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Aggregate Productivity Effects of Road Investment
A Reassessment for Western Europe

Andreas Kopp
OECD/ECMT Transport Research Centre
2, rue André Pascal
75016 Paris
FRANCE

Ph. 0033 14524 9721
Andreas.Kopp@oecd.org

ABSTRACT

Knowledge about the productivity effects of infrastructure would allow more informed decisions to be taken on the overall budget allocations for infrastructure investment in general and transport infrastructure in particular. This paper analyses the macroeconomic productivity effects of road investment in 13 western European countries. It reviews the previous attempts to measure the macroeconomic effects of infrastructure investment which often suffer from an unresolved endogeneity problem. The production theory framework used explicitly includes the modeling of national transport intensities and the fact that transport services depend on private capital investment and government investment in roads. The endogeneity bias is addressed by introducing an estimation breakdown which combines national productivity effects with overall productivity effects for the country group as a whole, to make residuals of the estimation orthogonal to the explanatory variables. Productivity is measured by the Toernquist productivity index. The productivity effects depend on the sign of the ratio of vehicle stock to the road stock elasticity of production. The fixed-effects panel data analysis shows that transport infrastructure has a positive effect on macroeconomic productivity. The variance of road infrastructure investment in the panel explains, however, only a small part of the macroeconomic productivity development.

Keywords: Road investment; macroeconomic productivity; panel data analysis.

1. INTRODUCTION

Transport infrastructure investment and road infrastructure investment in particular are seen, by a major part of the general public and by many political decisionmakers, as a central instrument to promote regional or national economic growth. Large-scale investment in the road network formed part of long-term growth policies in the US under the Dwight D. Eisenhower System of Interstate and Defence Highways, which was launched in 1956 and led to over 80 000 miles of highways by 1980 (Federal Highway Administration, 1976). In 1998, the Transportation Equity Act was signed, assigning US$203 billion to improve the national highway infrastructure. Of this amount, US$176 billion were allocated for highway construction (cf. Chandra and Thompson, 2000).

The European Council of October 2003 called on Member States to "...promote investment in networks and knowledge." It highlighted "*the importance of speeding up the roll-out of European transport, energy and electronic communications networks and of increasing investment in human capital. These are crucial steps to boost growth, better integrate an enlarged Europe and improve the productivity and competitiveness of European businesses on global markets* (Commission of the European Communities, 2003)." The Community budget contributes 700 million euros annually to fund up to 10 per cent of Trans-European Network (TEN) projects. The Structural Funds are foreseen to provide 29.2 billion euros for transport infrastructure, Cohesion fund resources can mobilise up to 1.5 billion euros per year for infrastructure investment. Furthermore, the Commission is considering setting up an innovative Guarantee Instrument to facilitate private sector funding in PPPs for TEN transport projects. The European Investment Bank supports the Growth Initiative with a 50 billion euro TEN Investment Facility to be allocated to TEN's priority projects. In addition, the EIB reinforces its financing capacity under the Structured Finance Facility which, *inter alia*, supports the TEN projects. On the national level, transport infrastructure investment is considered to be of equal importance to increase economic growth.

The strong role assigned to transport infrastructure investment as a vehicle for economic growth appears to be worth critical examination for at least two reasons:

There is no strong growth theory foundation for the hypothesis that an increase in transport infrastructure investment would lead to an immediate and lasting increase in *growth rates* of economic activity. Rather, according to the exogenous growth theory, an increase in the investment rate (which does not necessarily result from an increase in transport infrastructure investment) leads to an increase in the income *level* (Barro and Sala-i-Martin, 1995). Some variants of endogenous growth theory do provide a link between transport infrastructure investment and growth rates. The link is established by the effects of transport infrastructure investment on urban form and the size distribution of cities, and the resulting agglomeration economies (Lucas, 1988; Black and Henderson, 1999; Lucas, 2001; Lucas and Rossi-Hansberg, 2002). However, the links from transport infrastructure investment to economic growth are less direct than claimed in public debates, and related arguments are rarely used in policy discussions.

There is no clear, empirical evidence that transport infrastructure investment leads to higher growth or even to a higher level of income. Some authors interpret the strong correlation between public capital and macroeconomic productivity, which was found for the United States of America, as evidence that infrastructure generally provides valuable services to the private sector and that, in particular, the slowdown in US public investment after the early 1970s explains a substantial proportion of the concomitant productivity slowdown[1]. Other authors have argued that public capital is endogenous, in that higher public investment is due to the public sector response to an increased demand for infrastructure services resulting from higher aggregate income[2]. Sectoral and regional disaggregation have led to smaller, positive but more robust effects (see the review in Cohen and Morrison Paul, 2004). A number of studies have looked into issues which complicate the estimation of public infrastructure investment effects, such as the existence of spatial spillovers from public infrastructure investment in geographically linked areas and the temporal dependence of estimated infrastructure effects. Kelejian and Robinson (1997) allowed for spatial lags of dependent and independent variables along with spatial correlation of the error terms. Holtz-Eakin and Schwartz (1995) consider interstate spillovers in a production model based on long lags to accommodate long-run adjustment, and Boarnet (1998) measured cross-county spillovers using a Cobb-Douglas production function approach.

Among the studies which addressed the more specific question of whether road infrastructure investment increased productivity, Carlino and Voith (1992) found that the productivity of US states was higher the greater the density of highways. Holtz-Eakin and Schwartz (1995) could not confirm the strong positive productivity effects of transport infrastructure on the state level. Holtz-Eakin and Lovely (1996) succeeded in relating output growth to the positive effect transport infrastructure investment had on the number of firms in the manufacturing industry, without observing a direct effect on manufacturing productivity.

Within the production function approach, Canning (1999) and Canning and Bennathan (n.d.) have used a different method to solve the problem of the endogeneity of public capital. It is based on the non-stationarity of the data for output per worker and capital stock per worker. This means that the production function may represent a long-run, co-integrating relationship. They use this fact to apply the panel data co-integration methods of Kao and Chiang (2000). Using this method, and the assumption that production functions are identical for all countries, while the relationship between investment and income varies across countries, allows each country in the sample to have its own short-run investment dynamics, to give consistent estimates of the parameters of the production function which are robust to reverse causality.

This paper is related to the study of Fernald (1999). He tried to give an answer to the question of how changes in road stock affected the relative productivity performance of US industries from 1953 to 1989. His argument is based on the hypothesis that if roads contribute to industries' productivity, industries which use roads intensively should benefit more from their expansion. Given the complementarity between vehicle use and road use, and the lack of direct measures for industrial road use, vehicle use is employed as a direct measure of road intensity. The basic result of Fernald's study is that changes in road growth are associated with larger changes in productivity growth in industries which are relatively vehicle-intensive. This finding supports the hypothesis that industries with more than average vehicles benefited more than proportionately from road building. This result, in turn, suggests that the correlation between aggregate productivity and infrastructure reflects causation from changes in road stock to changes in productivity. If roads did not contribute to aggregate productivity at the margin, but governments just built more roads as aggregate income rose, one would not expect any particular relationship between an industry's vehicle intensity and its relative productivity performance when road growth changes. The results do not, however, support the idea that public investment offers a continuing route to increasing income. The US industry data are consistent with the view that the massive road-building of the 1950s and 60s offered a one-off boost to the level of productivity, rather than an instrument to continuing rapid growth in productivity.

In this paper a similar approach is taken. We distinguish the western European countries by their transport intensity, as well as their use of labour and capital. The next section sets out the conceptual framework for the empirical analysis. Section three explains some data and econometric issues, and the results of the empirical analysis are presented in section four. In section five we make some concluding remarks.

2. THE MODEL

In this section we develop the background of the estimation equation. We formalize the notion that countries which have relatively transport-intensive industries benefit more than countries with a relatively low transport intensity from an increase in road infrastructure investment. We consider a set of *n* countries. The growth accounting with road infrastructure starts out from national production functions. For each country *i*, the production of gross output Q_i, depends on non-transport capital stock K_i, employment L_i and transport services T_i. Output also depends on the economy's technological level U_i, which is assumed to progress in a Hicks-neutral way. Transport services depend on the services of road stock G_i as well as the national stock of transport equipment V_i. Omitting time subscripts, we have the following national production functions:

$$Q_i = U_i F^i\left(K_i, H_i, L_i, T[G_i, V_i]\right) \qquad (1)$$

for i = 1,…,n.

Equation (1) represents the gross production function of the representative firm using the primary inputs, capital *K*, labour *L* and transport services *T*, as the only intermediate input. The transport services are produced using road services *G* and the services of the vehicle stock *V*. The firms do not choose input *G* but the number of vehicles, which is *V*.

Taking logarithms of (1) and forming the total differential, we obtain:

$$\frac{dQ}{Q} = \frac{dU}{U} + \frac{1}{F}\left(F_K dK + F_L dL. + F_T T_V dV + F_T T_G dG\right), \text{ or} \qquad (2)$$

$$\frac{dQ}{Q} = \frac{dU}{U} + \frac{F_K K}{F}\frac{dK}{K} + \frac{F_L L}{F}\frac{dL}{L} + \frac{F_V V}{F}\frac{dV}{V} + \frac{F_G G}{F}\frac{dG}{G}. \qquad (3)$$

F_j denotes the derivative of the production function with respect to input *j*, while the coefficients $\frac{F_J J}{F}$ indicate production elasticities, i.e. the percentage increase of gross output if the input *J* is increased by one per cent. Firms do not take input decisions with respect to road services. However, input decisions with respect to vehicles are not independent of the road services provided by the existing road capital stock. The output elasticity with respect to road services can be expressed relative to the elasticity with respect to vehicles:

$$\frac{F_G G}{F} = \left(\frac{\frac{F_G G}{F}}{\frac{F_V V}{F}}\right)\cdot\left(\frac{F_V V}{F}\right) = \phi\cdot\left(\frac{F_V V}{F}\right) \qquad (4)$$

The parameter ϕ equals the ratio of output elasticities of roads and vehicles. The production elasticity of vehicles measures the transport elasticity of the national economy. Hence the parameter links the observed transport intensity of the economy to the indirect input road use. We expect ϕ to be positive, i.e. we expect economies which are relatively transport-intensive to be relatively road-intensive. Due to the separability assumption implicit in (1), ϕ also equals the ratio of the elasticities with respect to *G* and *V* in producing transport:

$$\phi_i = \frac{T_G G_i}{T_V V_i} \tag{5}$$

The formal derivation of the estimation equation and the interpretation of results are now greatly simplified by assuming that the ϕ_i are identical for all countries *i*, that is, we assume that the function for transport services T has the form of a Cobb-Douglas function. Assuming that the manufacturing

industries of all countries are price-takers in factor markets, cost minimization implies that the production elasticities can be interpreted as factor shares and the shares of intermediate goods in the value of gross production. Denoting the share of factor *j* in gross output of country *i* by:

$$s_{ij} = \frac{\partial F^i}{\partial J_i} \cdot \frac{J_i}{F^i} = \frac{F_j^{\,i} J_i}{F^i}\,, \tag{6}$$

adding country subscript i; we can then rewrite (3) by:

$$\frac{dQ_i}{Q_i} = \frac{dU_i}{U_i} + s_{Ki}\frac{dK_i}{K_i} + s_{Li}\frac{dL_i}{L_i} + s_{Vi}\frac{dV_i}{V_i} + \phi \cdot s_{Vi}\frac{dG_i}{G_i}\,. \tag{7}$$

To express the productivity increase as the Solow residual, i.e. as the increase in *value added* minus the contributions of the private factors of production, we have to take account of the following identity:

$$\frac{dQ}{Q} = \frac{dY}{Y}(1 - s_I) - \frac{s_I}{1 - s_I}\frac{dI}{I} \tag{8}$$

where Y denotes value added, I real intermediate goods and s_I the share of nominal inputs of intermediate goods I in the value of gross output[3].

We then have, as the expression for the Solow residual:

$$\frac{d\rho}{\rho} = \frac{dY}{Y} - s_K^*\frac{dK}{K} - s_L^*\frac{dL}{L} - s_V^*\frac{dV}{V} \tag{9}$$

with $s_j^* = s_j(1/(1-s_I))$ denoting the share of factor *j* in value added. Given (7) we have for country *i*:

$$\frac{d\rho_i}{\rho_i} = \phi s_{Vi}^* \frac{dG_i}{G_i} + \frac{dU_i^*}{U_i^*} \tag{10}$$

In other words, the observed growth in productivity is the sum of the technology shock in terms of value added and the percentage increase in production which is due to the relative increase in road services.

The road services enjoyed by country *i* do not only depend on the road investment in country *i* but also on:

the road services and road investment on the trading partners' territory, depending on trade intensities and the transport intensities of the bilateral goods trade[4];

congestion in the individual countries, which determines the level of road services provided by national road stocks.

To account for bilateral trade, the road service consumed by country *i* is defined as its own and the trading partners' road stock multiplied with the share of domestic consumption and the share of bilateral exports in the value added of country *i*:

$$\frac{dG_i}{G_i} = \frac{dg^i}{g^i} + \sum_{J=1}^{N} \frac{e_{ij}}{Y_i} \frac{dg^j}{g^j} \text{, for } i \neq j = 1,\ldots, \text{N} \tag{11}$$

Road services do not only depend on the stock of road capital but also on collective road use or, more specifically, on congestion. To account for congestion, the national road service supply g^i is defined as the real road stock value divided by the number of vehicles registered in country *i*. By measuring congestion in this way we implicitly assume that car usage does not change much over time or, in particular, that it does not go down. By dividing road stock by the number of vehicles we adopt the assumption of Barro and Sala-i-Martin (1995) and Mankiw (1992). With this specification, any individual producer takes road use by others as given.

With (10) as the estimation equation, there is still the problem of endogeneity. If reverse causality and public investment depended on aggregate income rather than the other way around, then country productivity shocks would affect road growth. To address the endogeneity problem, we consider the following regression breakdown:

$$\frac{dU_i^*}{U_i^*} = \frac{d\bar{U}^*}{\bar{U}^*} + \varepsilon_i \tag{12}$$

with $\bar{U}$ denoting the overall shock of the group of countries. The residuals ε_i of equation (12) are, by construction, orthogonal to the national productivity shocks and hence to the changes in national government expenditure on transport infrastructure. The Solow residual for the country group as a whole is defined as:

$$\frac{d\bar{\rho}}{\bar{\rho}} = \phi s_{\bar{V}}^* \frac{dG}{G} + \frac{d\bar{U}^*}{\bar{U}^*} \tag{13}$$

where G denotes the overall growth of road services, i.e. the ratio of real road stock to the number of vehicles and $s_{\bar{V}}$ is the share of vehicle cost in nominal value added.

Both Solow residuals, for the country group and the individual countries, are computed as Törnquist indices of value added growth. That is, the discrete changes in productivity are expressed as:

$$\begin{aligned}\ln(\rho_t) - \ln(\rho_{t-1}) = \ln(Y_t) - \ln(Y_{t-1}) - 1/2\left(s_{Kt}^* - s_{Kt-1}^*\right)\left(\ln(K_t) - \ln(K_{t-1})\right) \\ -1/2\left(s_{Lt}^* - s_{Lt-1}^*\right)\left(\ln(L_t) - \ln(L_{t-1})\right) \\ -1/2\left(s_{Vt}^* - s_{Vt-1}^*\right)\left(\ln(V_t) - \ln(V_{t-1})\right)\end{aligned} \tag{14}$$

To derive the estimation equation and substituting for the overall productivity shock, we have:

$$\frac{dU_i^*}{U_i^*} = \frac{d\bar{\rho}}{\bar{\rho}} - \phi s_{\bar{V}}^* \frac{dG}{G} + \varepsilon_i \tag{15}$$

The expression for the national growth rate of productivity is then:

$$\frac{d\rho_i}{\rho_i} = \phi s^*_{Vi} \frac{dG_i}{G_i} + \frac{d\bar{\rho}}{\bar{\rho}} - \phi s^*_{\bar{V}} \frac{dG}{G} + \varepsilon_i \tag{16}$$

and we have:

$$\frac{d\rho_i}{\rho_i} - \frac{d\bar{\rho}}{\bar{\rho}} = \phi s^*_{Vi} \frac{dG_i}{G_i} - \phi s^*_{\bar{V}} \frac{dG}{G} + \varepsilon_i = \phi\left(s^*_{Vi} s^g_i - s^*_{\bar{V}} \right) \frac{dG}{G} + \varepsilon_i \tag{17}$$

where s^g_i denotes the share of road services of country *i* in total road services of the country group.

The left-hand side of (17), the difference between the national growth in productivity and the productivity growth of the country group, is positive if country *i* has a higher productivity increase than average. The share of G_i in G, i.e. s^g_i, is higher, the higher the road stock of country *i* relative to the road stock of the country group and/or the higher the trade intensity of country *i*. If road infrastructure investment is productive, we would expect countries with an above-average road stock and an above-average vehicle intensity to benefit more than average from investment in road stock. Therefore, we would expect ϕ to be positive. Recall that ϕ equals the ratio of output elasticities of roads and vehicles, linking observed decisions on investment in vehicles to unobserved road use. A positive ϕ then captures the idea that vehicle-intensive countries are, or should also be, more road-intensive.

3. DATA AND ECONOMETRIC ISSUES

The empirical analysis includes western European countries for which data on all the variables involved are available. The largest gaps in the data were found for transport infrastructure investment, and for the real value of vehicle stock. The countries in the sample are Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom.

A major part of the data used were taken from the OECD's STAN (Structural Analysis) database (OECD, 2004e). This holds for gross production figures, for value added, gross capital stock figures and the data on labour compensation. The employment figures in terms of hours worked have been taken from the OECD Productivity database (OECD, 2004d). The changes in vehicle stock were computed from the STAN figures on the production of motor vehicles, trailers and semi-trailers, subtracting exports and adding imports. The vehicle stock figures were calculated by applying the permanent inventory method and using the depreciation rate of 25.37 per cent proposed by Joergensen and Yun (1991). The long-term interest rate reported in the OECD Outlook (OECD, 2004c) is used as the required rate of return on capital. Lacking information on the relevant taxes and subsidies, the user cost of capital is approximated by the sum of the discount rate and the required rate on return to capital. The total cost of vehicle capital divided by nominal value added gives the share of the vehicle capital cost in value added which is used to compute the Törnquist index of productivity growth. Nominal figures have been deflated using the deflator for private capital investment provided by the OECD Economic Outlook (OECD, 2004c).

Very few ECMT member countries provide data on transport infrastructure stocks. The road stock figures are computed by applying the permanent inventory method to the ECMT data (ECMT, 2004b) on transport infrastructure investment. Following Boskin *et al.* (1991), it is assumed that roads depreciate geometrically at a rate of 1.98 per cent per year. Constant national currency values for road stock are calculated by using the deflator for government investment, reported in the OECD Economic Outlook (OECD, 2004c). As mentioned above, the variable "road services" takes account of international trade relations and congestion. Bilateral trade coefficients are based on the bilateral trade data provided by the STAN Bilateral Trade Data Base (OECD, 2004a, 2004b)[5]. Congestion is depicted by dividing the constant currency value of road stock by the number of vehicles. The data on the number of vehicles are collected in the ECMT Statistical Report on Road Accidents (ECMT, 2004a).

Wherever absolute national currency values have had to be added up or compared, they have been made commensurable by using the PPP conversion factors of the OECD Economic Outlook (OECD, 2004c).

4. RESULTS

For all the countries in the sample, the Toernquist index of productivity increased during the period from 1975 to 2000 (see Figure 1), Portugal, Finland and Sweden having the greatest overall increase of total factor productivity. The increase in the index was highly volatile, but decreased on average over the whole period, as can be seen from Figure 2.

The transport infrastructure investment data show that the absolute numbers for transport infrastructure investment, and road infrastructure in particular, are highly volatile. They do, however, show a continuous increase in road stock which is, however, unable to keep pace with GDP growth. That is, the share of transport infrastructure investment in GDP is secularly decreasing for the western European countries. For road stock, this implies continuous growth, as shown by Figure 3, but at substantially decreasing rates (see Figure 4).

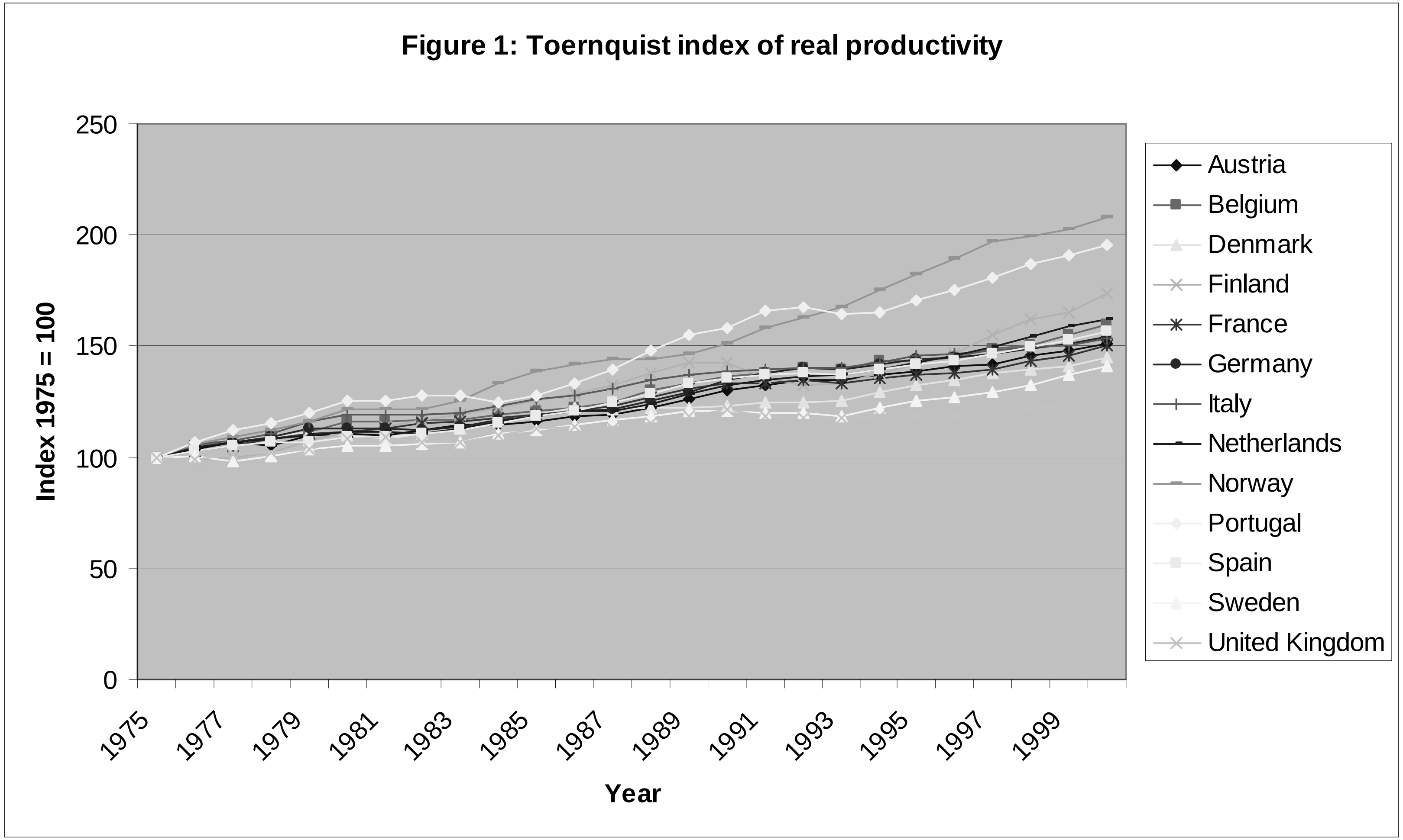


Figure 1: Toernquist index of real productivity
Index 1975 = 100
250
200
150
100
50
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year
Austria
Belgium
Denmark
Finland
France
Germany
Italy
Netherlands
Norway
Portugal
Spain
Sweden
United Kingdom

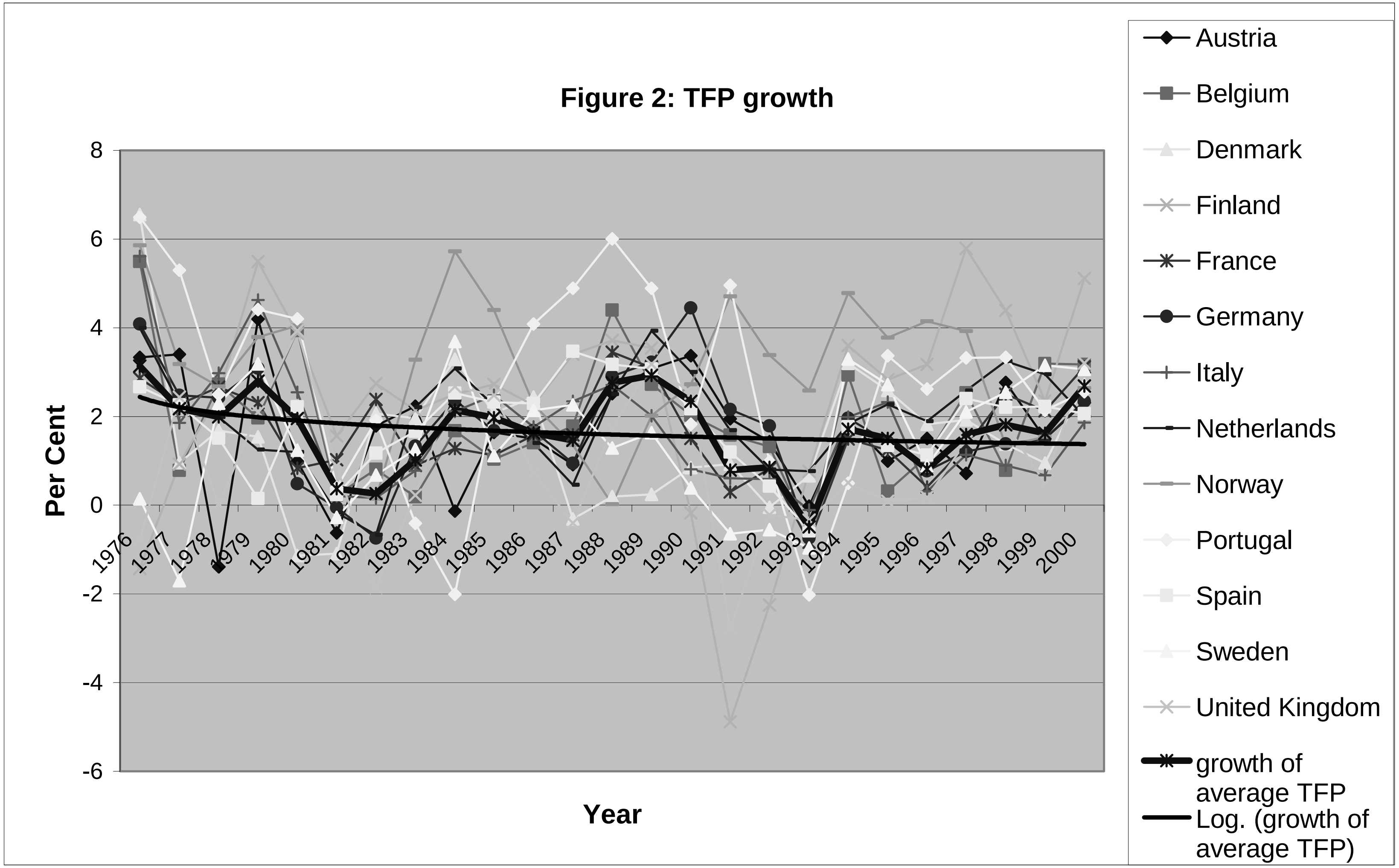


Figure 2: TFP growth
Per Cent
8
6
4
2
0
-2
-4
-6
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year
Austria
Belgium
Denmark
Finland
France
Germany
Italy
Netherlands
Norway
Portugal
Spain
Sweden
United Kingdom
growth of average TFP
Log. (growth of average TFP)

Figure3: Road stock in 1975 international dollars

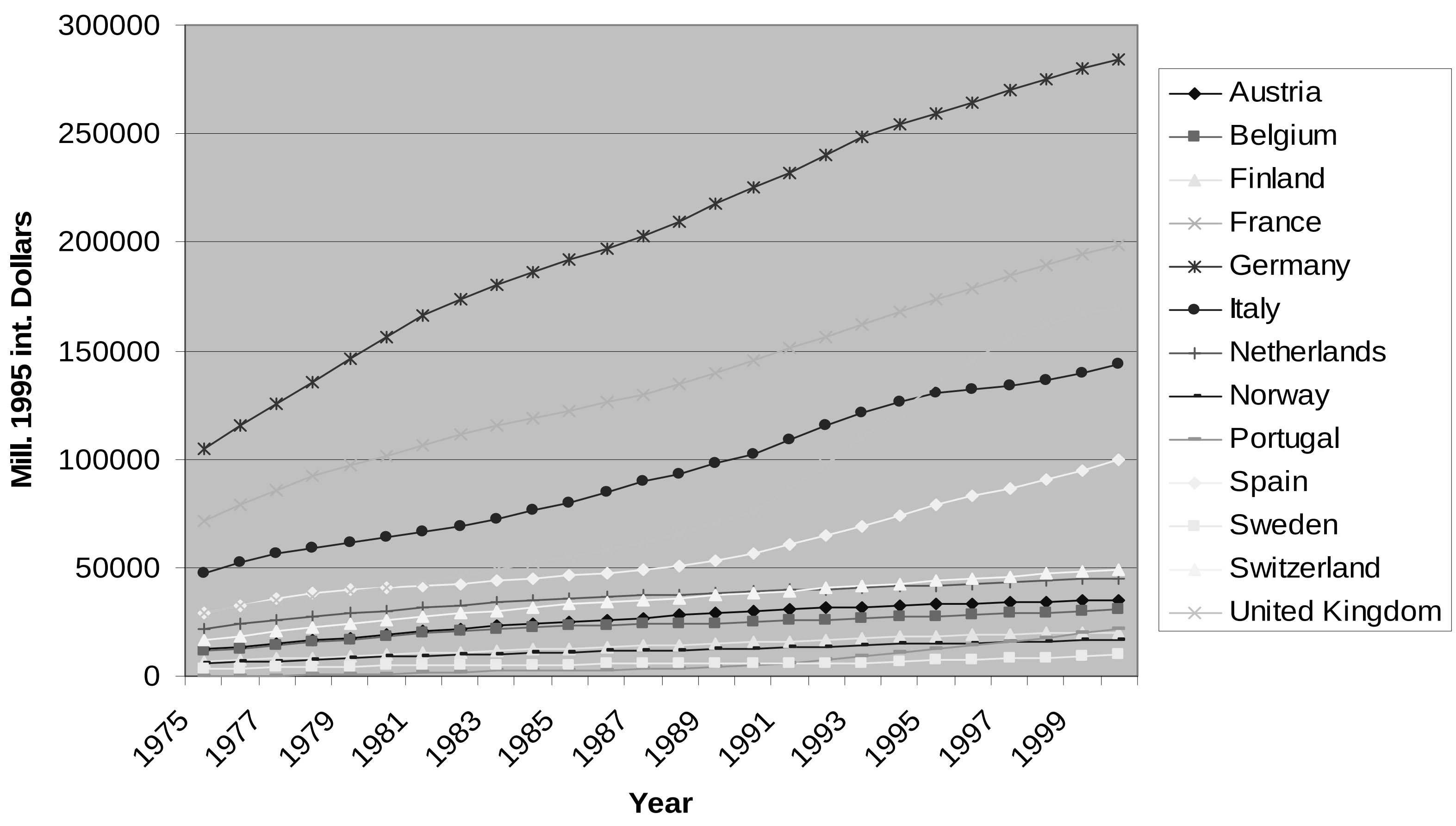
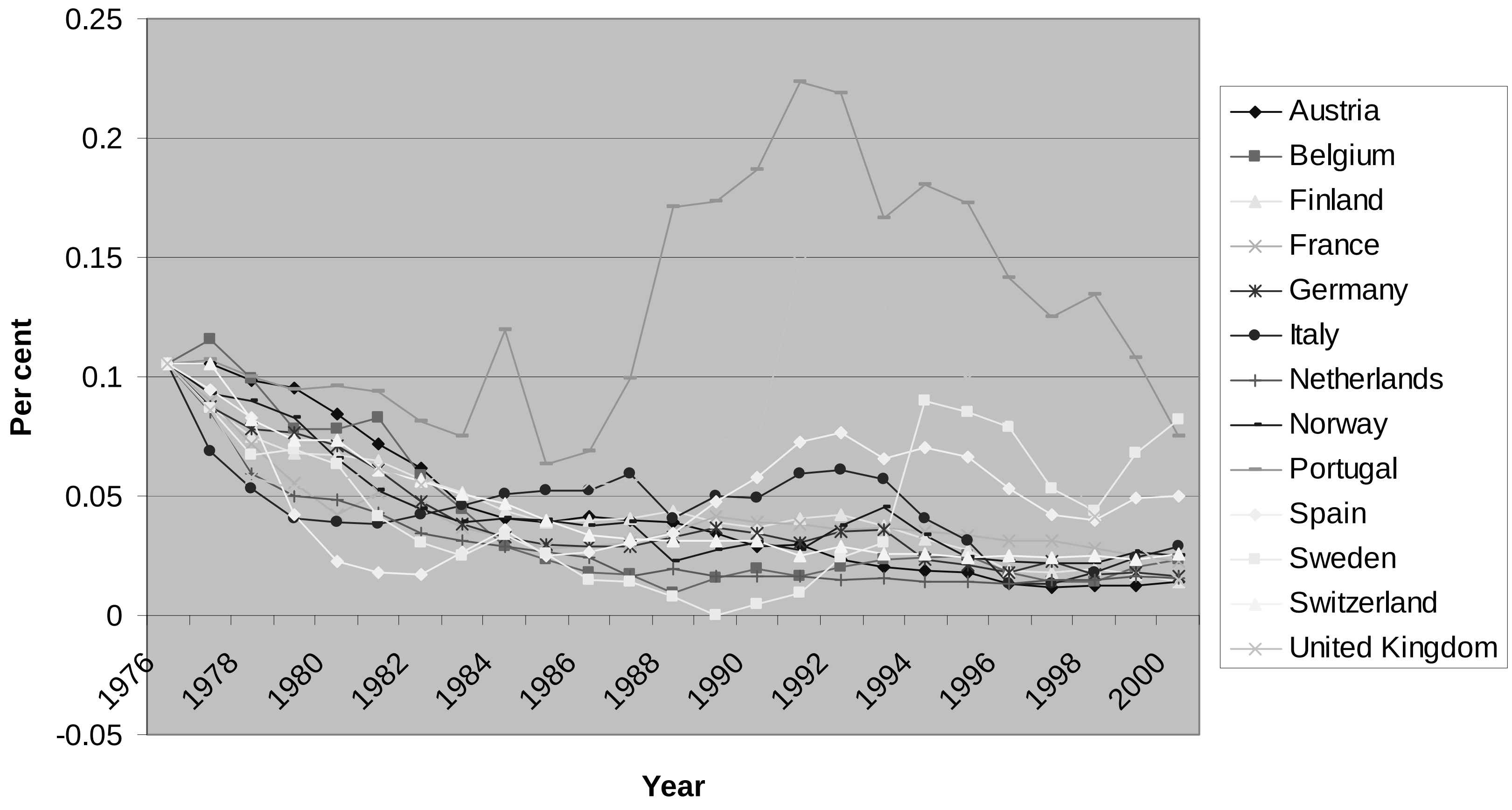


Figure 4: Growth rates of capital stock



We estimate the relationship between the growth of road services and the change in the Toernquist index by using a fixed-effects model. That is, we allow for country-specific, unobserved characteristics influencing the relationship between road infrastructure investment and macroeconomic productivity effects, which are assumed to be constant over time.

Estimating the difference between national productivity growth and productivity growth as a function of the product of national vehicle intensity and national road services, and the product of overall vehicle intensity and overall road services, we obtain the results given in Table 1.

Table 1. **Fixed effects regression 1,**
Independent variables for national and international road stock

Number of obs. = 300

difftfp	**Coefficient**	**Standard Error**	**t**	**P > $\|t\|$**	**95 p.c. Confidence Interval**
prod1	.7143729	.1921074	3.72	0.000	.3362493 1.092497
prod2	-2.478365	.49504	-5.01	0.000	-3.452749 -1.503981
constant	.2947857	.0294078	10.02	0.000	.2369025 .352669

R-sq: within = 0.0882
between = 0.0266
overall = 0.0458
F test that all $u_i = 0$: $F(11,286) = 53.41$ $Prob > F = 0.0000$

The table shows difftfp as the independent variable, and prod1 and prod2 as the explanatory variables, the estimation coefficients of the latter, the t values, the P values and the 95 per cent confidence interval. The table shows that the estimation coefficients have the expected signs, i.e. ϕ is positive, as the coefficient of the product of the national vehicle share and the national road services is positive, and negative for the product of the overall vehicle share and the overall road stock. An increase in national road services by investment in national road infrastructure improves, *ceteris paribus*, national productivity growth relative to the productivity growth of the country group. All coefficients are highly significant and the F-test shows desired results. However, as can be seen from the reported coefficients, the share in the variation of productivity growth explained by road investment is very low.

Estimating the difference in productivity growth on the national and country group levels as a function of the difference between the products of vehicle shares and road services on the national and international levels, does not change, as can be seen from Table 2, affect the fundamental results. ϕ, the ratio of production elasticities of road stock and vehicle stock, remains positive. The significance of the estimation coefficient is, however, slightly decreased and the regression coefficients are even worse than in the first model.

Table 2. Fixed effects regression 2,

Difference between vehicle share weighted national and international road stock

Number of obs. = 300

difftfp	**Coefficient**	**Standard Error**	**t**	**P > $\|t\|$**	**95 p.c. Confidence Interval**
diffprod	.6563709	.1964768	3.34	0.001	.2696527 1.043089
constant	.2159342	.0223437	9.66	0.000	.1719559 .2599126

R-sq: within = 0.0374
between = 0.0266
overall = 0.0282
F test that all $u_i = 0$: $F(11,287) = 50.81$ $Prob > F = 0.0000$

The third estimation model adds a time dummy to estimation model 2. This improves the performance of the estimate in that the statistical significance of the estimated ϕ is improved and the regression coefficients are increased. The low coefficient for the time variable suggests that there is no problem of spurious correlation, due to the independent and dependent variables following the same time trend.

Table 3. Fixed effects regression 3,

Difference of vehicle share weighted national and international road stock and year dummy

Number of obs. = 300

difftfp	Coefficient	Standard Error	t	P > $\|t\|$	95 p.c. Confidence Interval
diffprod	.7982335	.1919924	4.16	0.000	.4203362 1.176131
year	.0139947	.0029731	4.71	0.000	.0081427 .0198466
constant	-27.6085	5.911197	-4.67	0.000	-39.24347 -15.97353

R-sq: within = 0.1066
between = 0.0266
overall = 0.0528
F test that all $u_i = 0$: $F(11,286) = 54.46$ $Prob > F = 0.0000$

5. CONCLUDING REMARKS

This paper has argued that investment in road infrastructure indeed has positive macroeconomic productivity effects. The results of the paper do not, however, justify a general conclusion that national road infrastructure investment levels should be increased.

The rate of return implied by the above analysis does not seem to be high (for many countries around 5 per cent)[6]. A relatively low rate of return might not necessarily be due to too high a level of investment but could be due to a misallocation at the local level. As demand for transport services is highly unequally distributed over space and even over time, local road infrastructure investment projects might have high expected rates of return, even if the overall implied rate of return is low.

The greater income that can be achieved with the given resources may be associated with greater external costs, in particular in the form of environmental damage. On the other hand, the underprovision of transport infrastructure services leads to external costs in the form of time costs, which are not reflected in the national accounts data used here. While it is certainly true that GDP is an imperfect welfare measure, further research is required to identify how the impact of transport infrastructure on income differs from the impact on welfare.

An analysis such as the above can, however, give a broad indication as to an appropriate level of infrastructure investment, at least based on the hypothetical assumption that the assignment of investment resources to individual projects is rational. To link the above macroeconomic analysis to planning tools to allocate regional infrastructure resources and cost-benefit analysis at the project level is a matter of future research.

NOTES

1. Aschauer (1989, 1990) started the discussion on the productivity effects of public investment. His finding of large positive productivity effects being caused by public investment has been confirmed by Munnel (1990, 1992), Nadiri and Manuneas (1994), Kocherlakota and Yi (1996a), Morrison and Schwartz (1996b) as well as Duggal *et al*. (1999a).

2. See, for example, Aaron (1990), Hulten and Schwab (1991), Holtz-Eakin (1994) as well as Sturm and de Haan (1995).

3. On measuring the productivity increase by the Solow residual, see Hall (1990) and the discussion in Basu and Fernald (1997).
4. On the implications of international trade for the incentives to invest in transport infrastructure, cf. Bougheas *et al.* (2003).

5. Road investments might have an impact on the trade coefficients. Given the resulting concern about the potential endogeneity of the weights, the average values for the sample period are used. In this we follow an approach proposed by Case *et al.* They provide the argument that, when using average values over several years for the weights, the weights and the explanatory values are orthogonal. Thus the introduction of the weights does not lead to a correlation of the independent variables and the residuals.

6. It is calculated by multiplying the share of vehicle capital costs in value added by the ratio of value added to the value of road stock, and multiplying this product by ϕ.

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