Institut für
Volkswirtschaftslehre
und Statistik

No. 564-99

Competition in Transportation Modes and the Provision of Infrastructure Services

Klaus Conrad

Beiträge zur
angewandten
Wirtschaftsforschung

Universität Mannheim
A5, 6
D-68131 Mannheim

Competition in Transportation Modes and the Provision of Infrastructure Services

Klaus Conrad

Mannheim University

Abstract

The purpose of this paper is to model competition in freight transport and to work out the role of the government in providing infrastructure for the competitors. Freight transport could in principle be provided by the firm itself by using firm-owned trucks or transportation services could be outsourced by purchasing these services from rail and/or truck transport firms. We link production in the rest of the economy to transport demand, provided by two competing modes of transport. Since congestion is an increasing cost component in densely populated countries, we develop an index of congestion which can be controlled by investing in highway infrastructure. Given infrastructure, a fuel tax and the stock of vehicles, we first derive the conditional demand functions of the economy for truck and rail services. The two transport firms know these demand functions and compete in prices. We then propose a transportation policy which chooses two types of infrastructure, highways and the railway system, and a fuel tax in order to maximize welfare. The economic aspects for an optimal provision of the two types of infrastructure can be expressed by a set of unknown elasticities which measure the impact of infrastructure services on price and quantity variables in transport industries. With time series data for the German economy we measure these impacts on prices in the rail and truck industries, on the volume of transport, on congestion, and on the utilization of the stock of transportation equipment.

Key words

Infrastructure, congestion, railroads and trucks transportation, price competition

JEL classification

H 54, L 13, L 92, R 41

Klaus Conrad
Department of Economics
Mannheim University
Seminargebäude A5
D-68131 Mannheim
Phone: +49 621 292 5121
Fax: +49 621 292 3185
e-mail: kconrad@rumms.uni-mannheim.de

Competition in Transportation Modes and the Provision of Infrastructure Services

Klaus Conrad
Mannheim University

1. Introduction

The purpose of this paper is to set up a model which analyzes competition in the input market "traffic and transportation". A partial equilibrium model for the transport market is described that allows to analyze and optimize simultaneously transport dimensions of pricing and of provision of road and railway infrastructure. The emphasis is more on future competition given the liberalization and deregulation of this market in the EU. It is expected that price competition between different modes of transportation will increase. However, transportation by truck is hampered by insufficient infrastructure in highways and roads experienced every day by traffic congestion. On the other side, the steady increase in air pollution from truck transport curtails any incentive to extend the highway system. Although the railway is an environmentally friendly substitute, its problem is that it is heavily indebted and requires a fundamental reorganization in order to be a stable and serious competitor to the truck industry. Forecasts report a growth in freight transport by 40 per cent in Central Europe up to the year 2010, but for the railway such an outlook is only partly favorable because its competitors are professionals, well organized in small and efficient firms in the truck transportation business whereas the railway has only made first steps in the last years to become a profit maximizing company.

A detailed model of competition in traffic modes has to take into account the new organizational structure of the railway in terms of three subdivisions – passengers, freight, and the railway system. In passenger transport, a distinction in long-distance and short-distance traffic is necessary because competitors are different. In the freight transport, the competitors are the truck industry, transport by ship or airline, and trucks owned by firms in the manufacturing industry. The railway, a natural monopolist if seen from the cost side, has a huge fixed cost bloc which consists of the railway system, stations, tunnels and bridges. In the German reorganization of the railway, a new subdivision is responsible for investment in and care of this system and for marketing its services to suppliers of passenger and freight transport. In this paper we treat this subdivision as a public agency which invests in railway infrastructure and which charges user costs for the services from it. From 1994 on, all firms which want to be engaged in the railway transport business can use it by paying fees.

The goal of the railway firm to gain market shares in transport can only be realized if quality and price of its main input, the railway system, raises its competitive position. We assume that decisions of this new federal railway system agency are not made independently from those of a public highway authority which decides on the length and quality of road infrastructure. This means that the transport policy is considered to be a simultaneous decision process which provides infrastructure for both competitors. Competition is in freight transport and also with trucks owned by firms. They can either outsource those services or can purchase inputs to produce these services within the firm.

The literature on intermodal competition analyzes the second-best pricing and infrastructure investment rules in the presence of exogenous price distortions and financing constraints. Braeutigam (1979) deals with optimal pricing in regulated firms and concentrates on the interactions among rail, motor, and water carriers. As rail is characterized by economies of scale, its profits would be negative if its services were all priced at marginal cost. He therefore investigated an optimal departure from marginal cost pricing. Since we consider the period after deregulation, in our paper the rail rents the services from a railway system firm and competes with other modes in order to make non-negative profits. On the background of historical price distortion in the rail and trucking industries, Friedlaender and Mathur (1982) are interested in the optimal provision of infrastructure. For determining its optimal level, the first-best rule is an equalization of marginal investment benefits and costs. However, in the presence of institutional constraints that prevent prices from being set according to first-best rules, the optimal investment rules must be modified accordingly, and second-best investment rules will be related to the nature of the existing price distortions. They analyze the second-best structure of input and output taxes and of investment rules in the context of the distortions with specific emphasis on the role of intermodal competition and input taxes. The government provides the transportation infrastructure for all modes which is used by the private sector to produce freight services. In Nilsson (1992) insufficient pricing of road traffic externalities results in over-use of trucks. He therefore adjusts the split of transport assignments between road traffic and rail by rail-user fees below their first-best optimal level in order to offset the over-use of trucks. Prices below marginal costs do, however, result in a larger volume of transport than would be optimal. The consequence of this pricing policy is that investment in both modes has to be contracted.

In our paper the analysis of the structure of investment rules and input taxes is done in two stages as in Friedlaender and Mathur (henceforce FM) and in Nilsson. Each mode is assumed to maximize profits, taken as exogenous a fuel tax and the level of infrastructure determined by the government. Contrary to FM and Nilsson we assume price competition and determine the Nash solution for output prices and the factor demands as functions of the policy variables. At the second stage the government determines the levels of infrastructure in order to maximize social welfare. Whereas FM and Nilsson assume that price and output changes in the transportation sector do not cause price changes throughout the economy, we follow a different approach. We model transportation as an input for the rest of the economy. The cost of this input affects consumers' and producers' surplus in that economy. The government is therefore not concerned about consumer surplus in the transportation industry but about profits in that industry and about consumer and producer surplus in the rest of the economy. Furthermore, cross-market effects, produced by variations in the two types of infrastructure, have been suppressed by Nilsson but will be in the center of our analysis. One of our objective is to formalize the industrial organization structure of this market in a manner relevant for a transport policy analysis after deregulation. We finally have introduced congestion which increases the cost of road transport for the economy. Congestion is endogenous in our approach because investment in highways will reduce this negative externality.

The paper is organized as follows. In section 2 we set up a model of production for the rest of the economy with transportation as an input. In section 3 we model price competition between the two modes of transportation. In section 4 the government maximizes welfare of the economy choosing as instruments infrastructure investments for road and rail and the fuel tax for pricing negative externalities. In section 5 we specify cost functions for the transport industries and for the rest of the economy for a parametric characterization of the input market. The results of this empirical analysis are used in section 6 for a regression analysis in order to test economic aspects which influence the levels of infrastructure services. Section 7 concludes the paper.

2. Transportation as an input for the economy

We begin with the economy, transport modes excluded, which we denote by manufacturing. It produces its output by using, besides conventional inputs like labor and material, three transport inputs, namely commercial trucks (T_1), railway (T_2) and a business owned capital stock of trucks (KZ). Aggregate transport T is produced by a sub-production function

$$(1) \qquad T = T(T_1, T_2, F, KZ)$$

where F is fuel. KZ is related to an utilized stock of vehicles (K), but has been downward adjusted by an index of congestion $Z \geq 1$.[1] We specify KZ, the effective stock, as

$$(2) \qquad KZ = K \cdot Z^{-\gamma} \qquad \gamma \geq 0 .$$

Utilized K depends on the stock of trucks (K^0) in the rest of the economy as well as on the availability of infrastructure KI. We express this relation by

$$(3) \qquad K = K^0 \exp\left(\frac{-\alpha}{KI}\right) \qquad \alpha > 0$$

where $KI \to \infty$ implies a full utilization of the stock K^0.

Since we assume that K^0 and KI are fix in the short run, the variable cost function for transport is:

$$(4) \qquad CT = CT(T, p_1, p_2, p_F, KZ)$$

where p_1, p_2, and p_F are the input prices for truck services, rail and for fuel. It is

$$(5) \qquad \frac{\partial\, CT}{\partial\, KZ} < 0 , \quad \frac{\partial\, CT}{\partial\, K} < 0 \qquad and \qquad \frac{\partial\, CT}{\partial\, Z} > 0 .$$

The unit cost function for the intermediate good ‘transport’ is:

$$(6) \qquad PT = \frac{CT(\cdot)}{T} + \frac{PK \cdot K}{T}$$

where PK is the user cost of the services from K. We assume that part of the fuel costs are

[1] We give in section 5 a definition of congestion Z (see (46)).

directly related to the use of *K* and define *PK* as

(7) $$PK = PK^0\ (r+\delta)+(p_F+t_F)\cdot\gamma_F$$

PK^0 is the price of a truck, *r* is the rate of return on risk-free government bonds, and δ is the rate of replacement. The complementary fuel input comes from decomposing fuel consumption into a part, proportional to the utilized stock of vehicles with a factor γ_F, and a wasted part $\widetilde{F}$, which can be reduced by less congestion and more infrastructure investment (highways):

(8) $$F = \gamma_F\cdot K + \widetilde{F}.$$

The specification of transport in (1) represents the aspect that manufacturing can either use its own stock of vehicle, given congestion *Z* and infrastructure *KI*, or it can totally or partly outsource this activity by buying the transport services from the truck industry or from the railway company.

The manufacturing company maximizes profit under perfect competition:

(9) $$\max_x \quad p\cdot x - C(x,PT)$$

where *x* is output. Except for the price of transport *PT*, defined in (6), we have suppressed all other input prices. The FOC is

(10) $$p = C_x.$$

The impact of *KI* on output can be derived from total differentiation:

(11) $$\frac{d\,x}{d\,KI} = -\frac{T_x}{C_{xx}}\ \frac{d\,PT}{d\,KI} > 0$$

because of $\dfrac{d\,PT}{d\,KI} < 0$ and

(12) $$T = C_{PT} = T(x,PT)$$

as the derived transport demand of manufacturing. In addition, the conditional demand functions for the inputs T_1 and T_2, provided by trucks and by rail, can be derived from the cost function $C(x, PT)$ by Shephard's Lemma:

$$T_i = C_{PT} \cdot PT_{p_i} = T \cdot PT_{p_i} = T(x, PT) \cdot PT_{p_i}\ (T, p_1, p_2, p_F + t_F, KZ, K)$$

or

(13) $$T_i = T_i(T, p_1, p_2, p_F + t_F, KZ, K)$$

Prices of the transport modes, fuel prices, firms' stock of trucks, congestion and the transport volume affect the demand for the transport modes.

3. Price competition between trucks and the railway

We have derived in section 2 manufacturing's input demand functions $T_i(\cdot)$ for two transport services. They are provided by two transport firms which compete in prices. The problem of the truck firm is

(14) $$\max_{p_1} \quad \Pi_1 = p_1 \cdot T_1(\cdot) - C_1(T_1(\cdot), p_F, KZ_1) - PK_1 \cdot K_1$$

where the cost function depends on $KZ_1 = K_1 \cdot Z^{-\gamma}$ with K_1 as the service flow from the stock of trucks K_1^0. The interpretations given in (2), (3) and (5) are the same here. This holds also for (7) and (8) with respect to PK_1 and F_1. The problem of the railway company is:

(15) $$\max_{p_2} \quad \Pi_2 = p_2 \cdot T_2(\cdot) - C_2(T_2(\cdot), p_E, K_2) - PK_2 \cdot K_2$$

where p_E is the price of electricity and K_2 the service flow from the stock of capital (producers' durables) owned by the railway industry. Its effectiveness depends on the size of the railway system KR provided by the government. Similar to (3) we assume the relationship $K_2 = K_2^0 \exp\left(-\frac{\alpha_2}{KR}\right)$, where K_2^0 is the stock of trains ($\alpha_2 > 0$).

The FOC as implicit reaction functions in the prices are

(16) $$T_i + p_i \frac{\partial T_i}{\partial p_i} - C_{i,T_i} \frac{\partial T_i}{\partial p_i} = 0$$

or

(17) $$p_i - MC_i = -\frac{p_i}{\varepsilon_{T_i,p_i}} \quad , \qquad i = 1,2$$

where $$\varepsilon_{T_i,p_i} = \frac{\partial T_i}{\partial p_i} \frac{p_i}{T_i} < 0$$

is the price elasticity of input demand for traffic mode *i*. Solving (17) for the Nash equilibrium in prices yields

(18) $$\hat{p}_i = p_i(T, p_F, p_E, KZ, KZ_1, K_2)$$

where T in T_i (see (13)) is assumed to be exogenous for the moment although it depends on p_i (see 12)).

We finally determine fuel demand in manufacturing. From Shephard's Lemma we obtain

(19) $$F = \frac{\partial C(x, PT)}{\partial p_F} = \frac{\partial C}{\partial PT} \frac{\partial PT}{\partial p_F} = T \; \frac{\partial PT}{\partial p_F} = \frac{\partial CT}{\partial p_F} + K \frac{\partial PK}{\partial p_F} = \tilde{F} + \gamma_F \cdot K$$

where we kept T constant for simplicity. It is $\tilde{F} = \tilde{F}\,(x, PT(\cdot), p_F, KZ)$ the non-complementary fuel consumption which could partly be reduced by a better infrastructure due to less congestion. Similarly,

(20) $$F_1 = \frac{\partial}{\partial p_F}\left(C_1 + PK_1 \cdot K_1\right) = \tilde{F}_1 + \gamma_F \cdot K_1$$

with $\tilde{F}_1 = \tilde{F}_1(T_1, p_F, KZ_1)$ for the truck industry. When the government decides on investing in highways or in the railway system, its goal is also to reduce the waste of fuel for environmental reason.

4. A first-best infrastructure policy

The government provides infrastructure services by investing in the road system and in the railway system. It is aware that investment in road construction increases the productivity of the economy by improving the utilization of the stock of vehicles and by reducing the cost of congestion to the economy. It also knows that road infrastructure improves the competitive situation of the truck industry relative to the railway. Investment in the railway system in turn helps both the railway and the environment because the substitution of train services for truck services reduces the emission of nitrooxide (NO_X) and carbon dioxide (CO_2).[2] We assume that it is the objective of the government to maximize consumer surplus from the output x of manufacturing, profit of manufacturing as well as profit of the truck and railway industries minus the cost of the two modes of infrastructure and of environmental damage from traffic's emissions. As an additional instrument we add the fuel tax t_F, although it is not used as a mean to finance infrastructure investment. It internalizes the negative externality but does not balance a financial budget restriction.

$$\text{(21)} \qquad \begin{aligned} \max_{KI,KR,t_F} \quad & \int_0^x p(\zeta)\, d\zeta - C(x, PT) + \sum_{i=1}^{2} \left[p_i(\cdot) T_i - C_i(\cdot) - PK_i \cdot K_i \right] \\ & - PKI \cdot KI - PKR \cdot KR - D(e \cdot TF) + t_F \cdot TF \end{aligned}$$

$D(\cdot)$ is the damage function with e as an emission coefficient and with total fuel TF as

$$\text{(22)} \qquad TF = \gamma_F (K + K_1) + \widetilde{F} + \widetilde{F}_1 \ .$$

PKI and PKR are the public unit cost of the two types of infrastructure.[3] They depend on the

---

[2] Since electricity is mainly produced from using fossil fuel, the railway is indirectly also an air polluter.

[3] To see the difference between our approach and the approach chosen in the literature (Friedlaender and Mathur (1982), Nilsson (1992)), we consider the single-mode case. Welfare in this literature is

$$\int_0^{T_1} p_1(\zeta)\, d\zeta - C_1(T_1, t_F, KI) - PKI \cdot KI + t_F \cdot TF \ ;$$

in our paper it is

$$\int_0^x p(\zeta)\, d\zeta - C(x, PT) + (p_1 T_1 - C_1(T_1, t_F, KZ_1) - PK_1 \cdot K_1) - PKI \cdot KI + t_F \cdot TF - D(\cdot) \cdot$$

Apart from the aspect of congestion and environmental damage, the crucial difference is that in our approach the transportation industry produces an input T_1 which permits to derive consumers' and producers' surplus in the goods market.

social rate of return r_S, on the rate of replacement δ and on the cost of a km highway (PKI^0) or railway system (PKR^0):

(23) $$PKI = PKI^0(r_S + \delta_I) \quad , \qquad PKR = PKR^0(r_S + \delta_R) \ .$$

The FOCs of problem (21) are

(24)
$$(p - C_x)\frac{d\,x}{d\,KI} - C_{PT}\frac{d\,PT}{d\,KI} + \sum_{i=1}^{2}\left[p_i\frac{d\,T_i}{d\,KI} + T_i\frac{d\,p_i}{d\,KI} - C_{i,T_i}\frac{d\,T_i}{d\,KI}\right]$$
$$-PK_1\frac{d\,K_1}{d\,KI} - C_{1,KZ_1}\frac{d\,KZ_1}{d\,KI} - PKI - MD(\cdot)\cdot e\cdot\frac{d\,TF}{d\,KI} = 0$$

and

(25)
$$(p - C_x)\frac{d\,x}{d\,KR} - C_{PT}\frac{d\,PT}{d\,KR} + \sum_{i=1}^{2}\left[p_i\frac{d\,T_1}{d\,KR} + T_i\frac{d\,p_i}{d\,KR} - C_{i,T_i}\frac{d\,T_i}{d\,KR}\right]$$
$$-C_{2,K_2}\frac{d\,K_2}{d\,KR} - PKR - MD(\cdot)\cdot e\cdot\frac{d\,TF}{d\,KR} = 0$$

and

(26)
$$\left(p - C_x\right)\frac{d\,x}{d\,t_F} - C_{PT}\frac{d\,PT}{d\,t_F} + \sum_{i=1}^{2}\left[p_i\frac{d\,T_i}{d\,t_F} + T_i\frac{d\,p_i}{d\,t_F} - C_{i,T_i}\frac{d\,T_i}{d\,t_F}\right]$$
$$\frac{\partial}{\partial\,p_F}\left(C_1 + PK_1\cdot K_1\right)TF + \frac{\partial\,TF}{\partial\,t_F}\left(t_F - MD(\cdot)\cdot e\right) = 0$$

where MD is marginal damage. Since more of KI will increase transportation by trucks, $\frac{d\,TF}{d\,KI} > 0$ in (24) indicates an impact on damage although some waste of fuel will be reduced due to less congestion because of $\frac{\partial\,\tilde{F}}{\partial\,KI} < 0$. But some emissions can be avoided by extending the railway system which reduces fuel demand, indicated by $\frac{d\,TF}{d\,KR} < 0$ in (25).

For an interpretation of the FOCs we treat each of them as an implicit function, determining one of the instruments given the other two. Our objective is therefore not a simultaneous solution of the FOCs but we are interested in analyzing the economic aspects behind setting optimal levels of the policy instruments. We first derive from (26) an optimal fuel tax by using the FOCs (10) and (16) and the definition (22) (see the Appendix):

$$t_F = MD(\cdot)\cdot e + \frac{1}{\frac{\partial TF}{\partial t_F}} \left[\underset{(+)}{\frac{\partial CT}{\partial p_i}\frac{\partial p_i}{\partial t_F}} - \sum_{\substack{i=1 \\ j\neq i}}^{2} \left(p_i - C_{i,T_i}\right)\left(\frac{\partial T_i}{\partial p_F} + \underset{(+)}{\frac{\partial T_i}{\partial p_j}}\frac{\partial p_j}{\partial p_F}\right)\right]. \tag{27}$$

The term behind $p_i - MC_i$ is positive because it reflects outsourcing of transportation by manufacturing when fuel prices increase. T_i is an input for manufacturing and a substitute for own trucks. If user costs of trucks increase, demand for the substitutes T_i increases. As $\frac{\partial TF}{\partial t_F} < 0$, the tax should be below marginal damage if perfect competition prevails in the transportation industry $(p_i = MC_i)$. The reason is the spillover effect of the tax on the prices of the transportation modes, demanded by manufacturing. This increases the costs of transportation and hence the costs of output *x*. Therefore a tax below *MD* offsets this negative output effect. In case of $p_i > MC_i$, the option of outsourcing transport services to the non-competitive transportation industry is a reason to add economic damage to the tax. Therefore, the cost effect for manufacturing due to higher input prices from a fuel tax (a reason to set t_F below *MD*) is mitigated by the marginal economic damage of outsourcing transportation to an imperfectly competitive industry (a reason to add this damage to the environmental damage).

We next determine economic and environmental reasons to provide an optimal stock of infrastructure. Using the FOCs (10) and (16), then writing the derivatives in total elasticities and solving (24) for the optimal infrastructure *KI* yields:

$$\begin{aligned} KI = \frac{1}{PKI}\Big[& -PT\cdot T\cdot E_{PT,KI} + \sum_{i=1}^{2}\left(\frac{p_i T_i}{\varepsilon_i} E_{T_i,KI} + p_i T_i \cdot E_{p_i,KI}\right) \\ & - PK_1\cdot K_1\cdot E_{K_1,KI} - C_1\cdot E_{C_1,KZ_1}\cdot E_{KZ_1,KI} - MD\cdot e\cdot F_{net,KI}\Big] \end{aligned} \tag{28}$$

where $E_{PT,KI} = \frac{d\,PT}{d\,KI}\frac{KI}{PT}$ etc., and $F_{net,KI} := \gamma_F (K_1 \cdot E_{K_1,KI} + K \cdot E_{K,KI}) + \widetilde{TF} \cdot E_{\widetilde{TF},KI}$ summarizes the net effect of a change in *KI* on fuel consumption. The first term in the brackets represents a positive aspect for providing *KI* since $E_{PT,KI} < 0$ because infrastructure reduces the cost of transportation. The higher the cost savings, the more infrastructure services should be provided. The second and third term (*i* =1, 2) are negative because of $E_{T_i,KI} < 0$. Infrastructure improves the efficiency of trucks owned by manufacturing. Therefore demand for outsourced truck services and for the railway is lower. This deteriorates the profit situation of these two industries and slows down the incentive of the government to extend infrastructure investment. The fourth and fifth term (*i* = 1, 2) are negative because of $E_{p_i,KI} < 0$ (prices are strategic complements). The reduction in the mark-ups of the truck and railway industry is not intended by the government when improving infrastructure services. The sixth term is also negative because of $E_{K_1,KI} > 0$. It reflects the additional user cost of capital services in the truck industry when infrastructure has improved the utilization of its stock of trucks. The seventh term is positive and represents the reduction in the cost of congestion. *KI* improves efficiency of the stock of trucks and reduces the congestion index *Z* because of $E_{KZ_1,KI} > 0$. More efficient capital reduces costs of the truck industry ($E_{C_1,KZ_1} < 0$). Therefore, efficiency of stocks and less congestion is a positive aspect for investment in infrastructure. The last term expresses the negative environmental effect of an extended highway system. *KI* raises the efficiency of the stock of vehicles and by that emissions from fuel input. Some fuel, however, can be saved due to less waste of fuel from congestion ($E_{\widetilde{TF},KI} < 0$, $\widetilde{TF} = \widetilde{F} + \widetilde{F}_1$). Therefore, excessive fuel consumption and emissions caused by congestion affect the optimal provision of infrastructure.

There are still some effects which we have not mentioned yet because they are hidden in the total elasticities. One of it is the savings in congestion costs by the rest of the economy. This effect is included in the cost of transportation *PT*(·), which is a function of T, p_1, p_2, p_F, K and *KZ*. If we wish to isolate all effects, we have to decompose the total elasticities in a sum of partial elasticities. For $E_{PT,KI}$ such a decomposition is (for a proof see the Appendix)

$$E_{PT,KI} = -\varepsilon_{T,KI} + \frac{1}{PT \cdot T}\Big[\sum_{i=1}^{2} CT \cdot \varepsilon_{CT,p_i} \cdot \varepsilon_{p_i,KI} + CT \cdot \varepsilon_{CT,T} \cdot \varepsilon_{T,KI}$$
$$+ CT \cdot \varepsilon_{CT,KZ} \cdot \varepsilon_{KZ,KI} + PK \cdot K \cdot \varepsilon_{K,KI}\Big]$$

where $\varepsilon_{CT,p_i} = \dfrac{\partial\, CT}{\partial\, p_i}\dfrac{p_i}{CT}$, etc.

A similar decomposition can be done for $E_{T_1,KI}$ and $E_{p_i,KI}$ (see the Appendix). The next step is to replace all total elasticities in (28) by their expressions in partial elasticities. Then all terms are collected which have the elasticity $\varepsilon_{T,KI}$ in common, or the elasticity $\varepsilon_{p_i,KI}$, etc. This procedure leads to a linear regression equation which can be estimated in the unknown elasticities:

(29)
$$PKI\cdot KI = \underset{(+)}{\varepsilon_{T,KI}}\cdot x(T;KI) + \underset{(-)}{\varepsilon_{p_1,KI}}\cdot x(p_1;KI) + \underset{(-)}{\varepsilon_{p_2,KI}}\cdot x(p_2,KI) + \underset{(-)}{\varepsilon_{Z,KI}}\cdot x(Z;KI)$$
$$+\underset{(+)}{\varepsilon_{K_1,KI}}\cdot x(K,K_1;KI)$$

where the signs indicate the ones we expect (we made the assumption that $\varepsilon_{K,KI} = \varepsilon_{K_1,KI}$). The variable $x(T;KI) > 0$ includes all economic variables which are affected by an increase in transportation demand T induced by a higher KI:

(30)
$$x(T;KI) = PT\cdot T - CT\cdot\varepsilon_{CT,T} + \sum_{i=1}^{2}\left[-\frac{p_iT_i}{\varepsilon_{T_i,p_i}}\varepsilon_{T_i,T} + p_iT_i\cdot\varepsilon_{p_i,T}\right] - MD\cdot e\cdot\widetilde{TF}(\varepsilon_{\tilde{F}_1,T_1} + \varepsilon_{\tilde{F},T})\ .$$

The transportation relevant variables in $x(T;KI)$ are weighted by elasticities which emphasize the importance of the corresponding variable when T changes. If a weight is unity, the impact is a direct one (e.g. $PT\cdot T$). A higher T can increase costs CT (negative aspect), can increase profit in the duopoly due to higher T_i and prices p_i (positive aspects). However, more T implies more waste of fuel which has a negative impact in the calculation of the transportation representing variable $x(T;KI)$.

The variable $x(p_1;KI) < 0$ includes economic variables which are affected by price changes for truck services induced by KI. These variables are transportation costs in the economy CT and profits in the duopoly.

(31)
$$x(p_1;KI) = -CT\cdot\varepsilon_{CT,p_1} - \sum_{i=1}^{2}\frac{p_iT_i}{\varepsilon_{T_i,p_i}}\varepsilon_{T_i,p_1}\ .$$

A lower p_1 means cost saving in the economy, a lower mark-up in the truck business and a higher one in the railway. If $\varepsilon_{p_1,KI}$ in (29) turns out to be negative, the price effect has a positive impact on the provision of *KI*.

The variable $x(p_2;KI)<0$ includes economic variables which are affected by price changes for railway transportation.

(32) $$x(p_2;KI) = -CT \cdot \varepsilon_{CT,p_2} - \sum_{i=1}^{2} \frac{p_i T_i}{\varepsilon_{T_i,p_i}} \varepsilon_{T_i,p_2} .$$

Since prices are strategic complements, a higher *KI* lowers also p_2. Therefore the explanation of $x(p_2;KI)$ is similar to the one given for $x(p_1;KI)$.

The variable $x(Z;KI)<0$ includes economic variables which are affected by congestion. Costs, prices, transportation demand and fuel consumption are weighted by elasticities representing the importance of the corresponding variable in providing infrastructure. A lower congestion index *Z* due to more *KI* raises the effective stock of vehicles *KZ* which gives rise to cost savings and price reduction:

(33) $$\begin{aligned} x(Z;KI) = \Big[& -CT \cdot \varepsilon_{CT,KZ} + \sum_{i=1}^{2} \left(\frac{p_i T_i}{\varepsilon_{T_i,p_i}} \varepsilon_{T_i,KZ} + p_i T_i\, \varepsilon_{p_i,KZ} + p_i T_i \cdot \varepsilon_{p_i,KZ_1} \right) \\ & - C_1 \cdot \varepsilon_{C_1,KZ_1} - MD \cdot e \cdot \widetilde{TF} \cdot (\varepsilon_{\widetilde{F}_1,KZ_1} + \varepsilon_{\widetilde{F},KZ}) \Big] \varepsilon_{KZ,Z} \end{aligned}$$

First of all, $\varepsilon_{KZ,Z}<0$ at the end of (33) turns costs into cost savings because a lower *Z* raises the effective stock of vehicles. The higher *KZ*, in turn, lower cost *CT* in the economy (the weight is $\varepsilon_{CT,KZ}<0$), reduces profits in the duopoly because firms prefer to use own trucks, lowers the prices p_i due to competition with manufacturing owned trucks, lowers prices of the duopolists and cost of trucks, and reduces the environmental damage effect.

Finally, economic variables included in $x(K,K_1;KI)<0$ depend on the size of the utilized stock of vehicles. Most of them represent the cost aspect of more *KI*, some the benefit aspect, but the emphasis is here on the cost of production.

(34) $$\begin{aligned} x(K,K_1;KI) = & -PK \cdot K - PK_1 \cdot K_1 - MD \cdot e \cdot \gamma_F \cdot (K_1 + K) - CT \cdot \varepsilon_{CT,KZ} \\ & + \sum_{i=1}^{2} \left(\frac{p_i T_i}{\varepsilon_{T_i,p_i}} \varepsilon_{T_i,KZ} + p_i T_i \cdot \varepsilon_{p_i,KZ_1} \right) - C_1 \cdot \varepsilon_{C_1,KZ_1} - MD \cdot e \cdot \widetilde{TF} \cdot \left\{ \varepsilon_{\widetilde{F}_1,KZ_1} + \varepsilon_{\widetilde{F},KZ} \right\} \end{aligned}$$

Again, if the effect is direct, the weight is one, if it is indirect, the weight in $x(K,K_1;KI)$ is the corresponding elasticity. More *KI* results in a better utilization of the stock of vehicles K^0 and K_1^0 (see (3)). This raises capital costs, and has also a negative effect on the environment (first three terms in (34)), it lowers the cost CT (because of $\varepsilon_{CT,KZ} < 0$), it reduces the mark-ups of the duopolists because business-owned trucks become more effective, and then there are the positive effect of a higher KZ_1 on costs C_1 and on wasting less fuel.

A regression equation, similar to (29), can be derived from (25) for the optimal provision of the railway system *KR*. The variables $x(T;KR), x(p_1;KR)$ and $x(p_2;KR)$ are identical with the ones given in (30) - (32) because they reflect cost and benefit of infrastructure in general. There is no variable $x(Z;KR)$ because there is no direct effect of *KR* on congestion costs. Since infrastructure *KR* affects only the prices p_1, p_2 and the costs C_2 of the railway, the variable $x(K,K_1;KI)$ in (34) reduces to

(35) $$x(K_2;KR) = -PK_2 \cdot K_2 + \sum_{i=1}^{2} p_i T_i \cdot \varepsilon_{p_i,K_2} - C_2 \cdot \varepsilon_{C_2,K_2} \; .$$

Our second regression, now for *KR*, is

(36) $$\begin{aligned} PKR \cdot KR = {} & \underset{(+)}{\varepsilon_{T,KR}} \cdot x(T;KR) + \underset{(-)}{\varepsilon_{p_1,KR}} \cdot x(p_1;KR) + \underset{(-)}{\varepsilon_{p_2,KR}} \cdot x(p_2;KR) \\ & + \underset{(+)}{\varepsilon_{K_2,KR}} \cdot x(K_2 : KR) + \underset{(-)}{\varepsilon_{\widetilde{F},KR}} \cdot x(\widetilde{F};KR) \end{aligned}$$

where $x(\widetilde{F};KR) = -MD \cdot e \cdot \widetilde{F}$. If $\varepsilon_{\widetilde{F},KR} < 0$, environmental concern has a positive impact on investment in the railway system.

The variables $x(\cdot)$ are not directly observable, but have to be constructed from behavioral equations for manufacturing and for the two competitors in transportation services. All $x(\cdot)$'s summarize positive and negative effects on sales and costs for the economy. They will be influenced, if the government extends infrastructure services. Since we have neglected a budget constraint and the necessity to finance infrastructure investment, we have omitted an important allocative effect. As higher taxes are required if infrastructure services are provided at no extra charge, it is not obvious that the benefits always offset the disincentive and reallocating effect of taxation. However, as the creation of infrastructure promotes growth and attracts new firms - an aspect captured especially in $x(T;KI)$ and $x(T;KR)$ - the corresponding higher tax revenues can in the long run finance the provision of infrastructure. Our model includes at least a gasoline tax which could be used to finance infrastructure investment.

In order to fill the $x(\cdot)$ variables with numbers we have to specify functional forms for deriving demand functions and mark-ups. We will do this in the following section.

5. Transport demand by manufacturing and competition in an input market – a specified model

Although the railway is much more concerned about its competitive situation after the deregulation in 1994,[4] we are fully aware of the fact that it is highly unrealistic to interpret the railway performance in the last decade as the outcome of a duopolistic market structure. We therefore do not estimate econometrically the firm specific elasticities, derived in the previous section, but only calibrate them for a special year which was 1994. For the cost and revenue figures which appear in the x-variables we employ, however, time series data. Before we choose functional forms for the duopoly model, we should say some words to the competitive situation before 1994.[5]

Privatization of the railway in 1994 ended the area of this natural monopolist. Once the railway system as the fixed cost component has been the source for monopolistic power, but competition between railway, motor vehicles and airplanes prevailed since several decades. Separation of the railway system to a (still) government owned company was a first step to strengthen the competitive position of the railway. As the road infrastructure is provided by the government as is the infrastructure used by the airlines like runways and terminals, it is reasonable to free all three competitors from their fixed network costs. In addition, capacity restrictions and licenses in the truck business had to be abolished. Also price formation, formerly determined by the ministry of transportation in order to protect the railway and the inland navigation, was deregulated. One of such price measures was a special tax on company owned trucks because they substituted to an increasing extent the services from the heavily regulated truck business. In spite of all efforts to protect the railway, its market share declined from 56% in the fifties to 20% in 1994. In the same period the market

[4] In 1997 the railway company complained about the lower fuel prices which have favored the competitor motor vehicles and are one reason for the decline in revenue.
[5] For a more comprehensive survey see Bowers (1996) and Börsch-Supan/Schnabel (1998).

share of road transport increased from 20% to 60%. Transfer payments from the government of about 13 billion DM per year since 1980 were necessary for a survival of the railway. The reason for the steady increase in commercial road transportation is the higher quality of the goods to be transported (no mass products like iron or coal anymore), the just-in-time production process, and the regional mobility of trucks. Competitive price setting therefore required subsidies by the federal government to cover fixed cost and interest payments from debts.

The EU deregulation reform in 1993 proposed an entrepreneurial independency of the railway, a separation of the railway system from the transportation business, and free access of competitors to the railway system. The task of the newly founded Federal railway office (Eisenbahnbundesamt) is the expansion of the railway system. In 1999 there will be a stock company DB Cargo AG as a competitor for truck transportation which need not to invest in the railway system. Both the user of the road system as well as of the railway system have to cover at last the yearly depreciation by paying user fees. As prices for truck transportation and inland navigation have dropped by 30% after the abolition of the price control (once introduced to support the railway), the cargo AG has to make enormous efforts to regain market shares.

As mentioned above, we develop an econometric model for competitive interactions between trucks, business owned trucks and between the railway, but we do only calibrate the parameters for the year 1994. Our objective is to calculate the values of the firm-specific partial elasticities in order to be able to calculate time series for the *x*-variables in the linear regressions for the two types of infrastructure.

We assume the cost function for transport in manufacturing to be of the translog form with constant returns to scale in *T* and *KZ*:

(37) $$\ln CT = \frac{1}{\alpha.}\ln T - \frac{\alpha_K}{\alpha.}\ln KZ + \frac{1}{\alpha.}\sum_{i=1}^{3}\alpha_i \ln p_i + \frac{1}{2}\frac{1}{\alpha.}\sum_{i,j}^{3}\beta_{ij}\ln p_i \ln p_j$$

where i = 3 is F (fuel), $\alpha. = \alpha_1 + \alpha_2 + \alpha_3$ and $\alpha. + \alpha_K = 1$. Homogeneity of degree one in the input prices implies $\beta_{i1} + \beta_{i2} + \beta_{i3} = 0$, $i = 1,2,3$. From Shephard's lemma, manufacturing's demand functions for truck and railway services are:

(38) $$T_i = \frac{CT}{p_i}\left(\alpha_i + \sum_{j=1}^{3} \beta_{ij} \ln p_j\right) \qquad i = 1,2.$$

The price elasticities of input demand are:

(39) $$\varepsilon_{T_i, p_i} = w_i - 1 + \frac{\beta_{ii}}{w_i}$$

where $w_i = \dfrac{p_i T_i}{CT}$. These elasticities will be used for the mark-up conditions (17).

The cost function of the truck or railway industry are based on a Cobb-Douglas technology:

(40) $$\ln C_1 = \frac{1}{\tau.} \ln T_1 - \frac{\tau_{K_1}}{\tau.} \ln KZ_1 + \frac{1}{\tau.}\left(\tau_F \ln p_F + \tau_L \ln p_L\right)$$

where p_L is the price of labor, $\tau. = \tau_F + \tau_L$ and $\tau. + \tau_{K_1} = 1$.

Similarly,

(41) $$\ln C_2 = \frac{1}{\zeta.} \ln T_2 - \frac{\zeta_{K_2}}{\zeta.} \ln K_2 + \frac{1}{\zeta.}\left(\zeta_E \ln p_E + \zeta_L \ln p_L\right)$$

where p_E is the price of electricity, $\zeta. = \zeta_E + \zeta_L$ and $\zeta. + \zeta_{K_2} = 1$. Using the elasticities in (39) and the *MC*-function from (40), the revenue-cost share of the truck industry follows from (17):

(42) $$\frac{p_1 T_1}{C_1} = \frac{w_1 - 1 + \dfrac{\beta_{11}}{w_1}}{w_1 + \dfrac{\beta_{11}}{w_1}} \quad \frac{1}{\tau.}$$

where we have assumed that the share w_1 is constant. The price p_2 follows in a similar way.[6]

Based on our assumed specifications we can derive the firm-specific elasticities which

[6] We note from (42) that a Cobb-Douglas production technology for manufacturing is excluded if **input** demand functions are used for imperfect competition between input producing firms. With $\beta_{11} = 0$, the Bertrand price p_1 would be negative.

are needed to calculate the variables x_i. The elasticities which enter $x(T;KI)$ are:[7]

$$
\begin{aligned}
&\varepsilon_{CT,T} = \varepsilon_{T_i,T} = \frac{1}{\alpha.} = \frac{1}{1-\alpha_K} \qquad , \\
(43) \qquad &\varepsilon_{p_1,T} = \frac{\partial \ln T_1}{\partial \ln T}\left[\frac{1}{\tau.}-1\right] = \frac{\partial \ln CT}{\partial \ln T}\,\frac{\tau_{K_1}}{1-\tau_{K_1}} = \frac{\tau_{K_1}}{(1-\alpha_K)\,(1-\tau_{K_1})} \; . \\
&\varepsilon_{p_2,T} = \frac{\zeta_{K_2}}{(1-\alpha_K)\,(1-\zeta_{K_2})}
\end{aligned}
$$

In order to calibrate the parameters in a given base year, we need to know manufacturing's cost shares $w_i = \dfrac{p_i T_i}{CT}$ and the three cost of capital shares. The latter one can be derived from the envelope condition, which states that the partial derivative of the variable cost function with respect to capital – the endogenous ex-post price of capital – is equal to the given ex-ante price of capital. Or, written in cost shares:

$$
-\frac{\partial \ln C_1}{\partial \ln K_1} = \frac{PK_1 \cdot K_1}{C_1}
$$

and similar for K_2. Using our specifications, the shares are

$$
(44) \qquad \frac{PK_1 \cdot K_1}{C_1} = \frac{\tau_{K_1}}{1-\tau_{K_1}} \quad , \quad \frac{PK_2 \cdot K_2}{C_2} = \frac{\zeta_{K_2}}{1-\zeta_{K_2}}
$$

With data for these cost shares, we can calculate τ_{K_1} and ζ_{K_2}, and therefore some of the elasticities. Furthermore, from cost minimization of manufacturing with respect to K, we obtain the FOC: $\partial\, C(x,PT)/\partial\, K = 0$, or, using the specifications (2), and (6):

$$
(45) \qquad -\frac{\partial \ln CT}{\partial \ln K} = \frac{PK \cdot K}{CT} \quad , \qquad \text{i.e.} \qquad \frac{PK \cdot K}{CT} = \frac{\alpha_K}{1-\alpha_K}
$$

when using the specification of CT (see (37)). We finally have to find a value for $\varepsilon_{KZ,Z}$ the elasticity of vehicle stock utilization with respect to congestion (i.e. for $-\gamma$), which appears in

[7] For the other elasticities see the Appendix.

$x(Z;KI)$. For that purpose we have to define our index of congestion Z. Similarly as in Conrad (1997), Z is assumed to be a geometric mean of the following type

$$(46) \qquad Z = \left(\frac{K^0}{\hat{K}^0}\right)^{\beta} \left(\frac{K_1^0}{\hat{K}_1^0}\right)^{1-\beta} \geq 1, \qquad \beta > 0 .$$

K^0 is the required stock of vehicles under the present insufficient provision of infrastructure services KI including congestion. This stock can be utilized only to a certain percentage, according to (3); let us say 95 per cent. Since truck drivers experience congestion, the effective stock, KZ, enters the cost function CT, implying higher variable costs than under the higher K or K^0. With $\hat{K}^0$ (where $\hat{K}^0 < K^0$) we denote the lower stock of vehicles required if infrastructure is provided in an efficient manner. This means that infrastructure $\hat{KI}$ has been provided according to the principle that its marginal benefit is equal to its marginal cost including the cost of public funds. This does not necessarily imply that Z should be one in that case, i.e. that there should be no congestion. However, for our calibration we will assume that Z is equal to one. Since in that case less vehicles are required to transport the quantity T, $\hat{K}^0$ is less than K^0, and $Z \geq 1$ follows according to (46).[8] With the under-utilized K and the observed cost CT the parameter α_K can be calculated from (45).[9]

Using data from the national accounts and from an input-output table it is therefore possible to calculate the x-variables for a regression analysis.

6. Optimal provision of infrastructure and its impact on the economy – a regression analysis

For our empirical analysis we need data for three cost definitions. $CT = p_1 \cdot T_1 + p_2 T_2 + p_F \cdot \widetilde{F} + PK \cdot K$ are the costs of transportation for manufacturing with PK as defined in (7). We assume that 90 per cent of the fuel input are complementary to trucks. We use input-output tables to construct the data. The number of trucks owned by manufacturing are published in the Statistical Yearbook. The same holds for the number of trucks owned by the truck-transport industry. Profit of the truck industry is

---

[8] The arguments are similar in case of K_1^0 and $\hat{K}_1^0$.
[9] For more detail and an example see the Appendix.

$$\Pi_1 = p_1 T_1 - C_1 - PK_1 \cdot K_1$$

where $C_1 =$ wages + cost of material + $p_F \cdot \widetilde{F}_1$. We have included the cost of material which can easily be incorporated in our analytical part in the preceding section.[10] In addition, the costs of the railway are $C_2 =$ wages + cost of material + cost of electricity. Fixed capital costs are $PK_2 \cdot K_2 = PK_2^0 \cdot K_2\,(r+\delta)$ where $PK_2^0 \cdot K_2$ is the value of the net stock of producers durables of the railway, published in *Verkehr in Zahlen*.

The elasticities ε_{T_i,p_i} are calculated by multiplying the FOC in (17) by T_i and by using the specification for C_i in (40) or (41), respectively. For the truck industry, for example:

$$p_1 T_1 - \frac{1}{1-\tau_{K_1}}\; C_1 = -\frac{p_1 T_1}{\varepsilon_1} \tag{47}$$

which can be solved for ε_{T_i,p_i}. In the same way, ε_{T_2,p_2} can be calculated. Finally, β_{ii} follows from (39). Since the railway makes losses, we had to assume a rate of return for the railway which was low enough to guarantee that the left hand side of (47) for the railway is positive.[11/12]

Since trucks do not pay for using the highway system we assumed that the railway does not have to pay for the railway system. Its capital stock is the infrastructure variable *KR* and can be calculated by subtracting from total capital of the railway the figure for K_2 (see *Verkehr in Zahlen*). A time series for the capital stock of the highway system, *KI* can also be found in *Verkehr in Zahlen*. These data have been used to determine the endogenous variables in the two regressions (29) and (36). When calculating the *x*-variables, we kept the elasticities from the base year 1994 constant and used yearly cost and revenue datas to construct time series from 1980 to 1996.

Data on marginal damage *MD* are based on a study by Weinreich et al. (1998). They estimated external costs of road and rail freight traffic in 1995. We use only their estimate for external costs for air pollutants and exclude costs from noise or from accidents. Their cost

---

[10] The efficiency parameter α in (3) has been calibrated such that only 90 per cent of the stock K^0 (K_1^0 respectively) is utilized given the present infrastructure.

[11] Note that ζ_{K_2} in the corresponding equation (48) for rail is derived from (44).

[12] The congestion index *Z* has been constructed along the lines mentioned in the preceding section. We found *Z* = 1.1. We then assumed that the utilization of vehicles is reduced from congestion by 5 per cent. According to (2) this implies $0.95 = Z^{-\gamma}$. Since *Z* = 1.1, we obtain $\gamma = 1.7$ for the elasticity $\varepsilon_{KZ,Z} = -\gamma$ in $x(Z;KI)$.

estimate was about 30 DM/1000 tkm (ton kilometer). Since we measure fuel input in liter, we constructed an "emission" coefficient *e* as the ratio of tkm driven by trucks per liter diesel. By using *MD* of 30 DM, adjusted for inflation, fuel consumption and *e* as tkm/ltr. fuel, we constructed a time series for the environmental variable.

Parameter estimates of the system as seemingly unrelated are presented in the Table.

Table: Estimates of $\varepsilon_{j,KI}$ and $\varepsilon_{j,KR}$, $j = T, p_1, p_2, Z, K_1, \widetilde{F}$.

	$\varepsilon\left(T, \begin{matrix} KI \\ KR \end{matrix}\right)$	$\varepsilon\left(p_1, \begin{matrix} KI \\ KR \end{matrix}\right)$	$\varepsilon\left(p_2, \begin{matrix} KI \\ KR \end{matrix}\right)$	$\varepsilon(Z, KI)$	$\varepsilon\left(\begin{matrix} K_1, & KI \\ K_2, & KR \end{matrix}\right)$	$\varepsilon(\widetilde{F}, KR)$
	$x(T;KI)$	$x(p_1;KI)$	$x(p_2;KI)$	$x(Z;KI)$	$x\left(\begin{matrix} K_1;KI \\ K_2;KR \end{matrix}\right) < 0$	$x(\widetilde{F};KR)$
KI	0.104 (4.0)	n.s.	n.s.	-0.07 (2.0)	0.02 (0.7)	--
KR	0.023 (5.8)	n.s.	n.s.	--	-1.41 (-21.4)	-7.9 (-6.7)

It is by construction $x(T;KI) = x(T;KR)$, $x(p_1;KI) = x(p_1;KR)$ and $x(p_2;KI) = x(p_2;KR)$. The values in brackets are the *t*-statistics and n.s. means that the variable *x* has been dropped because the parameter was "not significantly" different from zero. R^2 was 0.9995.

The variable $x(T;KI)$ represented the net benefit of transport as an input for the economy. The estimated elasticity $\varepsilon_{T,KI} = .104$ or $(\varepsilon_{T,KR} = .023)$ expresses that an increase in infrastructure provision by one per cent would raise the volume of transport by 0.104 per cent (or 0.023 for the railway system). Our model indicates that the impact from investment in highways is much higher than the one from the railway system (about 4 times higher). The variable $x(p_1;KI) < 0$ represents the negative aspects of an increase in the price of truck services on transport demand and profit in the transport industries. We expected a negative sign for ε_{p_iKI} and ε_{p_iKR}, i.e. infrastructure investment reduces both prices because prices are strategic complements. However, our estimated elasticities turned out to be not significantly different from zero. We therefore dropped these two price variables from our two equation regression. Maybe in ten years deregulation will induce price effects which then will turn out to be significantly negative in sign.

The variable $x(Z;KI)<0$ measure the impact on the economy from congestion. The estimated elasticity $\varepsilon_{Z,KI}=-0.07$ means that one per cent more infrastructure reduces the congestion index $Z > 1$ by .07 per cent. The savings in congestion related costs supports an extension of road infrastructure. Finally, $x(K,K_1;KI)<0$ and $x(K_2;KR)<0$ summarize the costs and benefits to the economy from a more efficient utilization of the stock of vehicles. $\varepsilon_{K_1,KI}=.02$ indicates the positive effect of *KI* on the utilization of trucks (we had made the assumption $\varepsilon_{K,KI}=\varepsilon_{K_1,KI}$). One per cent more infrastructure services raises the utilization by 0.02 per cent. Since the net impact of a better utilization of the stock of vehicles to the economy is negative $(x(K,K_1;KI)<0)$, this aspect supports no extension of road infrastructure; i.e. the user cost effect dominates the efficiency effect in providing more infrastructure. The parameter is, by the way, insignificant. For trains, $\varepsilon_{K_2,KR}=-1.41$ is significantly different from zero but has the wrong sign. Extending the railway system raises the user cost of durables for the railway company $(x(K_2,KR)<0)$. If it were $\varepsilon_{K_2,KR}>0$, this cost aspect slows down an extension of the railway system. With $\varepsilon_{K_2,KR}<0$, the correlation is positive, saying that irrespective of the user cost of railway's durables their increase will not slow down the extension of the railway system. In the data therefore dominates the efficiency effect of a better railway system, given the stock of rail capital.

Finally, $x(\widetilde{F};KR)<0$ represents the damage to the environment from fuel consumption and $\varepsilon_{\widetilde{F},KR}=-7.9$ means that an extension of the railway system by one percent will reduce the waste of fuel due to inefficiency in the road network by 7.9 percent. This aspect speaks in favor of providing more services by the railway system.

The regression analysis does not only permit to estimate infrastructure elasticities, it can also be used to find weights to the economic aspects which explain the size of the user cost of infrastructure. For instance, the transport volume in nominal terms $(x(T;KI)>0)$ weighted by 0.104 (0.0023 for rail) explains part of the size of the infrastructure capital costs. The fact that infrastructure reduces the cost of congestion $(x(Z;KI)<0)$ accounts also a part of the cost of infrastructure capital. If congestion related costs amount to ten billion DM, than 0.7 bill. DM out of the cost of infrastructure capital can be attributed to mitigate the congestion problem. Finally, capital cost of the railway system $(PKR\cdot KR)$ has been increased by 7.9 million DM, because fuel consumption from trucks causes environmental damages of one million DM.

7. Summary and Conclusion

Our objective has been to model a market which is an important input market for the economy. We have restricted our analysis to freight transport demand by manufacturing. This input factor could in principle be provided by the firm itself by using firm-owned trucks. However, under certain economic conditions it is cost saving to outsource transport services. The manufacturing industry can purchase trucks and employ truck drivers in order to handle the transport volume or it can outsource its freight transport by purchasing these services from rail and/or truck transport firms. Contrary to the literature we do not model an output market which produces transport services and is controlled by the government via taxes and/or infrastructure services, but we link production in manufacturing to transport demand, provided by two competing modes of transport. Since congestion is an increasing cost component in densely populated industrialized countries, we develop an index of congestion which can be controlled by investing in highway infrastructure. Given infrastructure, a fuel tax and the stock of vehicles, we first derive manufacturing's conditional demand functions for truck and rail services. The two transport firms know these demand functions and compete in prices. Of interest in our analysis is also the derived demand for fuel in the economy because the government wishes to internalize the negative externality of emissions from fuel combustion. We then derive an optimal transportation policy which is based on two types of infrastructure and a fuel tax. In the welfare measure included is consumer and producer surplus of the good produced by manufacturing, profit of the two transport modes, environmental damage from emissions and the public cost of infrastructure services. We found that a first-best fuel tax should be below marginal damage since it raises prices of inputs which are required by manufacturing to produce output for the economy. The optimal provision of the two types of infrastructure depended on a number of economic aspects like the volume of transport demand, the competitive situation in the truck and rail industries, the cost of capital of the stock of vehicles or rail equipment, the cost of congestion and on environmental damage.

From our mathematical analysis two sets of unknown elasticities came up – elasticities which measure the response between variables chosen by economic agents, and elasticities which measure the impact of infrastructure services on these variables. In order to estimate the second set of elasticities econometrically, we had to specify cost functions for the industries in order to compute demand functions and Nash prices. This procedure permitted us to calculate the explaining variables in a two equation regression for the two types of infrastructure – the railway system and highways. The unknown parameters showed as infrastructure elasticities the impact of infrastructure provision on prices in the rail and truck industries, on the volume of transport, on congestion, and on the utilization of the stock of transportation equipment in the economy. Since privatization and deregulation in the transport industry have just started, the data reflect only roughly the situation we have described by our model. Maybe after a decade of fierce competition in freight transport services in the European Union, we know more about the empirical compatibility of our model with the actual situation in the transport market.

References

Bowers. P.H. (1996): Railway Reform in Germany, *Journal of Transport Economics and Policy*, 30 (1), 95-102.

Braeutigam, R.B. (1979): Optimal Pricing with Intermodal Competition, *American Economic Review*, 69 (1), 38-49.

Conrad, K. (1997), Traffic, transportation, infrastructure and externalities – a theoretical framework for a CGE analysis, *The Annals of Regional Science*, 31(4), 369-389.

Friedlaender, A.F. and S.C. Mathur (1982): Price Distortions, Financing Contraints and Second-Best Investment Rules in the Transportation Industries, *Journal of Public Economics*, 18, 195-215.

Nilsson, J.-E. (1992): Second-Best Problems in Railway Infrastructure Pricing and Investment, *Journal of Transport Economics and Policy*, 26 (3), 245-259.

Weinreich, S., Rennings, K., Schlomann, B., Geßner, C. and T. Engel (1998): External Costs of Road, Rail and Air Transport – a Bottom-up Approach, Discussion Paper No. 98-06, Centre for European Economic Research, Mannheim.

Appendix

Some remarks to the calculation of *Z*:

We first give some details on how $\hat{K}_0$ can be obtained, the optimal stock of trucks in case of no congestion.

For determining $\hat{K}^0$, we note that transport input *T*, produced by the production function (1), is based on the effective stock *KZ*. The optimal $\hat{K}$ produces also T but with lower variable cost $\hat{CT}$ due to sufficient infrastructure $\hat{KI}$ to reduce *Z* to one. Therefore $\hat{K}$ is derived from (45) with *CT* from (37) under the assumption that *Z* = 1; i.e. *KZ* = *K*. For the base year we obtain

$$\hat{CT} = T^{\frac{1}{1-\alpha_K}} \quad \hat{K}^{-\frac{\alpha_K}{1-\alpha_K}}$$

which has to be substituted for *CT* in (45). This yields

$$\hat{K} = \left(\frac{\alpha_K}{1-\alpha_K}\,\frac{1}{PK}\right)^{1-\alpha_K} \cdot T.$$

This desired demand of capital is lower than *K*. This alone would imply a lower stock than K^0 before. Since the utilization factor $\exp\left(\frac{-\alpha}{KI}\right)$ has improved under $\hat{KI} > KI$, a new and lower stock $\hat{K}^0$ follows from (3) as $\hat{K}^0 = \hat{K}\,\exp\,(\alpha/\hat{KI})$. Now *Z* in (46) can be calculated.

An example for the calculation of *Z*:

Let us assume a simple production function

(A1) $$T = L^{1-\alpha_K}\ (KZ)^{\alpha_K}$$

The demand for labor is $L = T^{\frac{1}{1-\alpha_K}}\ KZ^{-\frac{\alpha_K}{1-\alpha_K}}$

Total costs are $C = P_L \cdot L + PK \cdot K$

and variable costs *CT* are $CT = q_L \cdot T^{\frac{1}{1-\alpha_K}}\ KZ^{-\frac{\alpha_K}{1-\alpha_K}}$

We assume the following numbers:

$P_L = 1$, $L = 200$ (therefore $CT = 200$) , $K^0 = 1000$, $\alpha = 500$ and $KI = 10.000$.

According to (3): $$K = K^0 \cdot \exp\left(-\frac{500}{10.000}\right)$$

$$K = 950$$

With $PK = 0.1$, α_K follows from (43):

$$\frac{PK \cdot K}{CT} = \frac{95}{200} = \frac{\alpha_K}{1-\alpha_K} = 0.475$$

$$\alpha_K = 0.322$$

We assume KZ to be 90% of K because of inefficiency of congestion, i.e. $KZ = 855$

To corresponding T follows from (A1)

$$T = 200^{1-0.322} \cdot 855^{0.322} = 319.3$$

Next we determine $\hat{K}$ from

$$\hat{K} = \frac{\alpha_K}{1-\alpha_K}\ \frac{1}{PK} \cdot \hat{CT} = \frac{\alpha_K}{(1-\alpha_K)}$$

$$\hat{K} = \left(\frac{\alpha_K}{1-\alpha_K}\ \frac{1}{PK}\right)^{1-\alpha_K} T$$

$$= \left(0.475\,\frac{1}{0.1}\right)^{1-0.322} \cdot (319.3)$$

$$= 918.32$$

Let $\hat{KI}$ be equal to 11.000, i.e. 10% higher than KI. Then $\hat{K}_0$ follows from:

$$\hat{K} = 918.32 = \hat{K}_0 \cdot \exp\left(-\frac{500}{11.000}\right)$$

that is $$\hat{K}_0 = 961$$

The index is therefore:

$$Z = \frac{K^0}{\hat{K}^0} = \frac{1000}{961} = 1.0406$$

γ for $\varepsilon_{KZ,Z} = -\gamma$ can be found by using the definition (2):

$$855 = 950 \cdot (1.0406)^{\gamma}$$

or $$\gamma = 2.64$$

Proof of (27):

The FOC with respect to t_F, using (19) and (20), is:

$$\left(p - C_x\right)\frac{d\,x}{d\,t_F} - \tilde{F} - \gamma_F\,K + \sum_{i=1}^{2}\left[\frac{\partial p_i}{\partial p_F}\,T_i + \left(p_i - C_{i,T_i}\right)\left(\frac{\partial T_i}{\partial p_F} + \frac{\partial T_i}{\partial p_i}\frac{\partial p_i}{\partial p_F} + \frac{\partial T_i}{\partial p_j}\frac{\partial p_j}{\partial p_F}\right)\right]$$

$$-\tilde{F}_1 - \gamma_F\,K_1 + \frac{\partial\,TF}{\partial\,t_F}\left(t_F - MD\cdot e\right) + TF = 0$$

Using (10), (16) and (22):

$$-\sum_{i=1}^{2}\frac{\partial\,CT}{\partial\,p_i}\frac{\partial\,p_i}{\partial\,t_F} + \sum_{\substack{i=1\\ j\neq i}}^{2}\left\{\left(p_i - \frac{\partial\,C_i}{\partial\,T_i}\right)\left[\frac{\partial\,T_i}{\partial\,p_F} + \frac{\partial\,T_i}{\partial\,p_j}\frac{\partial\,p_j}{\partial\,p_F}\right]\right\} + \frac{\partial\,TF}{\partial\,t_F}\left(t_F - MD\cdot e\right) = 0$$

which proves (27).

Total elasticities as function of partial elasticities.

Proof of $\mathbf{E_{PT,KI}}$:

$$\frac{d\,PT}{d\,KI} = -\frac{1}{T_2}\frac{d\,T}{d\,KI}\,PT\cdot T + \frac{1}{T}\left[\frac{d\,CT}{d\,KI} + PK\,\frac{d\,K}{d\,KI}\right] = -\frac{PT}{T}\frac{d\,T}{d\,KI}$$

$$+\frac{1}{T}\left[CT_{p_1}\frac{d\,p_1}{d\,KI} + CT_{p_2}\frac{d\,p_2}{d\,KI} + CT_T\,\frac{d\,T}{d\,KI} + CT_{KZ}\,\frac{d\,KZ}{d\,KI} + PK\cdot\frac{d\,K}{d\,KI}\right]$$

or

$$\frac{d\,PT}{d\,KI}\frac{KI}{PT} = -\frac{KI}{T}\frac{d\,T}{d\,KI} + \frac{1}{PT\cdot T}\Big[CT_{p_1}\cdot p_1\cdot\varepsilon_{p_1,KI} + CT_{p_2}\cdot p_2\cdot\varepsilon_{p_2,KI} + CT_T\cdot T\cdot\varepsilon_{T,KI}$$
$$+CT_{KZ}\cdot KZ\cdot\varepsilon_{KZ,KI} + PK\cdot K\cdot\varepsilon_{K,KI}\Big]$$

This yields the expression for $E_{PT,KI}$. Although we could derive

$$\frac{d\,T(\cdot)}{d\,KI} = T_x\,\frac{d\,x}{d\,KI} + T_{PT}\,\frac{d\,PT}{d\,KI}$$

and could exchange $\frac{d\,T}{d\,KI}$ in $E_{PT,KI}$

to get $\frac{d\,x}{d\,KI}$ as the effect of KI on x to be estimated, we stopped with $\frac{d\,T}{d\,KI}$ as the effect to be estimated.

Proof of $E_{T_1,KI}$:

$$\frac{d\,T_1(p_1,p_2,T,KZ)}{d\,KI} = T_{1,p_1}\frac{d\,p_1}{d\,KI} + T_{1,p_2}\frac{d\,p_2}{d\,KI} + T_{1,T}\frac{d\,T}{d\,KI} + T_{1,KZ}\frac{d\,KZ}{d\,KI}$$

which can be written in terms of elasticities as

$$E_{T_1,KI} = \varepsilon_{T_1,p_1}\cdot\varepsilon_{p_1,KI} + \varepsilon_{T_1,p_2}\cdot\varepsilon_{p_2,KI} + \varepsilon_{T_1,T}\cdot\varepsilon_{T,KI} + \varepsilon_{T_1 KZ}\cdot\varepsilon_{KZ,KI}$$

Proof of $E_{p_i,KI}$:

$$\frac{d\,p_i(T;KZ,KZ_1,K_2)}{d\,KI} = p_{i,T}\frac{d\,T}{d\,KI} + p_{i,KZ}\frac{d\,KZ}{d\,KI} + p_{i,KZ_1}\frac{d\,KZ_1}{d\,KI} + p_{i,K_2}\frac{d\,K_2}{d\,KI}$$

Therefore, in terms of partial elasticities:

$$E_{p_i,KI} = \varepsilon_{p_i,T}\cdot\varepsilon_{T,KI} + \varepsilon_{p_i,KZ}\cdot\varepsilon_{KZ,KI} + \varepsilon_{p_i,KZ_1}\cdot\varepsilon_{KZ_1,KI} \qquad \text{(It is } \frac{d\,K_2}{d\,KI} = 0\text{).}$$

Furthermore, it is

$$\frac{d\,K_1}{d\,KI} = \frac{\alpha}{KI^2}KI \quad \text{and} \quad E_{K_1,KI} = \frac{\alpha}{KI_1}$$

$$\frac{d\,KZ_1}{d\,KI} = Z^{-\gamma}\frac{d\,K_1}{d\,KI} + K_1(-\gamma)Z^{-\gamma-1}\frac{d\,Z}{d\,KI} = \frac{K_1\cdot Z^{-\gamma}}{KI}\left[\varepsilon_{K_1,KI} - \gamma\cdot\varepsilon_{Z,KI}\right]$$

or

$$E_{KZ_1,KI} = \left(\varepsilon_{K_1,KI} - \gamma\cdot\varepsilon_{Z,KI}\right) > 0\,.$$

Finally, $E_{\tilde{F}_1 KI}$ can be calculated from

$$\frac{d\,\tilde{F}_1}{d\,KI} = \frac{d}{d\,KI}\left[\frac{\partial C_1(T_1,KZ_1,PF)}{\partial\,PF}\right] = \frac{d\,\tilde{F}_1(T_1,KZ_1,PF)}{d\,KI}$$

by using again the chain rule of differentiation .

Elasticities which enter *x(p₁; KI), x(p₂; KI), x(Z; KI), x(K, K₁; KI)*

The elasticities which enter $x(p_1;\ KI)$ and $x(p_2;\ KI)$ are $\varepsilon_{CT,p_i} = \frac{\alpha_i}{\alpha.}$ because we normalize prices to be unity in the base year. Therefore $\frac{\alpha_i}{\alpha.} = w_i$ is the cost share. Furthermore, $\varepsilon_{T_i,p_j} = w_j + \frac{\beta_{ij}}{w_i}$.

The elasticities in $x(Z;\ KI)$ are:

$$\varepsilon_{CT,KZ} = \varepsilon_{T_i,KZ} = \varepsilon_{\tilde{F},KZ} = -\frac{\alpha_K}{1-\alpha_K}$$

$$\varepsilon_{p_1,KZ} = -\left(\frac{\alpha_K}{1-\alpha_K}\right)\left(\frac{\tau_{K_1}}{1-\tau_{K_1}}\right), \quad \varepsilon_{p_2,KZ} = -\frac{\alpha_K}{1-\alpha_K}\ \frac{\rho_{K_2}}{1-\rho_{K_2}} \quad ,$$

$$\varepsilon_{p_1,KZ_1} = \varepsilon_{C_1,KZ_1} = \varepsilon_{\tilde{F}_1,KZ_1} = -\frac{\tau_{K_1}}{1-\tau_{K_1}} \quad , \quad \varepsilon_{p_2,KZ_1} = 0 \quad ,$$

$$\varepsilon_{\tilde{F}_1,T_1} = \frac{1}{1-\tau_{K_1}} \quad , \quad \varepsilon_{\tilde{F},T} = \frac{1}{1-\alpha_K}.$$

Elasticities which appear in $x(K,\ K_1;\ KI)$ do also appear in $x(Z;\ KI)$. Finally, the only elasticities in $x(\tilde{F};KR)$ are

$$\varepsilon_{p_1,K_2} = 0 \quad , \quad \varepsilon_{p_2,K_2} = \varepsilon_{C_2,K_2} = -\frac{\zeta_{K_2}}{1-\zeta_{K_2}} \ .$$