimates which are of plausible magnitudes and sign, although they do not imply much of a role for public transport infrastructure capital at the aggregate level. Using the likelihood ratio (LR) test we find that the hypothesis of constant returns to scale over K, L, M, and G is not consistent with the aggregate data ($LR=26.6$, $\chi^2_{(3)}(.05) = 7.82$) and is therefore not imposed. For the most part, the price and output coefficients are significant, and the goodness-of-fit statistics of the restricted regressions are acceptable. For the s_K equation (2.12), the estimated cost share elasticities, which measure the response of the cost shares to a change in input prices, are of the anticipated sign and are significant. According to the results, a 1% increase in the price of private capital leads to a .12% increase in that factor's cost share, while increases in the other private input prices lead to a decrease in s_K . The output coefficient in the same equation is negative and significant, and implies that a 1% increase in the output level reduces private capital's cost share by .14%, which is referred to as a negative bias of scale. Next, the infrastructure coefficient estimate suggests that infrastructure capital services do not affect the cost share of private capital at the aggregate level. The insignificant time trend in the s_K equation indicates that technological progress also does not meaningfully influence the cost share for private capital, *ceteris paribus*.

Equation (2.13) similarly confirms that increases in the prices of private capital and labor reduce the cost share of intermediates. The bias of scale is again significant, but here positive, which means that the cost share of intermediates rises with an increase in the output level. Lastly, infrastructure capital services and time again do not significantly affect the equation.

The cost flexibility (s_Y) equation contains basically the same information as in the private input cost share equations. In particular, the bias of scale effects are the same as discussed in (2.12) and (2.13) due to symmetry conditions. The aggregate cost flexibility is also estimated to be independent of the output level, the amount of transport infrastructure services available, and time.

The total elasticity of the demand for private inputs with respect to transport infrastructure capital is the sum of the *productivity effect* (s_G) and the *factor bias effect* ($\frac{\beta_{iG}}{s_i}$ for $i = K, L,$

M). Whether or not public capital and each private inputs are substitutes or complements depends on the relative signs of these two terms. This elasticity can be calculated at the sample means according to

$$(2.15) \quad \xi_{iG} = s_G + \frac{\beta_{Gi}}{s_i} \quad i = K, L, M .$$

However, our results suggest that there is no significant productivity effect or factor bias effect from the provision of public transport infrastructure capital at the aggregate level within the estimation period.

Conclusions from Aggregate Estimations

To summarize, our aggregate estimation yields the following main results about the Norwegian economy during the sample period 1971-1991:

1. Constant returns to scale (over K,L, M, G) at the aggregate level is not consistent with the data at the 95% significance level.
2. No significant productivity effect or bias effects from transport infrastructure capital are found.

Our results controvert those of the studies which conclude that public infrastructure capital plays an important role in private production.²² This difference in findings could be due to our focus on the aggregate level,²³ our use of a specific type of public infrastructure variable (transport), and/or our use of stationary data. Having found no evidence of productive effects from public transport infrastructure capital at the aggregate level, we now turn towards sectoral estimations in the hope that they will provide more insight as to how/whether public transport infrastructure capital affects private production/cost relationships.

²² For example, Nadiri and Mamuneas (1991) for the US manufacturing economy.

²³ Most other studies analyze only the manufacturing sector.

2.3 Disaggregated Estimation Results

Oil production contributes an increasing share to Norwegian GDP (aggregate) after the late 70s. Whereas oil revenues were negligible in 1971, by 1991 they accounted for 14.5% of GDP. However, the petroleum sector, as well as several other sectors, does not depend to a great degree on public transport infrastructure capital. Conversely, it is reasonable to expect that the road transport sector, for instance, would be heavily dependent upon the provision of a good highway system. Therefore, it was our aim that by disaggregating the data, we might be able to uncover the various degrees to which public transport infrastructure capital services can affect private sectoral costs. By dividing the economy into six major production sectors, we hope to find sector-specific infrastructure effects which were not revealed at the aggregate level. This is particularly important since different industries require different kinds and amounts of public transport infrastructure capital in the production process.²⁴ We first divide the economy as follows into six major sectors, based on our *a priori* beliefs as to their relative dependence upon transport infrastructure capital:

Sector A (*a priori belief about G dependency level: medium*)

Construction, excluding oil well drilling
Finance and Insurance
Wholesale and Retail Trade
Other private services
Defense

Central and Local Govt.:
Education and Research
Central and Local Govt.:
Healthcare and
Veterinary Services
Other Central and Local
Govt. services

Sector B (*a priori belief about G dependency level: low*)

Agriculture
Fishing and Fisheries
Forestry
Dwelling Services

Ocean Transport
Production and Pipeline
Transport of Oil and Gas
Oil and Gas Exploration
and Drilling

Sector C (*a priori belief about G dependency level: medium-high*)

Manufacture of Pulp and Paper Products
Manufacture of Industrial Chemicals
Petroleum Refining
Manufacture of Consumer Goods
Manufacture of Wood, Chemical, and
Mineral Products

Manufacture of Metals
Manufacture of Metal
Products and Equipment
Building of Ship and Oil
Platforms

Sector D (*a priori belief about G dependency level: low*)

Production of Electricity and Gas

Sector E (*a priori belief about G dependency level: high*)

Road Transport

Sector NV (*a priori belief about G dependency level: high*)

Air Transport, Rail Transport, Sea Transport, Post and Telecommunications

²⁴ While we have not disaggregated public transport infrastructure capital by type in this analysis, we hope to do so at the next stage of investigation.

Again, before estimating we check that the sectoral data are also stationary. The results of these tests are reported in Appendix B. Once more, none of the levels variables are stationary, but all of the first differenced variables are, as was the case for the aggregate variables. Using the first differenced sectoral data, we then perform the disaggregated estimations. The hypothesis of constant returns to scale is consistent with the data in only one of the six sectors: the manufacturing sector (sector C). Thus, only for this sector is the restriction imposed on the parameters. For the other four sectors, the data reject this hypothesis and no CRTS restrictions are imposed on the equations.²⁵

We use the same set of simultaneous equations as before. The LHS variables, therefore, are now the sectoral cost shares, instead of their aggregate counterparts. As for the exogenous variables, the input prices are now sectoral, as is (gross) output level. Public transport infrastructure capital services, however, is not a sectoral variable because we assume that all of the available infrastructure services are at the disposition of any industries which want to use them (i.e. G is a pure public good such that consumption of services are non-rival and non-excludable). Letting h be an index running over the 6 production sectors, we estimate the following set of equations (results follow in Table 1):

Unrestricted share equations (symmetry and homogeneity assumed):

$$(2.16) \quad s_{K_h} = \tilde{\beta}_K + \tilde{\beta}_{KK} \ln p_{K_h} + \tilde{\beta}_{KL} \ln p_{L_h} + \tilde{\beta}_{KM} \ln p_{M_h} + \tilde{\beta}_{KY} \ln Y_h + \tilde{\beta}_{KG} \ln G + \tilde{\beta}_{KT} \ln t$$

$$(2.17) \quad s_{M_h} = \tilde{\beta}_M + \tilde{\beta}_{MK} \ln p_{K_h} + \tilde{\beta}_{ML} \ln p_{L_h} + \tilde{\beta}_{MM} \ln p_{M_h} + \tilde{\beta}_{MY} \ln Y_h + \tilde{\beta}_{MG} \ln G + \tilde{\beta}_{MT} \ln t$$

$$(2.18) \quad s_{Y_h} = \tilde{\beta}_Y + \tilde{\beta}_{YK} \ln p_{K_h} + \tilde{\beta}_{YL} \ln p_{L_h} + \tilde{\beta}_{YM} \ln p_{M_h} + \tilde{\beta}_{YY} \ln Y_h + \tilde{\beta}_{YG} \ln G + \tilde{\beta}_{YT} \ln t$$

where

$$(2.19) \quad C_h = p_{K_h} K_h + p_{L_h} L_h + p_{M_h} M_h$$

$$(2.20) \quad s_{K_h} = \frac{p_{K_h} K_h}{C_h}$$

$$(2.21) \quad s_{M_h} = \frac{p_{M_h} M_h}{C_h}$$

$$(2.22) \quad s_{Y_h} = \frac{q_h Y_h}{C_h} \quad h=1, \dots, 6$$

²⁵ The relevant LR statistics here are:

$\chi_A^2 = 17.32, \chi_B^2 = 16.02, \chi_C^2 = 6.46, \chi_D^2 = 198.68, \chi_E^2 = 16.00, \chi_{NV}^2 = 13.67$, while the critical test statistic is $\chi_{(3)}^2(.05) = 7.82$.

Table 1 - Sectoral Estimation Results (1971-1991)

| Sector Coefficient | Sector A | (t stat) | Sector B | | Sector C | | Sector D | | Sector E | | Sector NV | |
|-------------------------|----------|----------|----------|---------|-------------|----------|----------|---------|----------|---------|-----------|---------|
| | | | | | CRTS | | | | | | | |
| B_K | -0,005 | (-2,47) | -0,007 | (-1,01) | -0,0002 | (-0,286) | -0,003 | (-0,43) | 0,007 | (2,77) | -0,006 | (-2,62) |
| B_{KL} | -0,093 | (-19,88) | -0,026 | (-4,39) | -0,029 | (-4,36) | -0,053 | (-7,97) | -0,079 | (-6,03) | -0,054 | (-6,33) |
| $B_{KM}=B_{MK}$ | -0,085 | (-12,60) | -0,261 | (-4,28) | -0,036 | (-4,67) | -0,160 | (-7,44) | -0,130 | (-6,21) | -0,052 | (-5,86) |
| $B_{KK}=-B_{KL}-B_{KM}$ | 0,178 | * | 0,287 | * | 0,065 | * | 0,213 | * | 0,209 | * | 0,106 | * |
| $B_{KY}=B_{YK}$ | -0,217 | (-20,01) | -0,122 | (-2,67) | -0,039 | (-2,83) | -0,252 | (-9,87) | -0,121 | (-4,96) | -0,145 | (-4,21) |
| B_{KG} | 0,227 | (8,86) | -0,022 | (-0,21) | 0,039 | * | 0,288 | (3,04) | 0,241 | (6,36) | 0,161 | (5,56) |
| B_{KT} | 0,003 | (0,44) | 0,024 | (0,89) | -0,004 | (-1,06) | 0,003 | (0,10) | -0,022 | (-2,17) | 0,001 | (0,11) |
| B_M | 0,002 | (1,15) | 0,004 | (0,58) | -0,002 | (1,22) | 0,004 | (0,44) | -0,001 | (-0,17) | 0,007 | (3,09) |
| B_{ML} | -0,074 | (-2,88) | -0,020 | (-1,30) | -0,066 | (-2,96) | -0,033 | (-2,01) | -0,030 | (-0,67) | -0,228 | (-5,22) |
| $B_{MM}=-B_{ML}-B_{MK}$ | 0,159 | * | 0,281 | * | 0,102 | * | 0,193 | * | 0,160 | * | 0,280 | * |
| $B_{MY}=B_{YM}$ | 0,233 | (7,76) | 0,146 | (3,12) | -0,102 | * | 0,296 | (6,70) | 0,068 | (1,17) | 0,246 | (5,57) |
| B_{MG} | -0,106 | (-4,01) | 0,061 | (0,56) | -0,077 | (-3,07) | -0,244 | (-1,96) | -0,073 | (-1,12) | -0,003 | (-0,10) |
| B_{MT} | -0,004 | (-0,53) | -0,011 | (-0,40) | -0,010 | (-1,22) | -0,013 | (-0,38) | -0,005 | (-0,29) | -0,018 | (-2,65) |
| B_Y | -0,001 | (-0,26) | 0,024 | (1,33) | -0,005 | (-1,68) | 0,007 | (0,71) | 0,005 | (0,86) | 0,015 | (1,43) |
| $B_{YL}=-B_{YK}-B_{YM}$ | -0,016 | * | -0,024 | * | .141 | * | -0,044 | * | 0,053 | * | -0,101 | * |
| B_{YY} | 0,238 | (4,06) | 0,147 | (1,10) | -0,001 | (0,010) | 0,316 | (3,28) | 0,082 | (1,00) | 0,363 | (2,31) |
| B_{YG} | -0,191 | (-4,39) | -0,488 | (-1,70) | .011 | * | -0,163 | (-1,14) | -0,212 | (-2,07) | -0,103 | (-0,81) |
| B_{YT} | -0,018 | (-1,63) | -0,034 | (-0,46) | 0,005 | (0,530) | -0,003 | (-0,08) | -0,003 | (-0,10) | -0,062 | (-2,01) |
| <i>LOG L</i> | 257,356 | | 186,741 | | 259,717 | | 203,39 | | 208,777 | | 229,347 | |
| <i>RSQ1</i> | 0,969 | | 0,772 | | 0,964 | | 0,814 | | 0,968 | | 0,932 | |
| <i>RSQ2</i> | 0,899 | | 0,696 | | 0,447 | | 0,541 | | 0,731 | | 0,855 | |
| <i>RSQ3</i> | 0,958 | | 0,446 | | 0,405 | | 0,748 | | 0,717 | | 0,721 | |
| <i>SER1</i> | 0,006 | | 0,023 | | 0,002 | | 0,021 | | 0,008 | | 0,006 | |
| <i>SER2</i> | 0,005 | | 0,024 | | 0,006 | | 0,027 | | 0,012 | | 0,004 | |
| <i>SER3</i> | 0,009 | | 0,066 | | 0,007 | | 0,031 | | 0,020 | | 0,023 | |
| <i>DW1</i> | 2,10 | | 1,08 | | 2,26 | | 2,03 | | 1,98 | | 2,18 | |
| <i>DW2</i> | 1,93 | | 1,07 | | 2,58 | | 2,00 | | 2,22 | | 2,13 | |
| <i>DW3</i> | 1,69 | | 1,70 | | 2,48 | | 2,16 | | 2,41 | | 2,50 | |

*=restricted a priori

nob = 21, novar = 15

Referring to Table 1 and looking first at the private capital (sectoral) share equation coefficients, the estimates appear to be of reasonable signs and magnitudes. All of the $B_{KL}/B_{KM}/B_{KK}$ estimates are highly significant and reflect that private input prices are the most important determinant of private input cost shares. We find that there are significant negative biases of scale for private capital (B_{KY}) in all sectors. Thus, as is the case at the aggregate level, the cost share of private capital decreases with increases in the level of output. Interestingly, the public capital coefficient estimates in the s_K equation (B_{KG}) are significant in all sectors except B (agriculture/oil), which we had anticipated would not be heavily dependent upon G. In the other five sectors, this bias effect of public capital is positive, which means that increasing the availability of public transport infrastructure capital services raises the cost share of private capital. Lastly, technological change appears to be factor neutral (i.e. it does not affect private factor cost shares) in all sectors except sector E (road transport), where technological progress is found to reduce private capital's cost share.

For the intermediate input cost share equation, all of the estimated price coefficients are significant, except for labor price in sectors B (agriculture/oil) and E (road transport). The bias of scale estimates (B_{MY}) are positive and significant, except for again in sector E. Thus, increases in output raise the cost share of intermediate inputs in the other five sectors. Next, the public transport infrastructure capital coefficient estimates are significant in two sectors-- A and C (services and manufacturing). Contrary to our aggregate results, here we find that increasing the availability of public transport infrastructure capital services significantly reduces the cost share of intermediate inputs. Also noteworthy is that the time coefficient is significant in the non-road sector (E), which suggests that the intermediate input cost share falls over time due to technological progress.

Turning next to the sectoral S_Y equations, we find that cost flexibility is significantly increasing in the level of output in sectors A, D and NV (services, electricity/gas, and non-road transport). The public transport infrastructure capital coefficient estimates are negative and significant in sectors A and E (services and non-road transport), which implies that a 1% increase in public transport infrastructure capital services leads to a .19% decrease in cost flexibility in sector A, and a .21% reduction in S_Y in sector E. Lastly, the negative time trend is again significant in the non-road sector (E), which means that cost flexibility in that sector falls over time. Using symmetry relations ($B_{YG}=B_{GY}$), we can also infer that increasing the output level reduces the shadow cost share of public transport infrastructure capital, i.e. S_G falls. This means that the marginal product of public capital (f_G) rises with the output level, according to equation (2.5e).

Using equation (2.15) which calculates the total elasticity of the (conditional) demand for private inputs with respect to the public input (ξ_{iG}) as the sum of a productivity effect (s_G) and a factor bias effect, we find the following relationships between the variables.

Table 2 - Summary Statistics from Sectoral Regressions

| Sector | s_G | Bias _{LG} | Bias _{KG} | Bias _{MG} | ξ_{LG} | ξ_{KG} | ξ_{MG} | Conclusions |
|---------------------|-------|--------------------|--------------------|--------------------|------------|------------|------------|---|
| A-Svcs. | 0 | -.306 | .966 | -.286 | -.306 | .966 | -.286 | L,G substitutes K,G complements M,G substitutes |
| B-Agric. /Oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | no effect of G on prvt. factor demand or productivity |
| C-Manuf. | -.04 | -.165 | .506 | -.111 | -.205 | .466 | -.151 | L,G substitutes K,G complements M,G substitutes |
| D-Electr. /Gas | 0 | -.005 | .679 | -.528 | -.005 | .679 | -.528 | L,G substitutes K,G complements M,G substitutes |
| E-Road Transp. | -.02 | -.691 | .873 | 0 | -.711 | .853 | -.02 | L,G substitutes K,G complements M,G substitutes |
| NV-Non- Road Tr. | -.013 | -.328 | 1.14 | 0 | -.341 | 1.13 | -.013 | L,G substitutes K,G complements M,G substitutes |

Examination of the Table 2 estimates reveals some interesting information about the relationships between the private and public variables. Most striking is that public transport infrastructure capital has no measurable impact whatsoever in the agriculture and oil sector (B). For all of the other sectors, we find a complementary relationship between private capital and public transport infrastructure. The other two private inputs, labor and intermediates, are found to be substitutes with the public input in all of these sectors. The productivity effect of public transport infrastructure capital is negative (i.e. cost reducing) in the manufacturing, road and non-road transport sectors (C, E, and NV)). We estimate that a 1% increase in public transport infrastructure capital services reduces manufacturing (variable) costs by .04%, road transport costs by .02%, and non-road transport sector costs by .01%. Thus, in these sectors the mean marginal product of public transport infrastructure capital services is positive. In the other three sectors, where no significant productivity effect was found, the total impact of G on private factor demand is just the bias effect. Note that in all cases, the bias effects are much stronger than the productivity effects.

Conclusions from Sectoral Estimations

The most important findings at the sectoral level are:

1. The hypothesis of constant returns to scale is rejected for all sectors except manufacturing (C). This is consistent with the literature, where many of the econometric studies which focus solely on the manufacturing sector find constant returns to scale (for example, Lynde and Richmond (1992)).
2. Public transport infrastructure capital is not estimated to have any effect on the agriculture/oil sector (B). This is consistent with our *a priori* expectations.
3. Public transport infrastructure capital and private capital are found to be complements in all sectors (except sector B). This shows the importance of disaggregation. Labor and intermediates are estimated to substitute for public transport infrastructure capital in all sectors (except B). These production relationships findings are basically undisputed in the literature, with the exception of Nadiri and Mamuneas (1991).
4. Public transport infrastructure capital is only found to be cost reducing in 3 sectors: manufacturing, road, and non-road transport, with this productivity effect being strongest in manufacturing.
5. In all sectors (except B), the bias effect is much greater than the productivity effect, indicating that the main influence of public transport infrastructure capital comes via its effect on private factor demand.

The only comparisons that can be made with the literature are for the manufacturing sector.²⁶ Our elasticity estimates for this sector of $\xi_{LG} = -.205$, $\xi_{KG} = .466$, and $\xi_{MG} = -.151$ are in accordance with the literature. For example, Lynde and Richmond (1992) find for UK manufacturing that $\xi_{LG} = -.45$ and $\xi_{KG} = .71$, Berndt and Hansson (1991) obtain $\xi_{LG} = -.60$ and $\xi_{KG} = .86$ for Swedish manufacturing, and Seitz (1994) estimate that $\xi_{LG} = -.138$ and $\xi_{KG} = .361$ for German manufacturing (the latter two studies use 'core' infrastructure as their G variable, which is dominated by transport infrastructure capital in both countries). Like Seitz's results, our elasticity estimates fall on the low end of the literature's range.

3 Final Conclusions and Direction for Further Study

In conclusion, our results indicate that during the sample period public transport infrastructure investment reduced costs in several sectors and significantly altered the demand for private inputs. (The main exception to these findings is the oil/agriculture sector.) The influence of public transport infrastructure investment appears to come primarily through a bias effect, rather than through a productivity effect.

²⁶ As noted earlier, the literature focuses almost exclusively on the manufacturing sector.

Our clear finding that public transport infrastructure capital and private capital are complements supports the «public capital hypothesis», which suggests that public capital raises the marginal productivity of private capital and must be in place before private investment can take place. A good public transport infrastructure network is a vital factor of production because it provides a conducive environment for private production. In this regard, infrastructure is a necessary prerequisite for production and growth, even though its quantitative effects may be quite small. In the case of our sample period, we found that public transport infrastructure capital has a positive (mean) marginal product in the manufacturing, road, and non-road transport sectors, and that its provision led to significant, but relatively small cost savings there.

We have shown that, almost without exception, studies like Aschauer's which flaunt seemingly significant and large public capital estimates have not checked their data for non stationarity, thus invalidating their conclusions (assuming they used nonstationary data, which most time series data are). While we feel confident that the cost function/cost share is the best approach to the question of returns to public capital, there still remains possible econometric problems to grapple with such as endogeneity of public capital, omitted variables, and reverse causation. Furthermore, due to infrastructure's unique nature, accurate measurement of its services will always be difficult. In particular, we need a better way to measure the flows of services from the infrastructure stocks, in order that the degree of utilization efficiency of the infrastructure network can be taken into account.

In future research work, many interesting extensions and improvements to our model could be made by: (a) including corporate taxation, i.e. how firms indirectly pay for the transport infrastructure services they use via the taxes they pay to the government, (b) modeling infrastructure as an impure public good, trying to capture congestion effects, (c) including other environmental externalities, (d) disaggregating public transport infrastructure capital by type (i.e. road, rail, etc.), and (e) focusing on the regional level to see whether infrastructure investment in the rural, 'political-motivated' road and tunnel projects generate less private cost reductions than the same level of infrastructure investment would generate in an urban area.

APPENDIX A

| | | | | | | Tests for Stationarity | | | Approx. ADF Critical Values | |
|---|-------------------|-------------------|-------------------|-------------------|------|---|------|----------------|--|--|
| 1972-1991 | | | | | | | | | no const, no t = -1.95 | |
| Test A: Levels of Variables (Z) | | | | | | $\Delta Z = \alpha + \beta Z(-1) + \delta T + \varepsilon \Delta Z(-1)$ | | | const, no t = -3.0 | |
| (t stat) | | | | | | | | | const, t = -3.6 | |
| Z | α | β | δ | ε | CRSQ | SER | DW | conclusion | | |
| ln (PL) | -2.320 (-2.75) | -0.321 (-2.77) | 0.008 (2.55) | 0.513 (3.02) | .437 | .025 | 1.79 | non stationary | | |
| ln (PK) | -2.840 (-2.30) | -0.843 (-2.44) | -0.057 (-2.14) | 0.142 (0.53) | .238 | .161 | 1.96 | non stationary | | |
| ln (PM) | -0.008 (-0.04) | -0.059 (-0.49) | 0.002 (0.16) | 0.298 (1.15) | .283 | .033 | 1.96 | non stationary | | |
| ln (Y) | 4.480 (1.93) | -0.261 (-1.94) | -0.010 (-1.72) | .579 (2.68) | .258 | .031 | 2.03 | non stationary | | |
| ln (G) | 7.120 (2.03) | -0.460 (-2.05) | -0.016 (-1.79) | 0.537 (2.07) | .199 | .041 | 1.66 | non stationary | | |
| SK | 0.147 (2.93) | -0.658 (-2.98) | 0.000 (-0.28) | 0.406 (1.81) | .243 | .025 | 1.88 | non stationary | | |
| SM | 0.309 (2.87) | -0.639 (-2.90) | 0.001 (1.16) | 0.365 (1.60) | .229 | .014 | 1.91 | non stationary | | |
| SY | 0.364 (2.03) | -0.365 (-2.02) | 0.001 (0.83) | 0.286 (1.20) | .065 | .032 | 1.98 | non stationary | | |
| 1973-1991 | | | | | | | | | | |
| Test B: First Differences of Variables | | | | | | (ΔZ) | | | $\Delta^{**2}Z = \alpha + \beta \Delta Z(-1) + \delta T + \varepsilon \Delta^{**2}Z(-1)$ | |
| | | | | | | | | | where Δ^{**2} is the 2nd difference | |
| ΔZ | α | β | δ | ε | CRSQ | SER | DW | conclusion | | |
| Δ ln (PL) | 0.025 (1.12) | 1.910 (4.72) | 0.000 (-0.29) | -0.313 (-1.37) | .737 | .029 | 1.99 | stationary | | |
| Δ ln (PK) | 0.191 (1.63) | 0.973 (2.99) | -0.006 (-0.82) | -0.273 (-1.07) | .310 | .187 | 2.07 | stationary | | |
| Δ ln (PM) | 0.151 (4.48) | 1.450 (4.47) | -0.005 (-3.70) | -0.285 (-1.41) | .822 | .028 | 2.58 | stationary | | |
| Δ ln (Y) | -0.054 (-2.29) | 1.640 (4.07) | 0.002 (1.32) | -0.188 (-0.80) | .708 | .033 | 2.17 | stationary | | |
| Δ ln (G) | -0.078 (-2.82) | 1.770 (4.99) | 0.003 (1.79) | -0.438 (-1.89) | .629 | .040 | 2.46 | stationary | | |
| Δ SK | -0.003 (-0.18) | 1.540 (4.45) | 0.000 (0.13) | -0.413 (-1.74) | .551 | .029 | 2.32 | stationary | | |
| Δ SM | 0.002 (0.23) | 1.440 (4.17) | 0.000 (-0.14) | -0.354 (-1.47) | .525 | .017 | 2.25 | stationary | | |
| Δ SY | 0.009 (0.44) | 1.320 (3.46) | 0.000 (-0.27) | -0.190 (-0.72) | .492 | .036 | 2.10 | stationary | | |

| APPENDIX B | | | | | | | | | |
|---------------------------------|---|-------------------|-------------------|-------------------|------|------|------|----------------|--|
| Tests for Stationarity | | | | | | | | | |
| 1972-1991 | | | | | | | | | |
| Test C: Levels of Variables (Z) | $\Delta Z = \alpha + \beta Z(-1) + \delta T + \varepsilon \Delta Z(-1)$ | | | | | | | | |
| Z | α | β | δ | ε | CRSQ | SER | DW | conclusion | |
| ln(PL.A) | -1,390 (-2,42) | -0,199 (-2,45) | 0,003 (2,00) | 0,445 (2,47) | ,554 | ,013 | 1,74 | non stationary | |
| ln(PK.A) | -2,450 (-2,87) | -0,725 (-2,81) | 0,049 (2,64) | 0,512 (2,23) | ,284 | ,130 | 1,78 | non stationary | |
| ln (PM.A) | -0,129 (-0,53) | -0,119 (-0,82) | 0,007 (0,63) | 0,477 (1,83) | ,315 | ,025 | 1,71 | non stationary | |
| ln(Y.A) | 11,380 (2,96) | -0,690 (-2,97) | -0,029 (-2,90) | 0,780 (2,92) | ,619 | ,018 | 2,18 | non stationary | |
| SK.A | 0,126 (2,61) | -0,559 (-2,71) | 0,000 (0,43) | 0,374 (1,67) | ,197 | ,027 | 1,78 | non stationary | |
| SM.A | 0,278 (3,46) | -0,758 (-2,48) | 0,000 (0,29) | 0,515 (2,38) | ,334 | ,012 | 1,75 | non stationary | |
| SY.A | 0,565 (2,71) | -0,559 (-2,74) | -0,002 (-1,32) | 0,400 (1,77) | ,204 | ,032 | 1,76 | non stationary | |
| ln(PL.B) | -0,867 (-0,79) | -0,099 (-0,90) | 0,008 (0,67) | 0,234 (1,12) | ,234 | ,038 | 1,36 | non stationary | |
| ln(PK.B) | -2,560 (-2,95) | -0,696 (-3,10) | 0,056 (2,78) | 0,538 (2,41) | ,305 | ,125 | 1,79 | non stationary | |
| ln (PM.B) | 0,089 (0,49) | -0,029 (-0,30) | -0,003 (-0,35) | 0,145 (0,58) | ,316 | ,049 | 2,20 | non stationary | |
| ln(Y.B) | 2,090 (0,92) | -0,147 (-0,95) | 0,003 (0,56) | 0,171 (0,65) | ,143 | ,112 | 2,06 | non stationary | |
| SK.B | 0,522 (4,46) | -1,040 (-4,34) | -0,005 (-3,74) | 0,548 (2,67) | ,490 | ,030 | 2,26 | non stationary | |
| SM.B | 0,430 (3,61) | -0,919 (-2,83) | 0,001 (1,34) | 0,464 (2,18) | ,432 | ,028 | 2,20 | non stationary | |
| SY.B | 0,233 (1,82) | -0,311 (-1,76) | 0,009 (1,64) | 0,265 (1,07) | ,021 | ,078 | 2,16 | non stationary | |
| ln(PL.C) | -3,540 (-2,95) | -0,494 (-2,97) | 0,014 (2,77) | 0,390 (2,01) | ,307 | ,031 | 1,92 | non stationary | |
| ln(PK.C) | -2,580 (-3,21) | -0,833 (-3,34) | 0,040 (2,90) | 0,524 (2,31) | ,331 | ,117 | 1,87 | non stationary | |
| ln (PM.C) | -0,044 (-0,19) | -0,093 (-0,64) | 0,003 (0,32) | 0,212 (0,80) | ,130 | ,044 | 1,91 | non stationary | |
| ln(Y.C) | 4,930 (2,08) | -0,307 (-2,10) | -0,016 (-1,93) | 0,600 (2,83) | ,272 | ,036 | 1,72 | non stationary | |
| SK.C | 0,034 (2,10) | -0,468 (-2,29) | 0,000 (0,28) | 0,237 (1,03) | ,107 | ,010 | 1,82 | non stationary | |
| SM.C | 0,303 (2,12) | -0,456 (-2,10) | 0,001 (1,89) | 0,170 (0,69) | ,072 | ,007 | 1,89 | non stationary | |
| SY.C | 0,419 (1,79) | -0,395 (-1,79) | -0,001 (-1,60) | -0,013 (-0,05) | ,053 | ,008 | 1,92 | non stationary | |

| | | | | | | | | |
|------------|---------|---------|---------|--------|------|------|------|-----------------------|
| In(PL.D) | -2,410 | -0,385 | -0,003 | 0,278 | ,188 | ,056 | 1,90 | non stationary |
| | -(2,38) | -(2,40) | -(1,35) | (1,28) | | | | |
| In(PK.D) | -2,640 | -0,786 | 0,052 | 0,542 | ,331 | ,128 | 1,79 | non stationary |
| | -(3,17) | -(3,32) | (2,93) | (2,43) | | | | |
| In (PM.D) | -1,230 | -0,600 | 0,059 | 0,722 | ,240 | ,070 | 2,02 | non stationary |
| | -(2,59) | -(2,81) | (2,71) | (2,41) | | | | |
| In(Y.D) | 4,330 | -0,317 | -0,013 | 0,533 | ,152 | ,052 | 1,96 | non stationary |
| | (1,81) | -(1,84) | -(1,49) | (1,83) | | | | |
| SK.D | 0,173 | -0,384 | -0,001 | 0,263 | ,076 | ,040 | 1,87 | non stationary |
| | (1,99) | -(2,08) | -(0,65) | (1,12) | | | | |
| SM.D | 0,142 | -0,354 | 0,002 | 0,243 | ,053 | ,034 | 1,92 | non stationary |
| | (2,07) | -(1,94) | (1,12) | (1,01) | | | | |
| SY.D | 0,339 | -0,747 | 0,007 | 0,498 | ,275 | ,046 | 1,66 | non stationary |
| | (2,55) | -(2,77) | (2,94) | (1,99) | | | | |
| In(PL.E) | -2,240 | -0,302 | 0,009 | 0,682 | ,302 | ,035 | 1,51 | non stationary |
| | -(2,05) | -(2,04) | (2,30) | (2,99) | | | | |
| In(PK.E) | -2,890 | -0,874 | 0,056 | 0,597 | ,382 | ,121 | 1,88 | non stationary |
| | -(3,42) | -(3,57) | (3,14) | (2,67) | | | | |
| In (PM.E) | -0,006 | -0,055 | 0,001 | 0,324 | ,230 | ,036 | 1,66 | non stationary |
| | -(0,02) | -(0,38) | (0,12) | (1,17) | | | | |
| In(Y.E) | 2,370 | -0,186 | 0,001 | 0,564 | ,370 | ,051 | 1,61 | non stationary |
| | (1,30) | -(1,33) | (0,25) | (2,38) | | | | |
| SK.E | 0,150 | -0,501 | -0,001 | 0,353 | ,161 | ,034 | 1,83 | non stationary |
| | (2,39) | -(2,51) | -(0,80) | (1,56) | | | | |
| SM.E | 0,198 | -0,624 | 0,003 | 0,218 | ,154 | ,019 | 1,98 | non stationary |
| | (2,55) | -(2,50) | (2,12) | (0,88) | | | | |
| SY.E | 0,483 | -0,799 | 0,008 | 0,532 | ,364 | ,026 | 2,05 | non stationary |
| | (3,41) | -(3,47) | (3,62) | (2,41) | | | | |
| In(PL.NV) | -0,705 | -0,108 | -0,001 | 0,063 | ,422 | ,020 | 2,01 | non stationary |
| | -(0,92) | -(0,99) | -(0,28) | (0,27) | | | | |
| In(PK.NV) | -2,750 | -0,806 | 0,054 | 0,547 | ,349 | ,123 | 1,82 | non stationary |
| | -(3,31) | -(3,45) | (3,08) | (2,49) | | | | |
| In (PM.NV) | 0,002 | -0,049 | 0,001 | 0,281 | ,296 | ,026 | 1,88 | non stationary |
| | (0,01) | -(0,45) | (0,16) | (1,08) | | | | |
| In(Y.NV) | 12,850 | -8,890 | -0,053 | 0,549 | ,370 | ,033 | 2,31 | non stationary |
| | (3,66) | -(3,38) | -(3,61) | (2,50) | | | | |
| SK.NV | 0,069 | -0,463 | 0,000 | 0,378 | ,167 | ,017 | 1,75 | non stationary |
| | (2,36) | -(2,47) | -(0,58) | (1,73) | | | | |
| SM.NV | 0,127 | -0,401 | 0,002 | 0,627 | ,399 | ,008 | 2,27 | non stationary |
| | (2,85) | -(2,86) | (2,80) | (3,21) | | | | |
| SY.NV | 0,672 | -0,540 | -0,001 | 0,217 | ,147 | ,035 | 2,00 | non stationary |
| | (1,71) | -(1,81) | -(0,55) | (0,71) | | | | |

| 1973-1991 | | | | | | | | | |
|--|-------------------|-----------------|-------------------|-------------------|----------------|---|----------------|-----------------------|------------|
| Test D: First Differences of Variables | | | | | (ΔZ) | $\Delta^{**2}Z = \alpha + \beta \Delta Z(-1) + \delta T + \varepsilon \Delta^{**2} Z(-1)$ | | | |
| | | | | | | where | Δ^{**2} | is the 2nd difference | |
| ΔZ | α | β | δ | ε | | CRSQ | SER | DW | conclusion |
| $\Delta \ln(PL.A)$ | 0,023 (1,52) | 1,900 (4,54) | -0,002 (0,00) | -0,287 (-0,27) | | 0,813 | 0,014 | 1,83 | stationary |
| | | | -0,930 | -1,140 | | | | | |
| $\Delta \ln(PK.A)$ | 0,110 (1,19) | 1,660 (4,79) | -0,003 (-0,42) | -0,461 (-1,95) | | 0,608 | 0,150 | 2,29 | stationary |
| $\Delta \ln(PM.A)$ | 0,116 (4,30) | 1,840 (5,41) | -0,003 (-3,31) | -0,421 (-2,05) | | 0,835 | 0,021 | 2,47 | stationary |
| $\Delta \ln(Y.A)$ | -0,042 (-2,37) | 2,060 (5,36) | 0,000 (0,40) | -0,446 (-1,97) | | 0,731 | 0,026 | 2,45 | stationary |
| $\Delta SK.A$ | -0,009 (-0,51) | 1,620 (4,71) | 0,001 (0,55) | -0,430 (-1,86) | | 0,584 | 0,03 | 2,38 | stationary |
| $\Delta SM.A$ | 0,005 (0,69) | 1,740 (5,45) | 0,000 (-0,78) | -0,516 (-2,43) | | 0,649 | 0,013 | 2,54 | stationary |
| $\Delta SY.A$ | 0,007 (0,35) | 1,640 (4,80) | -0,001 (-0,59) | -0,432 (-1,88) | | 0,602 | 0,036 | 2,36 | stationary |
| $\Delta \ln(PL.B)$ | 0,137 (2,57) | 1,710 (4,99) | -0,004 (-1,86) | -0,254 (-1,27) | | 0,793 | 0,036 | 1,62 | stationary |
| $\Delta \ln(PK.B)$ | 0,126 (1,40) | 1,740 (4,98) | -0,003 (-0,45) | -0,480 (-2,07) | | 0,632 | 0,143 | 2,28 | stationary |
| $\Delta \ln(PM.B)$ | 0,202 (3,89) | 1,000 (3,08) | -0,009 (-3,50) | -0,062 (-0,30) | | 0,803 | 0,044 | 2,35 | stationary |
| $\Delta \ln(Y.B)$ | -0,082 (-1,16) | 0,862 (2,34) | 0,006 (1,23) | 0,183 (0,73) | | 0,562 | 0,113 | 1,90 | stationary |
| $\Delta SK.B$ | 0,013 (0,53) | 1,470 (4,63) | -0,002 (-0,88) | -0,448 (-2,00) | | 0,581 | 0,04 | 2,49 | stationary |
| $\Delta SM.B$ | -0,021 (-0,97) | 1,390 (4,40) | 0,002 (1,13) | -0,413 (-1,85) | | 0,570 | 0,036 | 2,47 | stationary |
| $\Delta SY.B$ | 0,018 (0,34) | 0,962 (2,51) | 0,001 (0,23) | 0,135 (0,51) | | 0,469 | 0,087 | 1,95 | stationary |
| $\Delta \ln(PL.C)$ | 0,040 (1,48) | 1,600 (4,25) | -0,001 (-0,47) | -0,313 (-1,32) | | 0,600 | 0,036 | 2,11 | stationary |
| $\Delta \ln(PK.C)$ | 0,093 (1,09) | 1,600 (4,69) | -0,002 (-0,39) | -0,462 (-1,94) | | 0,588 | 0,140 | 2,34 | stationary |
| $\Delta \ln(PM.C)$ | 0,165 (4,65) | 1,380 (4,48) | -0,006 (-3,47) | -0,320 (-1,58) | | 0,758 | 0,036 | 2,55 | stationary |
| $\Delta \ln(Y.C)$ | -0,072 (-2,90) | 1,900 (5,20) | 0,002 (1,31) | -0,389 (-1,79) | | 0,751 | 0,035 | 2,36 | stationary |
| $\Delta SK.C$ | -0,005 (-0,76) | 1,440 (4,19) | 0,000 (0,74) | -0,372 (-1,52) | | 0,522 | 0,011 | 2,26 | stationary |
| $\Delta SM.C$ | 0,007 (1,59) | 1,110 (3,48) | 0,000 (-0,72) | -0,210 (-0,91) | | 0,436 | 0,008 | 2,11 | stationary |
| $\Delta SY.C$ | 0,000 (0,01) | 0,888 (2,65) | 0,000 (-0,46) | -0,085 (0,51) | | 0,310 | 0,009 | 1,91 | stationary |

| | | | | | | | | |
|---------------------------|-------------------|-----------------|-------------------|-------------------|-------|-------|------|-------------------|
| $\Delta \ln(\text{PL.D})$ | 0,017 (0,42) | 1,250 (2,71) | -0,001 (-0,51) | -0,052 (-0,19) | 0,441 | 0,067 | 1,79 | stationary |
| $\Delta \ln(\text{PK.D})$ | 0,107 (1,16) | 1,710 (5,03) | -0,002 (-0,36) | -0,502 (-2,18) | 0,624 | 0,149 | 2,35 | stationary |
| $\Delta \ln(\text{PM.D})$ | 0,120 (1,82) | 1,700 (3,36) | -0,002 (-0,43) | -0,396 (-1,30) | 0,524 | 0,083 | 1,70 | stationary |
| $\Delta \ln(\text{Y.D})$ | -0,080 (-1,79) | 1,440 (2,97) | 0,003 (1,12) | -0,221 (-0,81) | 0,592 | 0,057 | 1,73 | stationary |
| $\Delta \text{SK.D}$ | -0,025 (-0,92) | 1,350 (3,66) | 0,001 (0,73) | -0,206 (-0,82) | 0,518 | 0,044 | 2,09 | stationary |
| $\Delta \text{SM.D}$ | 0,030 (1,32) | 1,300 (3,64) | -0,001 (-0,96) | -0,221 (-0,90) | 0,512 | 0,037 | 2,05 | stationary |
| $\Delta \text{SY.D}$ | -0,021 (-0,73) | 1,680 (5,31) | 0,003 (1,33) | -0,576 (-2,63) | 0,652 | 0,048 | 2,17 | stationary |
| $\Delta \ln(\text{PL.E})$ | 0,013 (0,51) | 2,170 (4,69) | 0,001 (0,48) | -0,411 (-1,50) | 0,699 | 0,038 | 1,90 | stationary |
| $\Delta \ln(\text{PK.E})$ | 0,125 (1,36) | 1,690 (4,98) | -0,004 (-0,60) | -0,496 (-2,14) | 0,627 | 0,147 | 2,41 | stationary |
| $\Delta \ln(\text{PM.E})$ | 0,155 (5,05) | 1,690 (5,68) | -0,005 (-4,13) | -0,404 (-1,50) | 0,848 | 0,027 | 1,91 | stationary |
| $\Delta \ln(\text{Y.E})$ | -0,065 (-1,90) | 2,020 (5,00) | 0,005 (1,98) | -0,417 (-1,76) | 0,786 | 0,05 | 2,28 | stationary |
| $\Delta \text{SK.E}$ | -0,012 (-0,54) | 1,560 (4,45) | 0,001 (0,39) | -0,370 (-1,53) | 0,558 | 0,038 | 2,28 | stationary |
| $\Delta \text{SM.E}$ | 0,009 (0,69) | 1,170 (3,40) | 0,000 (-0,28) | -0,278 (-0,11) | 0,393 | 0,022 | 2,17 | stationary |
| $\Delta \text{SY.E}$ | 0,001 (0,03) | 1,560 (4,49) | 0,001 (0,69) | -0,406 (-1,73) | 0,590 | 0,033 | 2,30 | stationary |

APPENDIX C

In this appendix, we describe the Lynde and Richmond model in more detail for comparative purposes.

The Lynde and Richmond Model

Taking advantage of duality principles, Lynde and Richmond (1992) look at the effects that public capital has on US private sector (nonfinancial) production costs. Following the 'ownership' definition of infrastructure, they measure public capital as the net stock of nonmilitary fixed government-owned capital. Under perfect competition, the individual firm minimizes private production costs by choosing the optimal level of labor services (L) and private capital services (K) given the level of public capital services (G), which are provided by the government at no cost to the firm. Thus the optimization problem is

$$(1) \quad C(p_L, p_K, y, G, t) = \min_{L, K} p_L L + p_K K \quad \text{s. t. } y = A(t) f(L, K, G) ,$$

where $A(t)$ represents technological change, which is assumed to progress with time ($A'(t) > 0$), and y is (value-added) output.

Using the envelope theorem then yields the *shadow price* of public capital

$$(2) \quad \frac{\partial C}{\partial G} = -\lambda A(t) f_G ,$$

where λ is a Lagrange multiplier. (2) reflects the willingness to pay for an additional unit of public capital services or, equivalently, the private production cost savings which result from the provision of an additional unit of public capital.

Public capital's 'shadow cost share' can therefore be expressed as

$$(3) \quad s_G = \frac{-qA(t)f_G G}{C(\cdot)} ,$$

which is analogous to the standard private cost share expressions: $s_i = \frac{p_i i}{C}$ for $i = K, L$.

Since perfect competition is assumed, λ equals the price of output, q . The cost function, $C(\cdot)$, is homogeneous degree 1 in p_L and p_K and, under constant returns to scale (CRTS), also in y and G . Equation (3) shows that if the marginal product of public capital is positive ($f_G > 0$), then public capital 'subsidizes' production (i.e. has a negative shadow price), and thus s_G must be negative.

Lynde and Richmond use a translog cost function and estimate only the set of cost share equations using the iterated Zellner SURE (Seemingly Unrelated Regressions) estimation method for the period 1958-1989. We report below Lynde and Richmond's estimates under price homogeneity, CRTS, and symmetry. (Note that they include a dummy variable, DUM, to account for an outlying data point in 1974.)

$$(4) \quad s_L = \frac{\partial \ln C}{\partial \ln p_L} = .127 + .161 \ln p_L - .161 \ln p_K + .159 \ln y - .159 \ln G - .004t - .298DUM$$

(7.31) (43.75) (-43.75) (11.85) (-11.85) (-22.44) (-25.32)

$R^2 = .993 \quad DW = 1.39$

$$(5) \quad s_G = \frac{\partial \ln C}{\partial \ln G} = .368 - .159 \ln p_L + .159 \ln p_K - .342 \ln y + .342 \ln G + .009t + .268DUM$$

(5.67) (-11.85) (11.85) (-3.75) (3.75) (7.36) (6.83)

$R^2 = .919 \quad DW = 1.46$

The negative and significant infrastructure coefficient in the s_L equation implies that an increase in the provision of public capital services leads to a fall in the cost share of labor. When Lynde and Richmond calculate the *overall* effect of G on the demand for labor (i.e. after also taking the productivity effect into account), they find that labor and public capital are substitutes. They also find that private and public capital are complements. The infrastructure coefficient in the s_G equation is significant and positive, suggesting that the marginal product of public capital is falling over the period. That is, an increase in public capital services leads to an increase in its shadow cost share (by (3), for s_G to be rising, the marginal product of capital must be falling). Nonetheless, they find that the marginal product of public capital was not driven below zero, since s_G is negative over the whole sample period. In short, although Lynde and Richmond take a different methodological approach than Aschauer and Ratner, they also conclude that public capital is a significant determinant of US manufacturing sector costs. They do not, however, discuss the stationarity of their data, which is where our study deviates from theirs.

References

- Aaron, Henry (1990): "Discussion of 'Why is Infrastructure Important?'" in A.H. Munnell (eds.): *Is There a Shortfall in Public Capital Investment?*, Boston: Federal Reserve Bank of Boston, 51-63.
- Aschauer, David (1989): Is Public Expenditure Productive?, *Journal of Monetary Economics* 23, 177-200.
- Aschauer, David (1990a): *Public Investment and Private Sector Growth*, Economic Policy Institute: Washington D.C.
- Aschauer, David (1990b): "Why is Infrastructure Important?" in Munnell, Alicia (ed.): *Is There a Shortfall in Public Capital Investment?*, Boston: Federal Reserve Bank of Boston.
- Aschauer, David (1994): Infrastructure and Macroeconomic Performance: direct and indirect effects, Paper presented at OECD Conference on Capital Formation and Employment, Amsterdam, 27-28 January.
- Berndt, Ernst R. and Bengt Hansson. (1991): Measuring the Contribution of Public Infrastructure Capital in Sweden, NBER Working Paper No. 3842, Cambridge, MA.
- Biørn, E., and H.E. Fosby (1980): Kvartalsserier for brukerpriser på realkapital i norske produksjonssektorer. Rapporter nr. 80/3, Statistics Norway.
- Biørn E. (1983): Gross Capital, Net Capital, Capital Service Price and Depreciation. A Framework for Empirical Analysis. Rapporter nr. 83/27, Statistics Norway.
- Christensen L.P., Jorgenson D.W., and Lau L.J. (1973): Transcendental Logarithmic Production Function, *Review of Economics and Statistics* 55, 28-45.
- Deno, K.T. (1988): The Effect of Public Capital on U.S. Manufacturing Activity: 1970 to 1978, *Southern Economic Journal* 53, 400-411.
- Diewert, Walter E. (1986): *The Measurement of the Economic Benefits of Infrastructure Services*, New York: Springer-Verlag.
- Eisner, Robert (1994): Real Government Saving and the Future, *Journal of Economic Behavior and Organization* 23, 2, 111-126.
- Ford, Robert and Pierre Poret (1991): Infrastructure and Private Sector Productivity, *OECD Economic Studies* 17, (Autumn), 63-85.
- Fuller, W. (1976): *Introduction to Statistical Time Series*, New York: John Wiley.
- Granger, Clive and Paul Newbold (1986): *Forecasting Economic Time Series*, 2nd edition, London: Academic Press.
- Gramlich, Edward (1994): Infrastructure Investment: A Review Essay, *Journal of Economic Literature* 32, 1176-1196.

Hakfoort, Jacco (1993): Public Capital, Private Sector Productivity and Economic Growth: A Macroeconomic Perspective, Paper presented at the workshop "Infrastructure, Economic Growth and Regional Development: The Case of Industrialized Countries," Jönköping, Sweden, June 10-12.

Harvey, Andrew (1990): *The Econometric Analysis of Time Series*, 2nd edition, London: Phillip Allen.

Holtz-Eakin, Douglas (1988): Private Output, Government Capital, and the Infrastructure 'Crisis', Discussion Paper No. 394, Columbia University, New York, (May).

Hulten, Charles R. (1993): Optimal Growth with Public Infrastructure Capital: Implications for Empirical Modeling, University of Maryland Discussion Paper.

Hulten, Charles R. and Robert M. Schwab (1991): Is There Too Little Public Capital? Infrastructure and Economic Growth, paper presented at the American Institute Conference on "Infrastructure Needs and Policy Options for the 1990s." Washington DC, 4 Feb.

Hulten, Charles R. and Robert M. Schwab (1994): Infrastructure Spending: Where Do We Go From Here?, *National Tax Journal* **46**, 3, 261-273.

Jorgenson, Dale W. (1963): Capital Theory and Investment Behavior, *American Economic Review* **53**, 247-159.

Jorgenson, Dale W. (1991): Fragile Statistical Foundations: The Macroeconomics of Public Infrastructure Investment, Paper presented at the American Enterprise Institute Conference on "Infrastructure Needs and Policy Options for the 1990s." Washington DC, 4 Feb.

Kennedy Peter (1992): *A Guide to Econometrics*, 3rd edition, Oxford: Blackwell.

Lynde, Catherine and James Richmond (1992): The Role of Public Capital in Production, *The Review of Economics and Statistics* **74**, 37-44.

Lynde, Catherine and James Richmond (1993a): Public Capital and Long Run Costs in U.K. Manufacturing, *The Economic Journal* **103**, 880-893.

Lynde, Catherine and James Richmond (1993b): Public Capital and Total Factor Productivity, *International Economic Review* **34**, 2, 401-414.

Meade, J.E. (1952): External Economies and Diseconomies in a Competitive Situation, *Economic Journal* **62**, 54-67.

Munnell, Alicia (1990a): "How Does Public Infrastructure Affect Regional Economic Performance?" in Munnell, Alicia (ed.): *Is There a Shortfall in Public Capital Investment?* Boston: Federal Reserve Bank of Boston, 69-103.

Munnell, Alicia (1990b): Why has productivity growth declined? Productivity and public investment, *New England Economic Review* Jan./Feb., 2-22.

- Munnell, Alicia (1993): "An Assessment of Trends in and Economic Impacts of Infrastructure Investment," in *Infrastructure Policies for the 1990s*, Paris: OECD.
- Nadiri, M. Ishaq and Theofanis P. Mamuneas (1991): The Effects of Public Infrastructure and R&D Capital in Cost Structure and Performance of U.S. Manufacturing Industries, National Bureau of Economic Research Working Paper 3887, Cambridge MA, (October).
- OECD.(1982): *Historical Statistics: 1960-1980*, Paris.
- Ram, Rati, and Ramsey, David (1989): Government Capital and Private Output in the United States, *Economics Letters* **30**, 223-226.
- Ratner, Jonathan B. (1983): Government Capital and the Production Function for U.S. Private Output, *Economic Letters* **13**, 213-217.
- Seitz, Helmut (1993): A Dual Economic Analysis of the Benefits of the Public Road Network, *The Annals of Regional Science* **27**, 223-239.
- Seitz, Helmut (1994): Public Capital and the Demand for Private Inputs, *Journal of Public Economics* **54**, 287-307.
- Shah, Anwar (1992): Dynamics of Public Infrastructure, Industrial Productivity and Profitability, *The Review of Economic Statistics* **74**, 28-36.
- Sturm, Jan E. and Jakob de Haan (1995): Is Public Expenditure Really Productive?, *Economic Modelling* **12**, 60-72.
- Statistics Norway (1994), *National Accounts*, Official Statistics of Norway NOS C83.
- Tatom, John A. (1991): Public Capital and Private Sector Performance, *Federal Reserve Bank of St. Louis Review* **73**, 3, 3-15.
- Takayama, Akira. (1993): *Analytical Methods in Economics*, Ann Arbor: University of Michigan Press, 153-157.
- Varian, Hal (1984): *Microeconomic Analysis*, 2nd edition, New York: Norton.
- Wilson, Clifford (1991): Efficient Transportation Infrastructure Policy, *Journal of Economic Perspectives* **5**, 1, 113-127.

Issued in the series Discussion Papers

- No. 1 *I. Aslaksen and O. Bjerkholt (1985): Certainty Equivalence Procedures in the Macroeconomic Planning of an Oil Economy*
- No. 3 *E. Biørn (1985): On the Prediction of Population Totals from Sample surveys Based on Rotating Panels*
- No. 4 *P. Frenger (1985): A Short Run Dynamic Equilibrium Model of the Norwegian Production Sectors*
- No. 5 *I. Aslaksen and O. Bjerkholt (1985): Certainty Equivalence Procedures in Decision-Making under Uncertainty: An Empirical Application*
- No. 6 *E. Biørn (1985): Depreciation Profiles and the User Cost of Capital*
- No. 7 *P. Frenger (1985): A Directional Shadow Elasticity of Substitution*
- No. 8 *S. Longva, L. Lorentsen and Ø. Olsen (1985): The Multi-Sectoral Model MSG-4, Formal Structure and Empirical Characteristics*
- No. 9 *J. Fagerberg and G. Sollie (1985): The Method of Constant Market Shares Revisited*
- No. 10 *E. Biørn (1985): Specification of Consumer Demand Models with Stochastic Elements in the Utility Function and the first Order Conditions*
- No. 11 *E. Biørn, E. Holmøy and Ø. Olsen (1985): Gross and Net Capital, Productivity and the form of the Survival Function. Some Norwegian Evidence*
- No. 12 *J.K. Dagsvik (1985): Markov Chains Generated by Maximizing Components of Multidimensional Extremal Processes*
- No. 13 *E. Biørn, M. Jensen and M. Reymert (1985): KVARTS - A Quarterly Model of the Norwegian Economy*
- No. 14 *R. Aaberge (1986): On the Problem of Measuring Inequality*
- No. 15 *A.-M. Jensen and T. Schweder (1986): The Engine of Fertility - Influenced by Interbirth Employment*
- No. 16 *E. Biørn (1986): Energy Price Changes, and Induced Scrapping and Revaluation of Capital - A Putty-Clay Model*
- No. 17 *E. Biørn and P. Frenger (1986): Expectations, Substitution, and Scrapping in a Putty-Clay Model*
- No. 18 *R. Bergan, Å. Cappelen, S. Longva and N.M. Stølen (1986): MODAG A - A Medium Term Annual Macroeconomic Model of the Norwegian Economy*
- No. 19 *E. Biørn and H. Olsen (1986): A Generalized Single Equation Error Correction Model and its Application to Quarterly Data*
- No. 20 *K.H. Alfsen, D.A. Hanson and S. Glomsrød (1986): Direct and Indirect Effects of reducing SO₂ Emissions: Experimental Calculations of the MSG-4E Model*
- No. 21 *J.K. Dagsvik (1987): Econometric Analysis of Labor Supply in a Life Cycle Context with Uncertainty*
- No. 22 *K.A. Brekke, E. Gjelsvik and B.H. Vatne (1987): A Dynamic Supply Side Game Applied to the European Gas Market*
- No. 23 *S. Bartlett, J.K. Dagsvik, Ø. Olsen and S. Strøm (1987): Fuel Choice and the Demand for Natural Gas in Western European Households*
- No. 24 *J.K. Dagsvik and R. Aaberge (1987): Stochastic Properties and Functional Forms of Life Cycle Models for Transitions into and out of Employment*
- No. 25 *T.J. Klette (1987): Taxing or Subsidising an Exporting Industry*
- No. 26 *K.J. Berger, O. Bjerkholt and Ø. Olsen (1987): What are the Options for non-OPEC Countries*
- No. 27 *A. Aaheim (1987): Depletion of Large Gas Fields with Thin Oil Layers and Uncertain Stocks*
- No. 28 *J.K. Dagsvik (1987): A Modification of Heckman's Two Stage Estimation Procedure that is Applicable when the Budget Set is Convex*
- No. 29 *K. Berger, Å. Cappelen and I. Svendsen (1988): Investment Booms in an Oil Economy - The Norwegian Case*
- No. 30 *A. Rygh Swensen (1988): Estimating Change in a Proportion by Combining Measurements from a True and a Fallible Classifier*
- No. 31 *J.K. Dagsvik (1988): The Continuous Generalized Extreme Value Model with Special Reference to Static Models of Labor Supply*
- No. 32 *K. Berger, M. Hoel, S. Holden and Ø. Olsen (1988): The Oil Market as an Oligopoly*
- No. 33 *I.A.K. Anderson, J.K. Dagsvik, S. Strøm and T. Wenemo (1988): Non-Convex Budget Set, Hours Restrictions and Labor Supply in Sweden*
- No. 34 *E. Holmøy and Ø. Olsen (1988): A Note on Myopic Decision Rules in the Neoclassical Theory of Producer Behaviour, 1988*
- No. 35 *E. Biørn and H. Olsen (1988): Production - Demand Adjustment in Norwegian Manufacturing: A Quarterly Error Correction Model, 1988*
- No. 36 *J.K. Dagsvik and S. Strøm (1988): A Labor Supply Model for Married Couples with Non-Convex Budget Sets and Latent Rationing, 1988*
- No. 37 *T. Skoglund and A. Stokka (1988): Problems of Linking Single-Region and Multiregional Economic Models, 1988*
- No. 38 *T.J. Klette (1988): The Norwegian Aluminium Industry, Electricity prices and Welfare, 1988*

- No. 39 *I. Aslaksen, O. Bjerkholt and K.A. Brekke (1988): Optimal Sequencing of Hydroelectric and Thermal Power Generation under Energy Price Uncertainty and Demand Fluctuations, 1988*
- No. 40 *O. Bjerkholt and K.A. Brekke (1988): Optimal Starting and Stopping Rules for Resource Depletion when Price is Exogenous and Stochastic, 1988*
- No. 41 *J. Aasness, E. Biørn and T. Skjerpen (1988): Engel Functions, Panel Data and Latent Variables, 1988*
- No. 42 *R. Aaberge, Ø. Kravdal and T. Wennemo (1989): Unobserved Heterogeneity in Models of Marriage Dissolution, 1989*
- No. 43 *K.A. Mork, H.T. Mysen and Ø. Olsen (1989): Business Cycles and Oil Price Fluctuations: Some evidence for six OECD countries. 1989*
- No. 44 *B. Bye, T. Bye and L. Lorentsen (1989): SIMEN. Studies of Industry, Environment and Energy towards 2000, 1989*
- No. 45 *O. Bjerkholt, E. Gjelsvik and Ø. Olsen (1989): Gas Trade and Demand in Northwest Europe: Regulation, Bargaining and Competition*
- No. 46 *L.S. Stambøl and K.Ø. Sørensen (1989): Migration Analysis and Regional Population Projections, 1989*
- No. 47 *V. Christiansen (1990): A Note on the Short Run Versus Long Run Welfare Gain from a Tax Reform, 1990*
- No. 48 *S. Glomsrød, H. Vennemo and T. Johnsen (1990): Stabilization of Emissions of CO₂: A Computable General Equilibrium Assessment, 1990*
- No. 49 *J. Aasness (1990): Properties of Demand Functions for Linear Consumption Aggregates, 1990*
- No. 50 *J.G. de Leon (1990): Empirical EDA Models to Fit and Project Time Series of Age-Specific Mortality Rates, 1990*
- No. 51 *J.G. de Leon (1990): Recent Developments in Parity Progression Intensities in Norway. An Analysis Based on Population Register Data*
- No. 52 *R. Aaberge and T. Wennemo (1990): Non-Stationary Inflow and Duration of Unemployment*
- No. 53 *R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Sweden*
- No. 54 *R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Norway*
- No. 55 *H. Vennemo (1990): Optimal Taxation in Applied General Equilibrium Models Adopting the Armington Assumption*
- No. 56 *N.M. Stølen (1990): Is there a NAIRU in Norway?*
- No. 57 *Å. Cappelen (1991): Macroeconomic Modelling: The Norwegian Experience*
- No. 58 *J.K. Dagsvik and R. Aaberge (1991): Household Production, Consumption and Time Allocation in Peru*
- No. 59 *R. Aaberge and J.K. Dagsvik (1991): Inequality in Distribution of Hours of Work and Consumption in Peru*
- No. 60 *T.J. Klette (1991): On the Importance of R&D and Ownership for Productivity Growth. Evidence from Norwegian Micro-Data 1976-85*
- No. 61 *K.H. Alfsen (1991): Use of Macroeconomic Models in Analysis of Environmental Problems in Norway and Consequences for Environmental Statistics*
- No. 62 *H. Vennemo (1991): An Applied General Equilibrium Assessment of the Marginal Cost of Public Funds in Norway*
- No. 63 *H. Vennemo (1991): The Marginal Cost of Public Funds: A Comment on the Literature*
- No. 64 *A. Brendemoen and H. Vennemo (1991): A climate convention and the Norwegian economy: A CGE assessment*
- No. 65 *K.A. Brekke (1991): Net National Product as a Welfare Indicator*
- No. 66 *E. Bowitz and E. Storm (1991): Will Restrictive Demand Policy Improve Public Sector Balance?*
- No. 67 *Å. Cappelen (1991): MODAG. A Medium Term Macroeconomic Model of the Norwegian Economy*
- No. 68 *B. Bye (1992): Modelling Consumers' Energy Demand*
- No. 69 *K.H. Alfsen, A. Brendemoen and S. Glomsrød (1992): Benefits of Climate Policies: Some Tentative Calculations*
- No. 70 *R. Aaberge, Xiaojie Chen, Jing Li and Xuezheng Li (1992): The Structure of Economic Inequality among Households Living in Urban Sichuan and Liaoning, 1990*
- No. 71 *K.H. Alfsen, K.A. Brekke, F. Brunvoll, H. Lurås, K. Nyborg and H.W. Sæbø (1992): Environmental Indicators*
- No. 72 *B. Bye and E. Holmøy (1992): Dynamic Equilibrium Adjustments to a Terms of Trade Disturbance*
- No. 73 *O. Aukrust (1992): The Scandinavian Contribution to National Accounting*
- No. 74 *J. Aasness, E. Eide and T. Skjerpen (1992): A Criminometric Study Using Panel Data and Latent Variables*
- No. 75 *R. Aaberge and Xuezheng Li (1992): The Trend in Income Inequality in Urban Sichuan and Liaoning, 1986-1990*
- No. 76 *J.K. Dagsvik and S. Strøm (1992): Labor Supply with Non-convex Budget Sets, Hours Restriction and Non-pecuniary Job-attributes*
- No. 77 *J.K. Dagsvik (1992): Intertemporal Discrete Choice, Random Tastes and Functional Form*
- No. 78 *H. Vennemo (1993): Tax Reforms when Utility is Composed of Additive Functions*

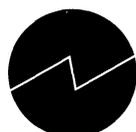
- No. 79 *J.K. Dagsvik (1993): Discrete and Continuous Choice, Max-stable Processes and Independence from Irrelevant Attributes*
- No. 80 *J.K. Dagsvik (1993): How Large is the Class of Generalized Extreme Value Random Utility Models?*
- No. 81 *H. Birkelund, E. Gjelsvik, M. Aaserud (1993): Carbon/energy Taxes and the Energy Market in Western Europe*
- No. 82 *E. Bowitz (1993): Unemployment and the Growth in the Number of Recipients of Disability Benefits in Norway*
- No. 83 *L. Andreassen (1993): Theoretical and Econometric Modeling of Disequilibrium*
- No. 84 *K.A. Brekke (1993): Do Cost-Benefit Analyses favour Environmentalists?*
- No. 85 *L. Andreassen (1993): Demographic Forecasting with a Dynamic Stochastic Microsimulation Model*
- No. 86 *G.B. Asheim and K.A. Brekke (1993): Sustainability when Resource Management has Stochastic Consequences*
- No. 87 *O. Bjerkholt and Yu Zhu (1993): Living Conditions of Urban Chinese Households around 1990*
- No. 88 *R. Aaberge (1993): Theoretical Foundations of Lorenz Curve Orderings*
- No. 89 *J. Aasness, E. Biørn and T. Skjerpen (1993): Engel Functions, Panel Data, and Latent Variables - with Detailed Results*
- No. 90 *I. Svendsen (1993): Testing the Rational Expectations Hypothesis Using Norwegian Microeconomic Data Testing the REH. Using Norwegian Microeconomic Data*
- No. 91 *E. Bowitz, A. Rødseth and E. Storm (1993): Fiscal Expansion, the Budget Deficit and the Economy: Norway 1988-91*
- No. 92 *R. Aaberge, U. Colombino and S. Strøm (1993): Labor Supply in Italy*
- No. 93 *T.J. Klette (1993): Is Price Equal to Marginal Costs? An Integrated Study of Price-Cost Margins and Scale Economies among Norwegian Manufacturing Establishments 1975-90*
- No. 94 *J.K. Dagsvik (1993): Choice Probabilities and Equilibrium Conditions in a Matching Market with Flexible Contracts*
- No. 95 *T. Kornstad (1993): Empirical Approaches for Analysing Consumption and Labour Supply in a Life Cycle Perspective*
- No. 96 *T. Kornstad (1993): An Empirical Life Cycle Model of Savings, Labour Supply and Consumption without Intertemporal Separability*
- No. 97 *S. Kverndokk (1993): Coalitions and Side Payments in International CO₂ Treaties*
- No. 98 *T. Eika (1993): Wage Equations in Macro Models. Phillips Curve versus Error Correction Model Determination of Wages in Large-Scale UK Macro Models*
- No. 99 *A. Brendemoen and H. Vennemo (1993): The Marginal Cost of Funds in the Presence of External Effects*
- No. 100 *K.-G. Lindquist (1993): Empirical Modelling of Norwegian Exports: A Disaggregated Approach*
- No. 101 *A.S. Jore, T. Skjerpen and A. Rygh Swensen (1993): Testing for Purchasing Power Parity and Interest Rate Parities on Norwegian Data*
- No. 102 *R. Nesbakken and S. Strøm (1993): The Choice of Space Heating System and Energy Consumption in Norwegian Households (Will be issued later)*
- No. 103 *A. Aaheim and K. Nyborg (1993): "Green National Product": Good Intentions, Poor Device?*
- No. 104 *K.H. Alfsen, H. Birkelund and M. Aaserud (1993): Secondary benefits of the EC Carbon/ Energy Tax*
- No. 105 *J. Aasness and B. Holtmark (1993): Consumer Demand in a General Equilibrium Model for Environmental Analysis*
- No. 106 *K.-G. Lindquist (1993): The Existence of Factor Substitution in the Primary Aluminium Industry: A Multivariate Error Correction Approach on Norwegian Panel Data*
- No. 107 *S. Kverndokk (1994): Depletion of Fossil Fuels and the Impacts of Global Warming*
- No. 108 *K.A. Magnussen (1994): Precautionary Saving and Old-Age Pensions*
- No. 109 *F. Johansen (1994): Investment and Financial Constraints: An Empirical Analysis of Norwegian Firms*
- No. 110 *K.A. Brekke and P. Børing (1994): The Volatility of Oil Wealth under Uncertainty about Parameter Values*
- No. 111 *M.J. Simpson (1994): Foreign Control and Norwegian Manufacturing Performance*
- No. 112 *Y. Willassen and T.J. Klette (1994): Correlated Measurement Errors, Bound on Parameters, and a Model of Producer Behavior*
- No. 113 *D. Wetterwald (1994): Car ownership and private car use. A microeconomic analysis based on Norwegian data*
- No. 114 *K.E. Rosendahl (1994): Does Improved Environmental Policy Enhance Economic Growth? Endogenous Growth Theory Applied to Developing Countries*
- No. 115 *L. Andreassen, D. Fredriksen and O. Ljones (1994): The Future Burden of Public Pension Benefits. A Microsimulation Study*
- No. 116 *A. Brendemoen (1994): Car Ownership Decisions in Norwegian Households.*
- No. 117 *A. Langørgeren (1994): A Macromodel of Local Government Spending Behaviour in Norway*

- No. 118 *K.A. Brekke (1994)*: Utilitarianism, Equivalence Scales and Logarithmic Utility
- No. 119 *K.A. Brekke, H. Lurås and K. Nyborg (1994)*: Sufficient Welfare Indicators: Allowing Disagreement in Evaluations of Social Welfare
- No. 120 *T.J. Klette (1994)*: R&D, Scope Economies and Company Structure: A "Not-so-Fixed Effect" Model of Plant Performance
- No. 121 *Y. Willassen (1994)*: A Generalization of Hall's Specification of the Consumption function
- No. 122 *E. Holmøy, T. Hægeland and Ø. Olsen (1994)*: Effective Rates of Assistance for Norwegian Industries
- No. 123 *K. Mohn (1994)*: On Equity and Public Pricing in Developing Countries
- No. 124 *J. Aasness, E. Eide and T. Skjerpen (1994)*: Criminometrics, Latent Variables, Panel Data, and Different Types of Crime
- No. 125 *E. Biørn and T.J. Klette (1994)*: Errors in Variables and Panel Data: The Labour Demand Response to Permanent Changes in Output
- No. 126 *I. Svendsen (1994)*: Do Norwegian Firms Form Extrapolative Expectations?
- No. 127 *T.J. Klette and Z. Griliches (1994)*: The Inconsistency of Common Scale Estimators when Output Prices are Unobserved and Endogenous
- No. 128 *K.E. Rosendahl (1994)*: Carbon Taxes and the Petroleum Wealth
- No. 129 *S. Johansen and A. Rygh Swensen (1994)*: Testing Rational Expectations in Vector Autoregressive Models
- No. 130 *T.J. Klette (1994)*: Estimating Price-Cost Margins and Scale Economies from a Panel of Microdata
- No. 131 *L. A. Grünfeld (1994)*: Monetary Aspects of Business Cycles in Norway: An Exploratory Study Based on Historical Data
- No. 132 *K.-G. Lindquist (1994)*: Testing for Market Power in the Norwegian Primary Aluminium Industry
- No. 133 *T. J. Klette (1994)*: R&D, Spillovers and Performance among Heterogenous Firms. An Empirical Study Using Microdata
- No. 134 *K.A. Brekke and H.A. Gravningsmyhr (1994)*: Adjusting NNP for instrumental or defensive expenditures. An analytical approach
- No. 135 *T.O. Thoresen (1995)*: Distributional and Behavioural Effects of Child Care Subsidies
- No. 136 *T. J. Klette and A. Mathiassen (1995)*: Job Creation, Job Destruction and Plant Turnover in Norwegian Manufacturing
- No. 137 *K. Nyborg (1995)*: Project Evaluations and Decision Processes
- No. 138 *L. Andreassen (1995)*: A Framework for Estimating Disequilibrium Models with Many Markets
- No. 139 *L. Andreassen (1995)*: Aggregation when Markets do not Clear
- No. 140 *T. Skjerpen (1995)*: Is there a Business Cycle Component in Norwegian Macroeconomic Quarterly Time Series?
- No. 141 *J.K. Dagsvik (1995)*: Probabilistic Choice Models for Uncertain Outcomes
- No. 142 *M. Rønsen (1995)*: Maternal employment in Norway, A parity-specific analysis of the return to full-time and part-time work after birth
- No. 143 *A. Bruvoll, S. Glomsrød and H. Vennemo (1995)*: The Environmental Drag on Long-term Economic Performance: Evidence from Norway
- No. 144 *T. Bye and T. A. Johnsen (1995)*: Prospects for a Common, Deregulated Nordic Electricity Market
- No. 145 *B. Bye (1995)*: A Dynamic Equilibrium Analysis of a Carbon Tax
- No. 146 *T. O. Thoresen (1995)*: The Distributional Impact of the Norwegian Tax Reform Measured by Disproportionality
- No. 147 *E. Holmøy and T. Hægeland (1995)*: Effective Rates of Assistance for Norwegian Industries
- No. 148 *J. Aasness, T. Bye and H.T. Mysen (1995)*: Welfare Effects of Emission Taxes in Norway
- No. 149 *J. Aasness, E. Biørn and Terje Skjerpen (1995)*: Distribution of Preferences and Measurement Errors in a Disaggregated Expenditure System
- No. 150 *E. Bowitz, T. Fæhn, L. A. Grünfeld and K. Moum (1995)*: Transitory Adjustment Costs and Long Term Welfare Effects of an EU-membership – The Norwegian Case
- No. 151 *I. Svendsen (1995)*: Dynamic Modelling of Domestic Prices with Time-varying Elasticities and Rational Expectations
- No. 152 *I. Svendsen (1995)*: Forward- and Backward Looking Models for Norwegian Export Prices
- No. 153 *A. Langørgen (1995)*: On the Simultaneous Determination of Current Expenditure, Real Capital, Fee Income, and Public Debt in Norwegian Local Government
- No. 154 *A. Katz and T. Bye (1995)*: Returns to Publicly Owned Transport Infrastructure Investment. A Cost Function/Cost Share Approach for Norway, 1971-1991

Statistics Norway
Research Department
P.O.B. 8131 Dep.
N-0033 Oslo

Tel.: + 47 - 22 86 45 00
Fax: + 47 - 22 11 12 38

ISSN 0803-074X



Statistics Norway
Research Department