Essays in Road Pricing –
Modeling, Evaluation and Case Studies

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1 Introduction

Developed road freight and passenger transport systems are essential for the existence of modern societies. They ensure the mobility of factors, goods and people across spatially differentiated markets, and increase the level of competition between these markets. While road freight transport is a necessary precondition for trade, road passenger transport provides individual mobility, which is a highly appreciated consumption good. In addition, both road freight and passenger transport amplify positive agglomeration and specialization economies,[1] as they help to decrease the economically relevant distances between market participants.

On the other hand road transport is associated with negative side effects, so-called externalities, which are not covered by the price mechanism of the market system. The most important of these externalities are congestion effects, local air pollution, noise and the emission of the greenhouse gas CO_2. For more than 80 years already, economists have been recommending user charges as a way of efficiently internalizing such externalities, but significant, practical applications did not appear for a long time. Only today, road pricing in metropolitan areas ("city toll") has become an accepted, although still controversial, policy instrument for the reduction of external effects caused by road transport. Experience gained from its implementation is growing rapidly, mainly in the US, Singapore, and Melbourne (City Link); two recent European schemes, the London Congestion Charge, and Stockholm, have been the subject of much public debate.

This thesis deals with potential welfare effects of different urban road pricing schemes (chapter 2, 3 and 4) and the potential impacts of different oil price scenarios on road transport (chapter 5) in Germany.

Chapter 2 provides an overview of the characteristics of external cost categories. This is important because these characteristics influence the efficient spatial and temporal structure of toll tariffs as well as their optimal level and differentiation. It becomes clear that not all external effects are equally well-suited to being internalized by road pricing systems. Moreover, the necessity for such schemes to have clearly defined objectives will be worked out, as tolling tariffs designed for the internalization of one cost category may contradict other internalization goals.

In chapter 2 we also review existing simulation studies on road pricing, first, to get first impressions of the range of possible effects for our own case studies, but also to derive some conclusions for the

[1] Positive agglomeration economies are the main reason for the spatial concentration and specialization of economic activities. They are characterized by market external effects between neighboring firms, e.g. labor market pooling, the sharing of intermediate inputs and local public goods as well as knowledge interactions between these firms. Cf. e.g. GRAHAM (2005).

simulation and modeling process as well as the benefit assessment of these case studies of our own. Furthermore, chapter 2 presents our methods of modeling and assessing the effects of urban road pricing schemes. In general, we used the static transport modeling suite VISUM, plus some procedures of our own to include price-sensitive transport demand in the simulations. The description of the cost-benefit framework for the evaluation of reduced externalities due to road pricing schemes is also part of chapter 2.

Chapter 3 is based on research work for the European Commission within the TELLUS project.[2] It analyzes the effects of environmental-oriented road charging schemes exclusively for trucks in Berlin. To date, available research literature has focused more on passenger and private vehicles instead of trucks. However, the negative impact of freight traffic should not be underestimated. Berlin's traffic of heavy trucks represented only 4% of total mileage in 1995, but 39% of PM 10 emissions. Roughly the same relationship exists between truck mileage and NO_X emissions. Freight traffic also strongly influences the absolute noise level: LINK ET AL. (2002) suggested that the cost of noise from a single truck is about 14 times higher than from a passenger car.[3] A toll solely levied on trucks could be seen as the first realistic approximation to an internalization strategy for noise and local environmental effects. Our simulation approach takes into account the interdependency of the two demand segments, truck and passenger car traffic. It is based upon recent empirical studies conducted in other cities; amongst other things we use data from the London congestion scheme to estimate general cost elasticities for truck trips.[4] Beside theoretical considerations necessary for the traffic modeling process we review and select input values regarding cost rates and cost elasticities. Then we quantify the positive effects of reduced air pollution, noise reduction, optimized capacity utilisation and the total welfare effects according to the methodology described in chapter 2.

Chapter 4 draws on research work conducted for the German Federal Ministry of Transport, Building and Urban Affairs[5] and the Volvo Research and Education Foundations.[6] In order to estimate the effects of a toll for cars and trucks in structurally differing agglomerations we conducted simulations for the metropolitan areas of Berlin and Stuttgart. The urban structures of these two agglomerations are quite different; while the Berlin road system is radial and focused on the monocentric center of the city, the network around the metropolitan area around Stuttgart has a mesh structure. These network configurations correspond to distinct distributions of transport demand. Due to these characteristics,

[2] Cf. WINTER / HIRSCHHAUSEN (2005).

[3] Cf. LINK ET AL. (2002, p. 139).

[4] Cf. SANTOS. / SHAFFER (2004).

[5] Cf. BECKERS ET AL. (2007).

[6] Cf. HIRSCHHAUSEN / NAGEL (2007).

different road pricing solutions, varying in spatial coverage (partial or full area) and appropriate toll structure (mileage-based vs. cordon) should be adequate for these metropolitan areas. Covering only the city center should be more suitable to the monocentric agglomeration Berlin, while the mesh network of Stuttgart's metropolitan area should benefit more from tolling schemes that rely on extensive distance-related fees. Hence, we analyzed different road pricing schemes for both agglomerations. On the one hand, this was a cordon-toll, differentiated according to the time of day, for the respective inner city, the Stuttgart "city basin", and the "great dog's head" in Berlin. Other scenarios feature distance-dependent tolls for the entire city area. The results were also evaluated according to the cost-benefit approach described in Chapter 2.

Tolls are only one potential part of the decision-relevant costs for the individual transport user, fuel costs being another important cost factor. Even if the oil price now, in January 2009, has fallen to levels last seen in the year 2004, the last few years were dominated by very high and volatile oil prices. From certain oil price levels up the fuel cost component could disturb or even override the predicted and desired welfare effects of tolling systems. That is why we consider the analysis of the impact of high crude oil prices on the transport sector in chapter 5 to be a useful supplement to our simulation studies.

First we describe the most important features of the world oil market in order to understand the current price levels of oil and petroleum products. As the transport sector accounts for more than 50% of world oil consumption, its share actually being expected to rise further,[7] we focus our analysis on the features of transport fuel demand. Then we analyze the supply side and the process of market price formation, which is basically made up of interactions between supply and demand. Here we focus on two decisive factors: The role of various risks on the supply side which translate into risk premiums on market prices, and the aspect of expectations and potential speculations on future markets. Both factors are supposed to have contributed to the recent increases and volatilities of the crude oil price.

We review empirical and model-based evidence for macroeconomic consequences of high oil prices, including some long-term forecasts from research literature. In addition, we explore the potential for adaptation and substitution processes in transport markets which may be induced by higher oil prices. As we are going to show, the reactions of both fuel market sides to high crude oil prices will contribute to limit the rise of crude oil prices. From potential reactions of both market sides we derive recommendations for a sustainable economic policy.

In addition, we explore some of the implications of different short-term oil price scenarios for the German road transport sector. In particular, we analyze the impacts of extreme, short-term increases of

oil prices up to 250 USD per barrel and shifts of the EUR-USD-exchange rate to 1:1. However, these basic assumptions for the scenarios should not be regarded as predictions, but as stylized if-then-analyses of the worst case. For the calculation of the effects of higher oil prices and changing exchange rates we chose a bottom-up-approach. In a second step, we calculate the changes in German car and truck mileage as well as adaptations of technical fuel efficiency and fuel consumption resulting from the fuel price increases. Finally, we draw conclusions concerning the potential impacts of different oil price levels on the transport sector and summarize our insights from the simulation studies.

[7] Cf. EIA (2007, p. 30).

2 The Evaluation of Urban Road Pricing Schemes - Background and Methodology

2.1 The Potential of Urban Road Pricing as an Economic Instrument

2.1.1 The Potential of Urban Road Pricing to Improve Capacity Utilization

The world over, urban centers suffer from temporary traffic congestion problems, in spite of massive expansions of road capacities. These problems can be considered the indirect price to be paid for the benefits derived from the agglomeration of population and economic activities in cities.[8] However, from an economic viewpoint, a central cause of the overutilization of urban roads indicated by traffic congestion can be seen as the failure to utilize suitable mechanisms for the allocation of this limited resource, road capacity. Even today, the right to use urban road capacities is still allocated, as a rule, by the principle of queuing. This principle does not allow of the efficient coordination of decentralized decisions made by road users, e.g. about the number of trips they demand and their departure times, because differences in the user's valuation of road capacity remain unconsidered.[9]

For more than 80 years already, economists have been recommending user charges as an efficient way of rationing infrastructure capacities,[10] but significant practical applications did not appear for a long time. Today, there are only very few city center road-pricing solutions in operation, e.g. in Singapore and London. However, the success of the London Congestion Charge, which drastically reduced traffic congestion in the city center, reveals the potential of road pricing for improving the capacity utilization of urban traffic systems.[11]

2.1.1.1 The Cause of Capacity Overutilization in Road Networks

Road transport is characterized by independent decisions of individual road users to use the road space at a particular time. Along with distance-related costs, e.g. for fuel, private time costs are decision-relevant for each individual trip. A view of a single link in the network produces the relationship illustrated in Figure 1 between traffic flow, i.e. the number of present users, and the average speed achieved.[12]

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[8] Cf. LINDSEY / VERHOEF (2000, p. 377).

[9] Cf. e.g. BUTTON (2004, pp. 62 f.).

[10] Cf. PIGOU (1920).

[11] Cf. e.g. TRANSPORT FOR LONDON (2004).

[12] Cf. BUTTON (2004).

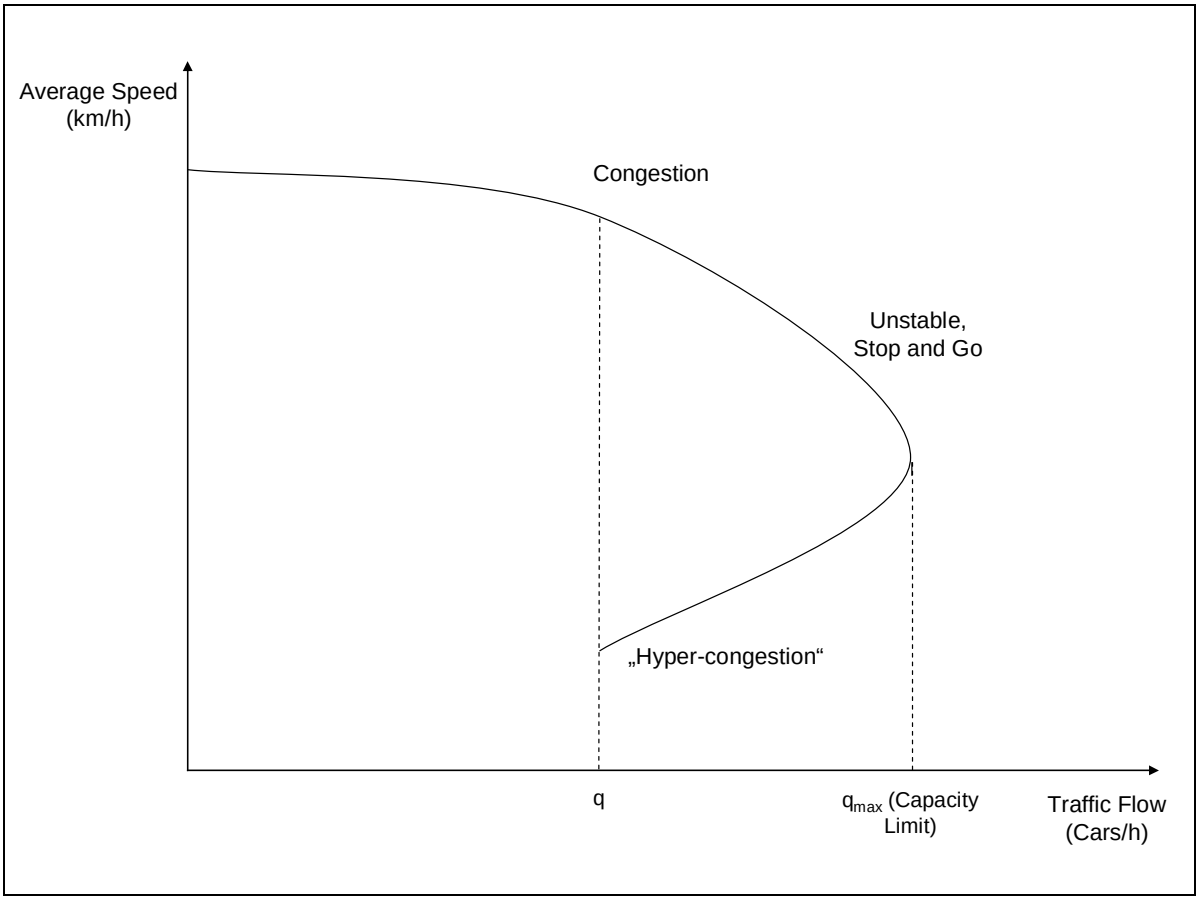

Figure 1: Relationship between Average Speed,
Level of Traffic and the Occurrence of Congestion[13]

As a result of mutual interference by road users, average speeds are reduced with increasing traffic volumes, down to stop-and-go traffic and temporary standstill at capacity limits. Each additional vehicle slows down all other road users and thus increases their private (time) costs. When making a decision about a trip at a particular time and on a chosen route, every road user takes his private trip costs (including his own time costs) into account. However, he ignores the fact that he has a direct influence on the journey time and hence on the costs of other road users. All road users decide about a trip according to this rational calculus. In the absence of overcapacities and without suitable allocation mechanisms, this will lead to an overutilization of the available road network at times of heavy demand, resulting in delays and congestion.

The additional trip costs with which other road users are burdened are known as marginal external congestion costs. These marginal external congestion costs rise continually with increasing traffic volumes, because average speeds decrease disproportionately, leading to increased travel times. The

total of marginal external congestion costs (MEC) and marginal private costs (MPC), which normally corresponds to the average variable costs (AVC), results in a trip's marginal social costs (MSC), as demonstrated in Figure 2. The left-hand part of the illustration shows the relationship (directly derived from Figure 1) between the number of road users and the travel time on the link. The average variable costs (AVC) shown in the function on the right in Figure 2[14] are journey time multiplied by the monetary value per user time unit (Value of Time; VoT), plus mileage-related costs.

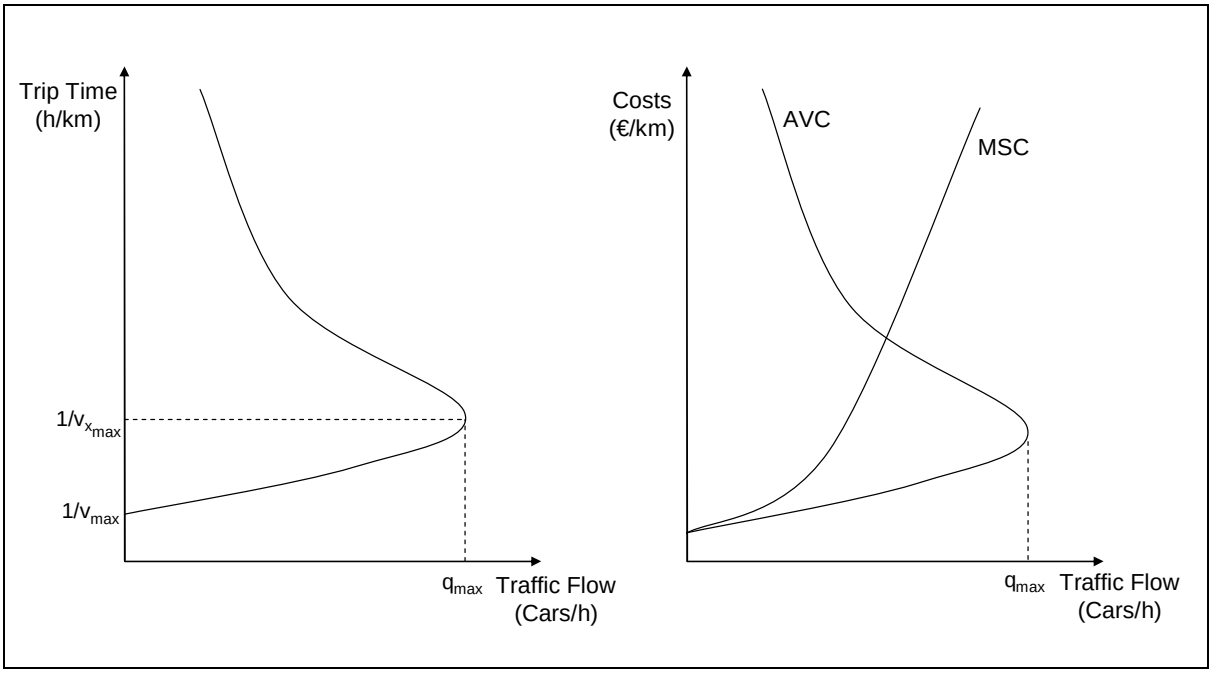

Figure 2: Derivation of a Link-Related Supply Curve[15]

This function can be interpreted as a supply or performance function for the representative link. The average costs per trip increase, at first moderately with the traffic volume, up to the capacity threshold. If the capacity limit q_{max} is exceeded, the reduced average speeds lead to an increase in travel times and costs, with sinking traffic flow levels; the average trip costs approach infinity. This results in the characteristic cost function with a backward-bending curve for the unstable state of hyper-congestion.[16] From Figure 2 it becomes clear that the marginal social costs (MSC) for a trip on the link approach infinity when capacity limits are reached. The further MSC and AVC diverge, the greater is

[13] Source: e.g. BUTTON (2004).

[14] Cf. BUTTON (2004).

[15] Source: e.g. BUTTON (2004).

[16] The unstable state of hyper-congestion can be examined adequately only through dynamic models. Within the scope of the traditional cost-benefit analysis with a static simulation approach, only the stable overload states are examined that are represented by the upward curve of the average costs, Cf. LINDSEY / VERHOEF (2000, p. 357).

the degree of overutilization on the route. The resulting welfare losses depend on the demand along the link, as made clear in Figure 3. The (inverse) demand function expresses the marginal private benefit (MPB) or the marginal willingness to pay for a trip by the road user. External benefits are not assumed in the case of road usage. Hence the marginal private benefits equal the marginal social benefits (MSB) for trips.[17] The traffic volume q*, at which the marginal social costs (MSC) correspond to the marginal willingness to pay (MPB=MSB), i.e. at the intersection between demand function and marginal social costs, is called welfare maximizing.

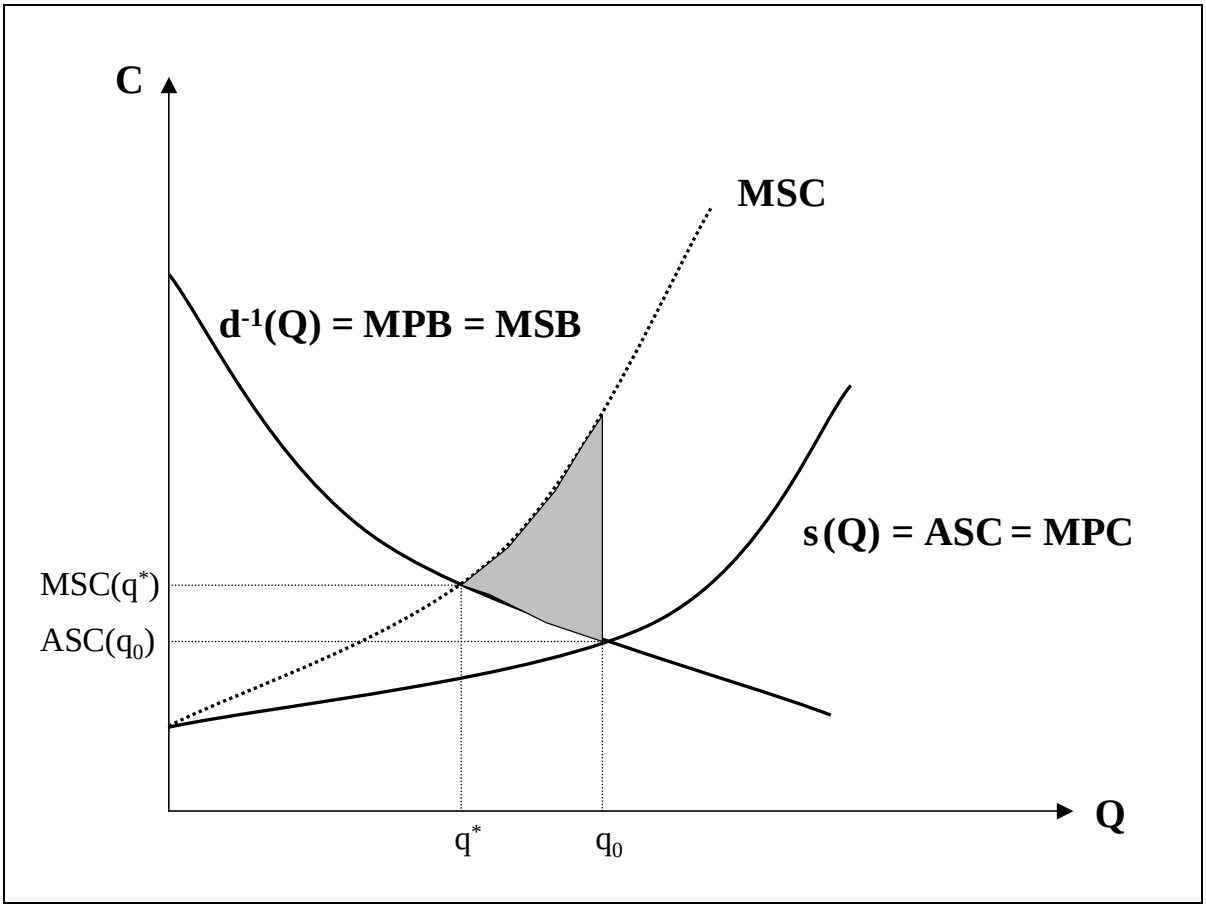

Figure 3: Welfare Losses due to External Congestion Costs[18]

However, due to the users' ignorance of congestion externalities, the higher traffic level q_0 is realized instead. Welfare losses are defined by the areas marked in gray in Figure 3, the so-called "Harberger's Triangle". They result from the difference between social benefits and social costs for both traffic levels q* and q_0.

[17] Cf. e.g. LINDSEY / VERHOEF (2000).

[18] Source: Own compilation.

2.1.1.2 Characteristics of Congestion Costs

The previous characterization of external congestion costs is based on a very simplified, link-based model. Essential knowledge resulting from this static model corresponds to reality. For example, marginal congestion costs do actually increase disproportionately with increasing traffic volumes. However, additional features of congestion costs that are not mapped in the basis model must be also taken into account when developing strategies for optimizing road capacity utilization.

A longer average trip time in the urban road network is indeed the most obvious example of a congestion externality. But low levels of reliability for trip and arrival times must also be considered, a factor that is of great importance for commuters and business travelers, but also for freight traffic.[19] For instance SMALL ET AL. (2002) calculate the median value for reliability at 97% of the monetary value of the journey time per hour,[20] and KÖNIG (2004) estimates for a 50% to 80% delay probability monetary values between 58% and 107% of the value of travel time.[21]

Traffic is usually not an end in itself, rather, its purpose is derived from other consumer or production activities.[22] Because these activities are characterized by different time patterns, the urban road traffic also shows exogenous daily, weekly or yearly profiles. The commuter traffic in the mornings and evenings, to work in the city center or from work to the outer areas, is an example of this. Not only the physical capacities of the road network, but also an essential part of the daily human activity plans is inflexible at short notice. Therefore, extreme traffic loads may arise in urban road networks at certain times of day (so-called "peaks"). Thus, congestion is not so much a permanent overload problem for the road network; the majority of welfare losses due to congestion externalities occurs during the morning and evening peak hours.[23]

In addition, the (over-)utilization of the urban road infrastructure differs strongly as to region. The closely interwoven road network in city centers is particularly affected by external congestion costs, as attractive destinations for motorized individual transport are to be found here, such as places of work and shops. Different from the basic model, which only relates to a representative road link, delays at

[19] Cf. e.g. GOODWIN (2004).

[20] Cf. SMALL ET AL. (2002, p. 38). The comparison between the monetary value of time and the value of reliability is based on the median values of the population, which were determined in a "Revealed Preferences" analysis. Unreliability is defined here as the difference between the 50th and the 80th percentile of the journey time.

[21] Exemplary calculations based on the results of the extensive “Stated Preferences” analysis of KÖNIG (2004, p. 108 and p. 113).

[22] Cf. e.g. BUTTON (2004, p. 4).

[23] Models that take account of the explicit choice of the optimum departure time were introduced by ARNOTT ET AL. (1990).

junctions are especially critical for congestion in city centers.[24] High marginal congestion costs also arise on well developed access roads to the center. These links are intended for a high concentration of motorized individual transport and, due to their location and high capacities, are a particularly attractive choice for the road users of many origin-destination pairs. In reality, moreover, maximum road capacities and an individual road link's liability to congestion depend on physical road characteristics (e.g. curve radius, number and width of lanes), as well as on exogenous factors such as the weather.[25] Table 1 illustrates the regional and time-related differences in marginal congestion costs based on the results of SANSOM ET AL. (2001) for Great Britain.

Road Category	**Percentage of Transport Performance**	**Low Estimate** (in Pence/vkm)	**High Estimate** (in Pence/vkm)
Motorway or Similar	17 %	12.80	12.80
London City Center, Peak	1 %	85.76	85.87
London City Center, Off-Peak	3 %	46.61	47.15
London outside of Center, Peak	4 %	22.89	24.26
London outside of Center, Off-Peak	8 %	11.09	13.67
Other Cities, Peak	7 %	4.58	8.38
Other Cities, Off-Peak	15 %	0.65	4.89
Rural, Main Road	30 %	9.11	9.21
Rural, Other	16 %	1.32	2.92

Table 1: Marginal Congestion Costs in Great Britain in 1998[26]

The very high marginal congestion costs for the London city center of more than one € per vehicle kilometer (vkm) are remarkable. With the introduction of the London Congestion Charge in 2003, these values as well as the resulting welfare losses have been significantly reduced. As expected, the time-of-day traffic situation (peak vs. off-peak) corresponds to the level of the marginal congestion costs. In addition, the marginal congestion costs vary considerably with regard to different regions.[27]

Along with the described differences according to region and time of day, it can be assumed that there are different values for (marginal) congestion costs for different trip purposes and vehicle categories. For the one thing, the cost per time-unit (value of time; VoT) for business travelers and delivery trips will be higher than for leisure traffic. Thus, these time-sensitive users are subject to congestion costs that are above average levels. On the other hand, trucks are involved to a disproportionately high

[24] Cf. SANTOS / NEWBERY (2001, p. 4).

[25] Cf. e.g. LINDSEY / VERHOEF (2000, p. 355).

[26] Source: SANSOM ET AL. (2001).

[27] This spreading of congestion costs is a general phenomenon and is not restricted to London.

degree in causing congestion in urban traffic systems, due to their low acceleration capabilities, their length and their low average speed. These characteristics must also be considered when evaluating the suitability of a road pricing solution for managing capacity utilization.

2.1.1.3 Implications for City Tolls as an Instrument to Manage Capacity Utilization

The fundamental idea of an urban road pricing solution for optimizing the utilization of available road capacities is to make road users aware of the external congestion costs they cause so that they can take these factors into account when deciding about a trip. The external congestion are made internal by inclusion in the user calculus. In analogy to other markets, a price for road usage serves to indicate its scarcity and, in an ideal case, ensure efficient rationing of demand according to the willingness to pay.

An existing road network is used efficiently if the marginal social costs of usage are equally high for all routes used between two points in the network, and none of the unused (alternative) routes have lower marginal social costs.[28] At the same time, the marginal willingness to pay for a trip between any two points must correspond to the marginal social costs, or, respectively, be lower if no trips take place on the route.[29] Theoretically, a welfare-optimal network equilibrium would be achieved if each road link were assigned a toll corresponding to its specific marginal external congestion costs.

Even if such a comprehensive tolling system covering all road links was possible, setting optimal prices would remain a problem that could hardly be solved, due to the variations in charges that would be necessary, according to time of day and current utilization. In addition, with constantly changing charges, it would be practically impossible for road users to make an efficient choice for the required trip.[30] For this reason, (second-best) efficient price systems for managing road capacity utilization will only be able to approach the temporal and regional variations shown in the marginal congestion costs. However, it certainly makes sense to vary the toll according to the time of day. This can be done in discrete steps, which the road users know and understand right from the start, thereby simplifying planning a trip. It may be appropriate to waive toll fees in the night, on Sundays and public holidays as well as in other low-load periods. When designing the spatial scope of a road pricing scheme, road links or city areas with high traffic volume and low ex ante average speeds should be regarded first; possible alternative routes have be considered as well.[31] Congested city centers are potentially most

[28] This corresponds to the second Wardrop principle, which formulates the conditions for a system optimum in a road network Cf. LINDSEY / VERHOEF (2000, p. 267).

[29] Cf. ibd.

[30] Cf. SANTOS / NEWBERY (2001, p. 3).

[31] Mathematical approaches for optimizing the regional positioning of cordons for urban road pricing schemes are delivered by e. g. SUMALEE (2004).

suitable for road pricing. Moreover, a city's regional configuration will always have a decisive influence on the ideal design of the road pricing solution. Because heavy vehicles cause higher marginal congestion costs than do private cars, the vehicle category should also be included as a differentiation criterion for the congestion toll.

Road pricing – in the same way as other transport policy instruments for managing utilization of urban road capacities – is intended to induce adjustment processes of the road users. Along with the cancellation of particular trips, not covered by willingness to pay, welfare impacts are also possible due to the following effects:[32]

- changing choice of route
- changing departure times
- changing destinations
- changing modes of transport
- changing vehicle occupancy / utilization rates

Changing the choice of route and departure time could, above all, lead to relieving regional or temporary peak loads. Possible changes in the choice of destination due to a toll will depend on the trip purpose. For example, the short-term possibilities of switching to other destinations outside the toll area are much greater for leisure or shopping trips than for business or commuter trips. However, commuters may adapt their place of residence to a toll in the long term. One short-term adaptation option for them is a switch to public transport, since the storage space in a private car hardly plays a role for commuters, while the opposite is true for shopping trips. Car pooling, which increases average occupancy rates of vehicles, may be a further alternative, especially for (synchronous) commuting or accompanying trips.[33] In addition, combinations of these demand reactions are possible, such as partial mode changes to Park&Ride and a change to linking trips with different purposes. All these possibilities for transport demand reactions have to be considered in designing a congestion-related road pricing solution.

Evaluating the traffic-related effects of a specific road pricing solution is the basis for determining its welfare effects. Above all, toll-induced changes in choice of route can neutralize potential welfare

[32] Cf. z. B. ENGLMANN ET AL. (1996, pp. 60 ff).

[33] Accompanying traffic is mostly caused by parents taking their children to school or kindergarten.

gains due to reduced numbers of trips if road users accept longer travel distances and journey times (avoidance traffic). Especially in closely interwoven urban networks with a great number of possible route choices, mapping the interaction of individual route decisions by using regionally detailed simulation models is indispensable.

2.1.2 The Potential of Urban Road Pricing to Improve Environmental Quality

During the last 10 years the emissions of nearly all airborne pollutants have been considerably decreased in European metropolitan areas. The reduction of pollution has been due to immobile sources like private heating as well as mobile sources i.e. road traffic. In the road transport sector, technical and legal restrictions like the mandatory introduction of the Euro norms for new cars and cleaner fuel standards have succeeded in diminishing most of the adverse effects on humans and the environment. Current emission levels of lead, CO2, benzene and sulfur dioxide are so low that the former problems caused by these pollutants can be considered as nearly solved.[34]

Nonetheless, due to more recent medical evidence on the harmfulness of some airborne pollutants, tougher EU restrictions on immission levels are coming into force in 2010. This poses additional difficulties for the responsible public authorities, as at present these immission limits for NO_X and PM10 are still being exceeded in many European cities.[35] Due to the latter, many local authorities have been required to produce a local air quality plan.[36] This plan contains specific local measures to address these environmental problems. The transport sector as one of the main classic emitter of PM10 and NO_X is being targeted, too.[37]

While traffic-induced air pollution should decline further within the next few years, the importance of noise-related problems will rise. This is reflected by new legislation on the European level dealing with this issue, such as the EU directive 2002/49/EC on environmental noise. Beside the information of the public about noise exposure and its effects, a key requirement of this directive was to draw up binding action plans for larger cities to address noise issues by the year 2008.

The large potential risks of further man-made climate changes has attracted considerable attention in the last few years, too. Road transport emits about 17% of global energy-related greenhouse gas

[34] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999, p. 21).

[35] Cf. LUTZ (2004, p.1).

[36] This is necessary according to §13 of 22. BImSchV, based on EU directive 96/62/EG.

[37] Cf. LUTZ (2004, p. 2).

(GHG) emissions. [38] Hence many proposals to reduce the sector-specific CO_2 emissions have been suggested.

The potential contribution of road pricing schemes to an effective reduction of these environmental problems has been discussed in research literature for a long time.[39] The next sections will briefly consider the characteristics of external costs of local air pollution, climate change and noise in order to derive implications for the design of road pricing schemes targeting these effects.

2.1.2.1 Characteristics and (Marginal) Damage Costs of Local Air Pollution

The majority of traffic-related external effects caused by local air pollution are the result of negative effects of three substances: PM10, NO_X and ozone. The resulting health damages make up the main part of the external air pollution costs. On the other hand, detrimental effects caused by natural ecosystems and negative effects of crop growing, occurring above all in rural areas, are relatively low.[40]

Nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are normally combined under the designation NO_X.[41] NO_2 is considered an irritant gas even in low concentrations and causes an acute increase in resistance in the respiratory system. Long-term, intensive exposure can restrict aeration, lead to inflammation and reduce resistance to infections.

Ground-level ozone is not emitted directly, rather it is created by chemical reactions between nitrogen dioxide and hydrocarbon (HC) under the influence of heat and sunshine. The health-damaging effects of ozone primarily affect the respiratory system. Ozone can cause disorders such as irritation of the respiratory tract, coughs, headaches and breathing difficulties as well as watery eyes.

PM10 ("particulate matter") is breathable dust whose particles are smaller than 10 micrometers, PM2.5 particles are, accordingly, only up to 2.5 micrometers in size. Viewed chemically, they consist of a mixture of organic and inorganic materials which vary regionally according to the source of emission. The emission particles PM10 are so fine that, once they are breathed in, they end up deep in the lungs and may remain there. The cause and intensification of some respiratory and cardiac illnesses is attributed to these particles. The effect of floating dust on human health differs according to the chemical composition and the size of the particles. While the intake of larger PM10 particles is more

[38] Cf. IPCC (2007, p. 325).

[39] Cf. e.g. JOHANSSON-STENMAN / STERNER (1998), MITCHELL ET AL. (2002) and SANTOS (2003).

[40] Cf. e.g. INFRAS / IWW (2000), LINK ET AL. (2002) and MAYERES ET AL. (2001).

closely connected to coughs, asthmatic fits and respiratory deaths, the quantity of the finer particles PM 2.5 correlates more to the number of cases of irregular heartbeat and increased cardiac deaths.[42] Furthermore, the very fine soot particles are suspected of causing lung cancer. In medicinal studies, for example, rates of cancer up to 40 % higher than normal have been proved to be related to extended exposure to high levels of diesel exhaust particles.[43]

It applies generally that urban areas, above all, are affected by air pollution by traffic, because not only those mainly damaged (residents), but also the emitters (motorized traffic) are concentrated here. The impact chain of air pollutants – from deposition and immissions to the damages caused – is extremely complex and involves passing through numerous chemical processes.[44] It is noteworthy that the contribution to pollution from a single emission source is not only local, but rather can take effect more than several hundred kilometers away.[45] Meteorological conditions such as the direction and the strength of the wind play an important role with regard to distribution. For example, WEINREICH (2000) estimated external air pollution costs for motorized individual transport in Germany. In the south-western region of Freiburg these costs were up to three times higher than in the northern region of Flensburg.[46] For one thing, the predominant north-west wind in Germany leads to higher concentrations of air pollutants in the former region. For another, the higher population density in the Freiburg area is a decisive factor for this result.

Local air pollution is usually assumed to be accompanied by constant marginal damage costs with increasing levels of traffic. These do indeed vary with the geographical location of an urban agglomeration and the density of its traffic and population, but there are no noteworthy variations relating to the time of day. Table 2 gives an overview of the dimensions of the marginal damage costs of selected air pollutants (per exhausted t) in large European cities.

[41] The non-toxic NO oxidates rapidly in the atmosphere becoming NO_2; quantities for NO_X are normally given in NO_2 equivalents for this reason. Cf. BUWAL (1995, p. 24).

[42] Cf. BUWAL (2001, p. 31).

[43] Cf. WHO (2000, p. 20).

[44] Cf. BICKEL / FRIEDRICH (1995, p. 47).

[45] Cf. RICCI / FRIEDRICH (1999, p. 5).

[46] Cf. WEINREICH (2000).

Air Pollutant / € per t	**McCubbin / Delucchi (1999)**		**Holland / Watkiss (2002)**	**Maibach et al. (2008)**
	Low Estimate	High Estimate		
Carbon Monoxide (CO)	38	229	157	-
Nitrogen Oxide (NO_X)	8,395	100,120	4,285	9,600
Sulfur Oxide (SO_2)	44,631	289,489	100,425	11,000
Particulate Matter (PM10)	69,766	649,663	368,457	153,800
Particulate Matter (PM2.5)				384,500
Hydrocarbons (HC)	651	5,537	2,926	1,700

Table 2: Marginal Damage Costs of Air Pollutants in Large European Cities[47]

It can be seen that particulate matter causes the highest level of damages per quantity unit of all local air pollutants. However, Table 3 shows that NO_X is emitted in considerably larger amounts. Therefore, high priority should be given to reducing these two pollutants.

Pollutant	**Exhaust p. a. in t (2003)**
Carbon Monoxide (CO)	593.521
Nitrogen Oxide (NO_X)	1,707,230
Sulfur Oxide (SO_2)	824
Particulate Matter (PM10)	27,747
Hydrocarbons (HC)	179,877

Table 3: Emission of Air Pollutants by Road Traffic in Germany in 2003[48]

In terms of an efficient reduction strategy, all relevant sources should be charged the same amount per emitted quantity of a pollutant, not only within the traffic sector but also outside. This charge rate should be geared to the marginal damage costs. In road traffic, these charges would correspond to toll fees, which can be differentiated according to a vehicle's exhaust characteristics, e.g. their Euro norm. Since PM10 is almost exclusively emitted by diesel vehicles, the charges for diesel and petrol operated vehicles have to differ substantially. Equally, trucks and busses have to be charged higher rates than cars, due to their considerably higher exhaust emissions. Table 4 from BICKEL / SCHMID (2002) provides an overview of the ranges of marginal air pollution costs per vehicle kilometer for different vehicle categories in Berlin.

[47] Source of data: MCCUBBIN / DELUCCHI (1999) and HOLLAND / WATKISS (2002), updated in WINTER / HIRSCHHAUSEN (2005, p. 34) to the base year 2003; and MAIBACH ET AL. (2008, p. 52) to the base year 2000.

[48] Source: UBA (2005).

Vehicle Category and Euro Norm	Marginal Air Pollution Costs in ct/vkm
Petrol Drive	
Motor Cycle Euro 0	0.45
Car Euro I	0.33
Car Euro II	0.25
Car Euro IV	0.14
Diesel Drive	
Car Euro I	1.75
Car Euro II	1.45
Car Euro IV	0.37
Light Truck Euro II	2.10
Heavy Truck Euro II	17.52
Coach Euro II	12.44
City Bus Euro II	13.55

Table 4: Marginal Air Pollution Costs per Vehicle Category in Berlin (2002)[49]

Even if there are considerable differences between the marginal air pollution costs for the individual vehicle categories, their level is mostly below that of the external congestion costs. This restricts the potential for welfare gains through an environment-based toll, as compared to to an urban road pricing solution aiming at capacity optimization. At the same time the effects of a city toll on the environment, as opposed to effects on capacity utilization, are almost always positive, since a reduction in vehicle mileage is sufficient for this.

2.1.2.2 Characteristics and (Marginal) Damage Costs of CO_2

As a result of the heavy use of fossil energy sources, the level of carbon dioxide in the earth's atmosphere has increased steadily, from 280 ppm in pre-industrial times to 379 ppm in 2005.[50] There is a broad scientific consensus now that these increased CO_2 levels in the atmosphere have caused a strong and irreversible change of global climate. Among its negative consequences are rising sea levels and more frequent extreme weather events, like heavy storms, floods, heat waves and droughts. A further global warming may also provoke irreversible damages of ecosystems, losses in biodiversity

[49] Source: BICKEL / SCHMID (2002). Only pollutants emitted from vehicles are listed in the table; emissions created during production of vehicles and fuel, are not considered here. In comparison to other studies, such as HOLLAND / WATKISS (2002) and MCCUBBIN / DELUCCHI (1999), the cost rates in BICKEL / SCHMID (2002) are lower.

[50] Cf. IPCC (2007).

and negative impacts on human health, e.g. by a spread of tropical diseases.[51] The Intergovernmental Panel on Climate Change IPCC (2007) predicts an increase of the average temperature of between 1.8 and 6.4 °C before the end of the 21st century, depending on the emission reductions of greenhouse gases (GHG) that can be achieved.[52] Even the inevitable impacts of the man-made climate change are very serious challenges to the world's population and economy today. Without stabilizing the world's climate at a maximum average increase of +2 °C, as suggested by the IPCC, the risks of disastrous consequences for mankind may become uncontrollable. A study by the economist Nicholas Stern on behalf of the British government estimates that immediate, efficient action to tackle climate change until 2050 would cost only about 1% of worldwide Gross Domestic Product (GDP), while later action may imply economic losses which could sum up to 20% of worldwide GDP.[53]

With 95% of its energy consumption based on crude oil products, road transport is among the sectors with the largest CO_2 emissions. It currently accounts for about 17 % of global energy-related GHG emissions.[54] In addition, due to rising incomes and economic growth, transport activity is expected to grow robustly over the next several decades. In the absence of a major shift away from current patterns of energy use, IPCC (2007) predicts increases of 80% for total energy use and CO_2 emissions in the transport sector by 2030. This indicates an urgent need to involve the global transport sector in the efforts to reduce GHG emission levels by providing it with a suitable policy framework.[55]

The most important characteristic of global pollutants such as CO_2 is that their impact is not dependent on location, time of day or type of emission. Only the absolute quantity of the climate gas that is emitted worldwide is relevant for the damage caused. As a consequence, efficient CO_2 reduction strategies can not be limited to certain regions or particular sectors, as long as there are significant differences in the avoidance costs of emitters.

While in some Middle Eastern and Eastern Asian countries there exist large fuel subsidies, which contradict global climate protection goals,[56] in many European countries (high) fuel taxes are levied. Even if their primary aim is to yield revenue, they provide a cheap and effective transport policy instrument to support climate protection goals. Moreover, the inclusion of the transport sector in cross-sectoral trading systems for CO_2 emission certificates is extensively being discussed as an alternative

[51] Cf. MAIBACH ET AL. (2008, p. 72).

[52] Cf. IPCC (2007).

[53] Cf. STERN (2006).

[54] Cf. IPCC (2007, p. 325).

[55] Cf. BUNDESREGIERUNG (2005, p. 7).

[56] Cf. Chapter 5.

or supplement for existing fuel taxes in Europe.[57] High marginal avoidance costs for CO_2 emissions, as assumed by most analyses,[58] would predestine the transport sector as net-buyer in a European market for CO_2 emission certificates. As shown by HOHENSTEIN ET AL. (2002), the additional fuel costs from the participation of road transport in an emissions trading scheme amounted to merely 2-8 ct per liter of fuel, with assumed prices for emissions certificates of 10-30 € per ton of CO_2. This appears relatively low in comparison to earlier increases of eco tax and fuel tax.[59] A cross-sector system for trading with certificates is not likely to have a large effect on the reduction of CO_2 emissions from the transport sector, as fuel demand is very inelastic. Emission trading including the transport sector would, however, have a direct effect on reducing climate gas emission in other sectors; this should be considered equivalent, from an ecological viewpoint.

As there are suitable transport-sector specific and cross-sectoral instruments for the reduction of GHG emissions available, urban road pricing solutions should not be explicitly linked to a reduction of CO_2. However, a reduction of CO_2 can be anticipated as a positive side effect of reduced vehicle mileage due to a toll.

The independence of damages caused by CO_2 from location, sector or time of the emission results in constant marginal damage costs per quantity unit for any given period. The broad range of estimates for the marginal damage or avoidance costs of carbon dioxide is noteworthy; this reflects evaluation uncertainties as to climate impacts in the distant future. The cost estimations depend essentially on the estimating procedure used (damage costs vs. avoidance cost approach) as well as on the chosen time horizon, reduction goal and discount rate.[60] For example, the value of 205 € per ton of CO_2 saved has been set for the German Federal Transport Infrastructure Plan. This very high value is based on avoidance costs for a reduction of CO_2 emissions by 80 % in Germany from 1987 to 2050.[61] The EU project UNITE, on the contrary, assumes avoidance costs for achieving the reduction goals in the Kyoto protocol by 2010, this results in considerably lower marginal avoidance costs of 38 € per ton of CO_2.[62] The potential CO_2 shadow prices for an environmental toll resulting from this estimate differ by

[57] Cf. e. g. EWRINGMANN ET AL. (2005), CAMES / DEUBER (2004), HOHENSTEIN ET AL. (2002) and DEUBER (2002).

[58] Cf. e.g. CAPROS / MANTZOS (2000) and SRU (2002, p. 244).

[59] Cf. HOHENSTEIN ET AL. (2002, p. 98).

[60] Cf. MAIBACH ET AL. (2008, pp. 74 ff.)

[61] Cf. BMVBW (2003, p. 88).

[62] Cf. VAN DEN BOSSCHE ET AL. (2003, p. 62).

a factor of 5 and vary between 0.76 and 4.1 ct/vkm for cars and between 3.8 and 20.5 ct/vkm for trucks.[63]

Table 5 summarizes the recommendations of the new "Handbook on estimation of external costs in the transport sector", commissioned by the European Commission, on monetary values for reduced CO_2.[64] They are based on an extensive survey of the available literature. Nevertheless, the huge bandwidth of estimations is remarkable, so when using them in cost-benefit analyses, this needs to be taken into careful consideration.

Year of Application	**Lower Value** in € / t CO_2	**Central Value** in € / t CO_2	**Upper Value** in € / t CO_2
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Table 5: Recommended Values for External Costs of Climate Change in € / t CO_2[65]

2.1.2.3 Characteristics and (Marginal) Costs of Traffic Noise

Noise is sound which is unwanted and felt to be disturbing.[66] Subjective and objective damages, which may lead to economic costs, are caused to the affected persons by this disturbance. The effects of this disturbance can be a reduced ability to concentrate or communicate during the day, as well as interrupted sleep at night. The noise level at which disturbance occurs is very subjective and, among other things, related to age.[67]

Damage to health caused by noise cannot usually be identified as there is no typical "noise illness".[68] This difficult delimitation compared to other causes is probably the most important reason for the lack of empirical confirmation of health damages due to traffic noise. This is due, above all, to the fact that the illnesses arising are not very specific. In particular, the multi-causal factors of stress and interrupted sleep can play a central role in cardiovascular illnesses and high blood pressure. These

[63] This calculation was based on (rather high) specific emissions of 200 g CO_2 per vehicle kilometer for cars and 1,000 g for trucks in urban traffic, Cf. KELLER ET AL. (2004).

[64] Cf. MAIBACH ET AL. (2008, p. 80).

[65] Source: MAIBACH ET AL. (2008, p.80).

[66] Cf. e.g. WHO (1999, p. 8).

[67] Cf. UBA (2002, p. 39).

[68] Cf. ECOPLAN (1998, p. 17).

influencing factors are also central to the occurrence of noise-related health problems.[69] Nevertheless, significant effects are considered scientifically plausible for the most vulnerable groups of the population, e.g. elderly people.

The major part of all noise stress in industrial centers is attributed to the transport sector, with road traffic being the predominant cause. In 2004 about 60 % of the German population felt disturbed or even greatly disturbed by road noise.[70] The number of those feeling subjective stress through traffic noise has remained largely constant over the last years. This indicates that the (considerable) reductions of engine noise levels in new vehicles achieved in the past have been counterbalanced by a growth in traffic volumes.[71] It can be assumed that the problem of noise will increase in importance, absolutely and relatively to other external environmental effects.[72]

The same physical qualities apply to all noises, as they are inherent to sounds in general. These are determined, in particular, by the factors of frequency (in Hz) and sound intensity (in W/m²). Sound intensity is usually logarithmically scaled because of the wide range in W/m^2.[73] This scale causes an increase (reduction) of only ca. 3 dB(A) when the number of sound sources is doubled (halved). This relation applies equally to vehicles if they are the cause of the noise. With road traffic noise, this 3 dB(A) corresponds to the difference that is just audible between two levels. With road traffic noise, however, the subjective perception of halving the noise is achieved only when the sound level is reduced by 8-10 dB(A).[74] Other things being equal, a reduction of road traffic by 90 % would be necessary to obtain such a reduction in noise.

Normally, a linear connection can be made between traffic noise levels measured logarithmically (in dB(A)) and noise costs. This is accepted explicitly e.g. in INFRAS / IWW (2000) and confirmed by numerous empirical studies.[75] Constant marginal costs for increasing dB(A) levels are equivalent to sinking marginal noise costs for additional vehicles. This can also be easily seen intuitively: Noise levels rise sharply during the changeover from a quiet state; it is, above all, the first truck, the first

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[69] Cf. PORTER (1998, p. 12).

[70] Cf. SRU (2005, p. 35).

[71] Cf. e.g. ibid. p.290

[72] Cf. e.g. WHO (1999, p. 8).

[73] To simplify this, one sets the ratio for the sound intensity of the auditory threshold to 1=100, the pain threshold corresponds to 10^{13} times the intensity of the auditory threshold. These ratios are measured in Bel units. The loudness levels 0 to 13 are obtained from their common logarithms. The familiar unit for noises- decibel - is obtained by sub-dividing these levels in steps of 10. To adjust the dB values measured to subjectively felt loudness values, an internationally normalized filter is used for inaudible and poorly audible high and low frequencies, the so-called "A-Filter". Sound levels evaluated by means of this filter are given in dB(A).

[74] Cf. BMV (1998, p. 16).

[75] Cf. INFRAS / IWW (2000, p. 75) and e.g. also BICKEL / SCHMID (2002).

motor cycle and the first car that disturb the peace. With increased traffic volumes, the peace disturbance only increases degressively with further vehicles. This leads to very high costs at first, but also to sinking marginal costs later on for each vehicle's noise.[76] These noise characteristics are different to other external traffic impacts, especially congestion costs and air pollution which show increasing or constant marginal costs. In Table 6 marginal noise costs for different times of day, vehicle categories and load situations (heavily used roads in Berlin vs. less heavily used roads in Stuttgart) are summarized by BICKEL / SCHMID (2002).

Vehicle Category	Daytimes	Evenings	Nights
Car – Low Traffic Volumes	1.50	2.00	4.50
Car – High Traffic Volumes	0.47	0,62	1.45
Heavy Trucks – Low Traffic Volumes	25.75	34.25	78.25
Heavy Trucks – High Traffic Volumes	7.67	10.17	23.33

Table 6: Marginal Noise Costs for Road Traffic for Different Traffic Situations (in ct/vkm)[77]

A direct consequence of these noise cost characteristics for transport policies is that a reduction in the amount of traffic through road pricing solutions cannot be considered as an effective instrument for lowering noise levels, in particular for heavily used road links. If traffic-related noise damages are to be reduced efficiently, it should be checked systematically whether other measures can fulfill this purpose better and cheaper. The potential to reduce noise emissions by the application of vehicle-related technical measures and local and/or temporal driving bans for vehicles in vulnerable areas is much larger than that of road pricing solutions. Nevertheless, locally changing noise levels caused by the introduction of a road tolling system should be included in the cost-benefit analysis.[78]

2.1.2.4 Implications for City Tolls as an Instrument to Improve Environmental Quality

In the past, no road pricing solution which was implemented in practice was primarily or solely geared to environmental aspects. Financing goals, as with Norway's Toll Rings, and / or congestion reduction goals, as in Singapore and London, dominated these schemes.[79] With the German truck toll as well, which is differentiated according to environmental criteria (among others), the primary goal is to raise additional funds for financing the transport infrastructure.

[76] Cf. e.g. INFRAS / IWW (2000, p. 102).

[77] Source: BICKEL / SCHMID (2002).

[78] Of course this inclusion depends on the availability of detailed spatial data for population and noise levels.

[79] Cf. e.g. MAY / SUMALEE (2003). SCHÜTTE (1998, pp. 71 ff) provides an older overview of field trials.

Road usage charges have a certain potential for being used as an instrument to improve air quality in urban areas. Today, there are toll-raising systems available that can charge road users differentiated according to time of day and location.[80] Along with vehicle-specific price differentiation (e. g. according to the class of emission, age, mileage) there is, in theory at least, the possibility of specifically internalizing the local external effects of air pollution.[81] The level of ecological accuracy potentially achieved through road pricing is to be considered an advantage as compared to other ecological instruments whose impact is not differentiated, such as fuel and vehicle taxes. However, costs of toll-raising systems can still be very high, and realization costs for the road pricing solution are likely to rise with growing levels of vehicle-related differentiation. These costs could be decisive for the efficiency of introducing an ecological road usage charge, when local air pollution levels further decrease in the future.[82] As regards transport noise, road user charges are not well suited to tackle urban noise problems. Moreover, there are far more efficient measures available to reduce climate change gas emissions than local road pricing systems. Nevertheless, if a road pricing scheme will be introduced anyway, a differentiation of tolls according to environmental criteria makes sense, and an evaluation of specific urban road pricing solutions should include these effects.

2.2 Review of Selected Simulation Studies

In order to identify and assess important factors for the modeling and evaluation of road pricing schemes in the next section some available case studies will be reviewed, concentrating on analyses that use a similar (static) modeling framework to the one we apply in order to derive consequences for our own modeling work.[83]

[80] Cf. SANTOS (2000, p. 6).

[81] Cf. HARTWIG (2001, p. 172).

[82] Cf. ibid. p.179.

[83] A promising new modeling framework has been developed and applied by NAGEL ET AL. (2007). They use a dynamic, agent-based simulation approach to model the effects of road pricing on urban traffic. Since the basic concepts of both modeling frameworks are quite different, it is difficult to compare results and derive conclusions without a real-world test. That is why we have not included the extensive research works of NAGEL ET AL. (2007) in this review.

2.2.1 Simulation Studies on the Effects of City Tolls on the Reduction of Congestion

2.2.1.1 Study by Englmann et al. (1996)

The study by ENGLMANN ET AL. (1996) is one of the very few empirical network simulation studies on private car tolls in German cities.[84] They analyzed in detail different road pricing solutions, based on cordons, zones and distances, for the morning commuter traffic between 7.00 and 9.00 in Stuttgart. For this, they used a network-related TRIPS model, which is based on the classic four-stage algorithm used in transport planning and engineering.[85] This model was extended by modules with which the influence of road usage charges at all stages of the algorithm could be demonstrated, together with the choice of departure time. The extended model was run iteratively, until no further essential changes arose as to mileage, journey time and modal split control parameters.

The model used by ENGLMANN ET AL. (1996) includes eight different trip purposes for passenger traffic, while truck traffic is only used as a background load when calculating journey times and routes in the network. Thus, one important demand segment was systematically excluded from the analysis; this only makes up about 5 % of the mileage but is responsible for ca. 20 % of the total private costs of the traffic system. Total user costs in the model consist of toll charges plus users' time costs, while distance-related costs were omitted. It is possible to make such an abstraction because time costs make up about 70 % of the total costs of a city centre trip.[86] However, this makes it difficult to analyze the impact of relative changes between these cost categories adequately. In addition, a relatively inelastic demand for passenger transport is assumed. A change of destination choice, which is endogenous to the model, is only possible for shopping and leisure trips, but not for journeys having other purposes. For trips having other purposes, e. g. journeys to and from the place of work, the model can, however, consider changes in choice of departure time and means of transport after the introduction of a toll. Through this, the simulation takes short-term reactions by the road users explicitly into consideration.

The allocation of transport demand to the available road network, the so-called assignment, is conducted according to a successive procedure; thus no Nash equilibrium is guaranteed between

[84] Cf. ENGLMANN ET AL. (1996).

[85] The four-stage algorithm of transport planning consists of the stages (1) Generation of traffic (2) Distribution of traffic / choice of destination (3) Mode choice (4) Traffic assignment / Route choice, see e.g. the Citilabs Internet pages, for an up-to-date description of the software of the TRIPS model, (accessed on the Internet on 22/11/06 at http://www.citilabs.com/trips/index.html).

[86] Cf. WINTER / HIRSCHHAUSEN (2005).

supply and demand.[87] Problems arise with this procedure, above all, due to the fact that mutual influences resulting from the road user's choice of route are not mapped adequately. Rather, in the model, the majority of individual demands for a trip do not react to changed costs caused by changes in the choice of route by other road users. While the level of regional details included in the ENGLMANN ET AL. (1996) model is remarkable, the question remains whether the results do come anywhere close to reality, because of the points mentioned. Some central results of the study are summarized in Table 7. Target values for the simulations were reductions in total trip times by 5 % or 10 % respectively for the remaining demand in the respective toll area.

Road Pricing Form	**Cordon-based**		**Zonal**	**Distance-based**	
Details	Double Cordon	Double Cordon, time-of-day Toll Structure	Toll System with five Zones	Distance-based Toll (excl. Highway)	Distance-based Toll (incl. Highway)
Toll Rates	7.00 DM at both cordons	7-8 am: 8.00 DM 8-9 am: 4.00 DM at both Cordons	9.00 DM at every Zone Boundary	0.26 or 0.13 DM/vkm[88]	0.40 or 0.20 DM/vkm
Cost of a Journey from the Airport to the City Centre in DM	14.00	16.00 or 8.00, respectively	18.00	1.69	2.60
Revenues p. a in Million DM	137.5	187.0	127.3	50.9	77.0
Time Saved p. a in Million DM	63.6	49.7	70.0	33.8	64.8

Table 7: Effects of Different Road Pricing Solutions Aimed at Reducing the Total Trip Time in Stuttgart by 10 Percent[89]

As seen in Table 7, very high toll rates are necessary for the target reduction of 10 % with all road pricing systems in the simulation that are not related to distance. This is also expressed in the considerably higher revenues as compared to distance-related road pricing systems. However, the time-savings shown here only relate to toll payers within the charged area.[90] Time losses due to detours outside of the toll area as well as losses of consumer surplus by canceling trips are not included in the calculations. Therefore, these time savings are hardly sufficient for evaluating the systems' welfare effects. Nevertheless, ENGLMANN ET AL. (1996) do conclude that all of the road

[87] In this Nash equilibrium, all used routes between a given relation of start and destination points have the same costs, and the costs of all unused routes are at least as high. Thereby, no individual can obtain a unilateral advantage from diverging from their (route) choice. In traffic planning this is also referred to as the Wardrop first principle.

[88] The amount of the toll was differentiated between inner and outer toll zones. The boundaries of these zones correspond to the location of both cordons.

[89] Source: ENGLMANN ET AL. (1996, p. 244).

[90] Cf. ENGLMANN ET AL. (1996, p. 257).

pricing solutions in Stuttgart they examined would lead to welfare gains.[91] However, the chosen methods for determining these effects seem to be not entirely convincing, so the reliability of the conclusions must be questioned. Besides, the costs of installing and operating the tolling system were not considered, which could indeed overcompensate the potential welfare gains.

2.2.1.2 Study by May / Milne (2004)

MAY / MILNE (2004) investigate the effects of different road pricing solutions for passenger transportation at peak hours on the capacities of the road networks in the English towns of Cambridge, York and Leeds.[92] For this, they use the transport planning software SATURN to simulate cordon systems and distance-related road usage charges as well as time-related tariff systems in which a charge related to the trip time has to be paid for the period spent inside the toll area.[93] The reactions of road users to the introduction of road pricing charges are illustrated through relation-related, elastic, exponential demand functions.[94] MAY / MILNE (2004) also do not explicitly calculate dead weight effects. Selected traffic-related events of road pricing solutions for Cambridge are compiled in Table 8.

Road Pricing Form	Toll Rates	Change in %				
		Number of Journeys	Length of Journey		Duration of Journey	
		Total	Toll Area	Total	Toll Area	Total
Triple Cordon	1.17 GBP/ cross over	-9.7	-26.3	+1.4	-26.7	-6.8
Distance-based	0.48 GBP/km	-8.8	-32.5	+0.6	-34.6	-12.5
Time-based	0,25 GBP/min	-4.5	-18.3	+0.6	-27.7	-14.1

Table 8: Effects of Different Road Pricing Solutions on Traffic Volumes in Cambridge[95]

For Cambridge, according to MAY / MILNE (2004), a distance-related road pricing solution is to be preferred over any other pricing instruments for reducing traffic volumes in chargeable city areas, not

[91] Cf. ENGLMANN ET AL. (1996, p.258).

[92] Cf. MAY / MILNE (2004).

[93] In the cordon systems of MAY / MILNE (2004) the charge has to be paid when driving in both directions, as opposed to the systems by ENGLMANN ET AL. (1996) and SANTOS (2004). See the Internet pages of Atkins and the ITS Leeds for a description of the SATURN software (accessed on the Internet on 22/11/08 at http://www.saturnsoftware.co.uk/).

[94] If the demand is represented by an exponential function instead of a function with constant cost elasticity, the influence of road usage charges on low-value short trips is higher than on long trips with a high value; intuitively, this appears to be more realistic, Cf. MAY / MILNE (2004, p. 70).

[95] Source: MAY / MILNE (2004). The shown charges for the different systems come about through the assumption of toll revenues that are roughly equal.

only with regard to journey distance but also journey time. A time-related road pricing solution is, on the contrary, theoretically more effective if a reduction in total trip times in the examined area is wanted. Furthermore, less diversion traffic could be expected with this solution. However, the reactions of road users to variable, time-related road usage charges are harder to predict than those to cordon and distance-based charges, since the actual amount of the charge to be paid is uncertain before the trip is started. This limits the potential effectiveness of time-based road charges. Moreover, with trip time related tolls there is a possibility of increased accident rates due to higher speeds. Both factors limit the practical relevance of such time-related road pricing solutions. According to MAY / MILNE (2004), cordon pricing has the lowest effectiveness of all road pricing systems for reducing inner-city congestion in spite of a comparatively high level of avoidance of inner-city journeys.

2.2.1.3 Study by Santos (2004)

Different to MAY / MILNE (2004) and ENGLMANN ET AL. (1996), SANTOS (2004) calculates not only the network-wide effects on traffic of the introduction of specific road pricing solutions, but also the welfare effects accompanying them.[96] However, here again, the costs of installing and operating a tolling system are not considered. The study analyzes road pricing solutions with single or double cordons for commuter traffic in the peak hours between 8.00 am and 9.00 am, in eight English cities with populations of around 50,000-100,000. For this, SANTOS (2004) like MAY / MILNE (2004) uses assignments for an elastic, relation-specific car demand with the SATURN model, leading to a Nash equilibrium.[97] This procedure explicitly takes into account the economic calculations of individual road users which causes changes to the own cost situation if other users choose a different route, and maps the respective modifications with respect to the number of trips and the choice of route.

Corresponding to the comparatively small size of the cities examined, SANTOS (2004) chooses relatively small areas of 0.7-2.0 km^2 for the inner cordon. Toll areas are normally city centers surrounded by a ring road. The latter serves as a cordon boundary crossing which incurs a charge to be paid. The high number of trips with the city center as their destination is noteworthy. These amount to ca. 30-50 % of journeys in the entire city area. Accordingly, the median of average speeds within the cordon is 15.7 km/h, while it is 30.7 km/h outside this area. Table 9 shows selected findings from the

[96] SANTOS (2004) uses the methodology of NEWBERY (1990), which is shown in chapter 2.4.2.1, for the calculation of welfare effects due to reduced levels of congestion.

[97] SANTOS (2004) uses a relation-specific demand function with a constant elasticity of 0.7 (total from time, distance and toll costs) for generalized costs. The value of this generalized cost elasticity is also determined by changes in departure times and choice of means of transport along with the cancellation of trips.

study by SANTOS (2004) for a simple cordon pricing system in Northampton, Cambridge and Norwich.

City	Optimal Cordon Toll in GBP	Change in Cordon Crossings %	Change in the Number of Trips in %	Welfare Gains p. a. in m. GBP (2002)	Revenues p. a in m. GBP (2002)
Northampton	3.47	-30.7	-2.5	5.13	8.96
Cambridge	1.60	-29.4	--3.0	1.60	2.98
Norwich	0,80	-26.9	-2.2	1.28	1.78

Table 9: Effects of Cordon Tolls in English Cities[98]

As can be seen in Table 9 a cordon pricing system causes a considerable reduction in cordon crossings and thereby a reduction in traffic overloads in the toll area, with only a slight reduction of the total number of trips. The achievable welfare gains through higher average speeds average around 50 % of the toll revenues achieved, with optimally structured rates. However, SANTOS (2004) also does not include toll-raising costs, which can overcompensate the potential welfare gains. SANTOS (2004) also calculates the effects of road pricing systems with a double cordon where the inner cordon is extended by an outer toll ring. With this 1.9 times the welfare gains of a simple cordon pricing system could be achieved on average, if toll-raising costs are excluded. However, SANTOS (2004) makes the qualification that the benefit-costs relationship is reduced to around half by extending to a road pricing system with two cordons. This is due to a four-fold increase in toll-raising costs in comparison to the simple cordon system.[99] The comparison of double cordon systems and a load-dependent, first-best-optimal congestion charge is also interesting: SANTOS (2004) calculates that on average 64 % of the welfare gains achieved by a load-dependent first-best toll seem to be realizable by cordon-systems, which are technically considerably simpler and thus cheaper.

2.2.2 Simulation Studies about the Effects of City Tolls to Improve Environmental Quality

Even if tolls are widely discussed in research literature as a useful instrument for the reduction of external environmental effects,[100] specific studies on this topic are rather rare. The next sections summarize the most important results of two of these studies, SANTOS (2003) and MITCHELL ET AL. (2002).

[98] Source: SANTOS (2004, p. 354).

[99] Cf. ibid. p. 361. The reason for the disproportionate rise in toll-raising costs, according to SANTOS (2004), is the disproportionate increase in toll-relevant entry points accompanying the extension of the toll zone. Concrete figures for assumptions for the (rough) calculation of toll-raising costs are, however, not given by SANTOS (2004).

[100] Cf. JOHANSSON-STENMAN / STERNER (1998).

2.2.2.1 Study by Santos (2003)

SANTOS (2003) calculated, iteratively, the optimal level of charges of cordon pricing solutions for reducing congestion during the morning peak hour in Cambridge and in other smaller English cities.[101] Using regionally detailed traffic models, volumes of local traffic and choice of route changes were mapped, and the resulting reductions in emissions were monetarized. Even when assuming high damage-cost rates for air pollution and CO_2, the welfare gains due to reduced congestion and journey times predominated considerably, as Table 10 shows.

City	**Optimal Cordon Toll** in GBP per Day	**Benefits of Improved Utilization** in million GBP p.a.	**Environmental Benefits** in million GBP p.a.	**Total** in million GBP p.a.	**Environmental Benefits** as Share of Total
Northampton	3.47	+ 5.13	+ 0.19	+ 5.32	3.7 %
Kingston upon Hull	3.73	+ 5.48	+ 0.36	+ 5.84	6.5 %
Cambridge	1.60	+ 1.35	+ 0.13	+ 1.48	9.9 %
Lincoln	1.07	+ 0.57	+ 0.06	+ 0.63	10.5 %
Norwich	0.80	+ 1.28	+ 0.09	+ 1.37	7.2 %
York	1.60	+ 0.93	+ 0.09	+ 1.02	9.2 %
Bedford	1.60	+ 0.37	+ 0.11	+ 1.71	28.2 %
Hereford	1.60	+ 0.91	+ 0.08	+ 1.68	9.0 %

Table 10: Reduction of Environmental Effects due to second-best Congestion Tolls[102]

Typically, the positive environmental effects make up less than 10 % of the total welfare gains. On the one hand, the calculated effects should, if anything, be distorted for the benefit of improved air quality, because the study does not take future changes in the structure of the fleet of vehicles into account. On the other hand, the main aim of the road pricing solution was the optimal utilization of road capacities, not the efficient reduction of external environmental effects. Thus cordon pricing can indeed cause general reductions in the number of journeys; this explains the improvements in air quality achieved here. Depending on the system, it is not always able to counteract local environmental damages, since displacement of near-centre traffic to the outer areas of the city is to be expected. This could be counteracted with distance-related road pricing, as examined e.g. in MITCHELL ET AL. (2002).

[101] Cf. SANTOS (2003).

[102] Cf. ibid. Here we used the figures for the higher demand elasticity and the high monetary values for environmental effects.

2.2.2.2 Study by Mitchell et al. (2002)

The study by MITCHELL ET AL. (2002) modeled the effects of transport strategies for improvements in air quality in the English industrial city of Leeds [103] coupling transport models with emission and immission models; this allowed of very detailed mapping. Future improvements in the environmental characteristics of cars were included in the analysis. The focus of the observation was on effects on health. These were not monetarized but rather expressed as changes to case figures for hospital admissions and premature deaths due to changed concentrations of air pollutants. Central results are shown in Table 11.

Scenario	**Mileage**	**Admittance to Hospital**			**Premature Deaths**	
Change in %		NO_X	SO_2	PM10	PM10	SO_2
Cordon Road Pricing						
(1) Single Cordon (3 GBP)	-1.95	-0.653	-0.072	-0.073	-0.072	-0.096
(2) Single Cordon (3 GBP)	-5.08	-1.453	-0.113	-0.168	-0.182	-0.125
Double Cordon (2 GBP + 1 GBP)	-17.17	-3.441	-0.244	-0.351	-0.489	-0.332
Distance-based Road Pricing						
2 pence / vkm	-12.49	-4.221	-0.309	-0.486	-0.482	0.-302
10 pence / vkm	-46.05	-14.450	-1.040	-1.570	-1.770	-1.169
20 pence / vkm	-55.72	-16.792	-1.200	-1.787	-2.084	-1.394

Table 11: Reduction of Mileage and Health Damage Caused by Air Pollutants as Result of Road Pricing Scenarios for Leeds[104]

Even with a very high kilometer price of 20 pence (ca. 30 ct), which would suppress the mileage by more than 55 %, reductions of only a few percent, or tenths of a percent, appear possible for air pollution-related illnesses. With PM10 particles, which represent the greatest future threat to human health from traffic-related emissions, reductions of only 0.072 % or 2.1 % of all cases are likely. MITCHELL ET AL. (2002) conclude from this: “The environmental (air quality) case for road user charging is weak. Very high charges (beyond the economic optimum and not likely to be implemented) are required to achieve the scale of air quality improvement that will occur anyway due to fleet turnover".[105] For PM10, they recommend measures for avoidance of emissions at point of origin as a more efficient alternative for the reduction of pollution burdens. They see no further need to take

[103] Cf. MITCHELL ET AL. (2002)

[104] Source: MITCHELL ET AL. (2002, p. 6-2). The two single cordon scenarios are based on different assumptions about the development of the Leeds road network; scenario (1) assumes a less developed network than does scenario (2).

[105] Cf. MITCHELL ET AL. (2002, p. 10-24).

action for other air pollutants in the case of a more environmentally friendly fleet of vehicles. One should, indeed, view these results before the background of the high levels of air pollution in Leeds due to power plants, factories and other immobile sources. However, the potential for positive welfare effects as a result of a road pricing solution purely geared to environmental goals appears limited, even under different local conditions.

2.3 Implications for the Design and Evaluation of our own Road Pricing Case Studies

From the theoretical considerations in section 2.1 and the review of existing studies with a similar framework in section 2.2 we can derive some conclusions for our own modeling and evaluation work.

- As traffic conditions and external effects like noise and congestion strongly vary locally, spatially disaggregated network models including differentiated trip demands are needed to model urban road transport adequately.

- Both noise and congestion effects have a markedly temporal structure. Hence, the analysis of time-differentiated tolls in time-dependent models seems to be useful.

- In contrast to most of the studies reviewed, we consider the inclusion of at least two demand segments, i.e. car and trucks, necessary in our analysis. Both demand segments share the existing road capacities and interact with each other. Moreover, they differ in their values of time and distance, respectively. Furthermore, they show different user behaviors.

- Like most of the existing studies we are not including public transport in our simulations. This may result in slightly underestimated user benefits; but comparatively low cross-price elasticities to urban road transport, in the order of 0.1-0.3, indicate a rather low interdependency between the public and private transport sectors.[106]

- Analogously to the studies reviewed we consider a cost-sensitive trip demand indispensable. The potential demand reaction on changes of generalized costs should at least include rerouting and the cancellation of road trips, either due to mode changes, or complete abandonment. Combining an elastic transport demand with a spatially disaggregated network model should allow of a realistic view on possible changes of the local traffic situation due to tolls.

[106] Cf. the review of LITMAN (2008).

- Only assignment procedures converging to Nash equilibria are suited for our modeling, since this concept implies the – reasonable – assumption of rational road user behavior.

- Like SANTOS (2003) and SANTOS (2004) we consider the application of a bandwidth for generalized cost elasticities as very useful; this should contribute to the robustness of the simulation results. The same applies to the use of cost-rate ranges for the monetarization of environmental effects, as there are substantial uncertainties still involved in the evaluation of these effects.

- Promising toll solutions we are going to analyze are distance-dependent tolls for larger areas or cordon tolls for highly congested city centers. While distance-based charges should induce only minor negative rerouting effects, cordon tolls seem to be quite effective and easier/cheaper to operate. Travel time-dependent charges, suggested by MAY / MILNE (2004), we consider impracticable and so are not going to include them in our case studies.

2.4 Methods for the Simulation and Evaluation of Urban Road Pricing Schemes

2.4.1 Transport Simulation Approach

2.4.1.1 Basic Structure and Functionality of the VISUM Models Used

In order to model urban transport we used the transport planning software VISUM . VISUM is a tactical modeling suite for the representation of traffic flows in networks, developed and maintained by PTV AG Karlsruhe.[107] Basic components and inputs of the traffic planning software are origin-destination-matrices for different user classes to characterize the traffic demand, and a geographically detailed supply model, which describes a specific road network. Further core elements of VISUM are different assignment procedures, which are essential to interlink traffic demand with the supply side. Results of the assignment process are estimated flows for each vehicle category on each link of the network. Although VISUM is capable of handling public transport means as well, this feature was omitted in these simulations, as the interdependency between public and private transport demand is rather low.[108] In addition, calculation times and data requirements for public transport assignments are considerably higher than for individual motorized traffic.[109] Due to high interdependencies between

[107] For more information on VISUM see http://www.ptv.de.

[108] The cross price elasticity between private and public transport is usually 0.3 or below. Cf. e.g. LITMAN (2008).

[109] For an integrated simulation model for private and public transport in Berlin, which is partly based on the present thesis, cf. LÖWA (2008).

freight traffic and passenger cars on the supply side both demand segments were included in our simulations.

Figure 4 describes the fundamental principles of a transport assignment model like VISUM.

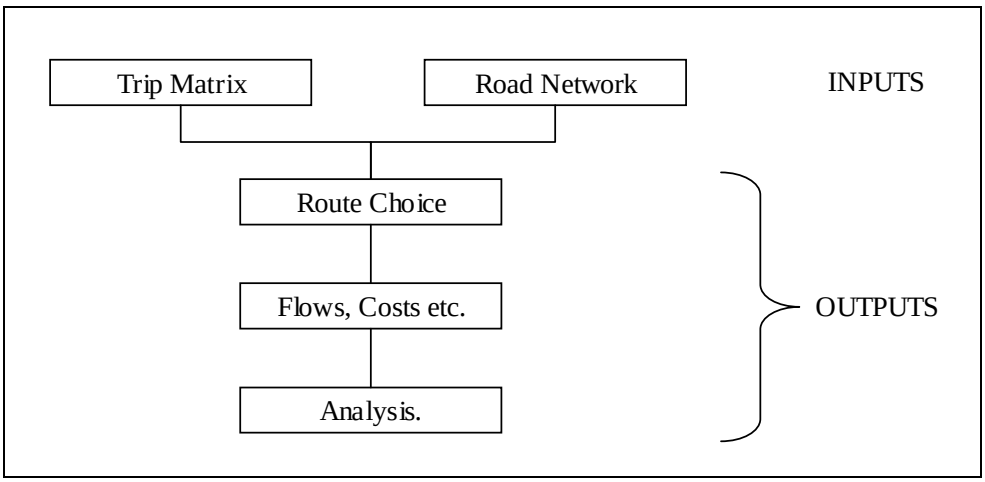

Figure 4: Basic Structure of Transport Assignment Models[110]

2.4.1.2 Supply Side: The Network Model

The network model provides a simplified representation of the existing traffic infrastructure. It consists of nodes connected by links. The network structure to be mapped first determines the regional position and connections of nodes and links in the network model. In addition, each network element can be assigned specific attributes in VISUM. For links, these are, above all, the length of the stretch, the speed when driving freely, the maximum capacity, as well as the relationship between traffic flow and trip time. The latter is described by speed-flow functions,[111] which reflect the tendency to congest for stretches of road. For the speed-flow functions, the function type recommended by the US Bureau of Public Roads (BPR) (1964) is usually used.[112]

$$t_1 = t_o * \left[1 + \alpha * \left(\frac{q}{q_{\max} * \beta} \right)^{\gamma} \right]$$

[110] Source: VAN VLIET / HALL (2002, p. 2-2).

[111] Another usual expression for the speed-flow function is capacity restraint function.

[112] Cf. US BUREAU OF PUBLIC ROADS (1964).

In the formula, t_1 represents the traveling time on the link, t_0 is the trip time for a free journey without delays, q shows the current number of vehicles on a link during a time period and q_{max} is the maximum number of vehicles that can pass the link during a time period. α, β and γ are empirical parameters, which specify the rise of average journey times in greater detail, resulting from a higher vehicle load on the link. These parameters vary for different types of roads.

The attributes mentioned constitute the individual generalized costs for a certain route through the road network. They form the basis for the route choice algorithm of the assignment process. In principle, tolls can be modeled in VISUM as direct attributes of a network link. The adjustment of traffic following the introduction of a road pricing scheme is realized through different internal weights to link attributes in the re-assignment process. A slight disadvantage of such a complex model is the relatively low transparency of modeled results, which is a direct consequence of the impressive network model size. However, for strategic considerations of the effects of road pricing measures the network models used should be more than sufficient. Figure 5 shows a sample of such a VISUM network.

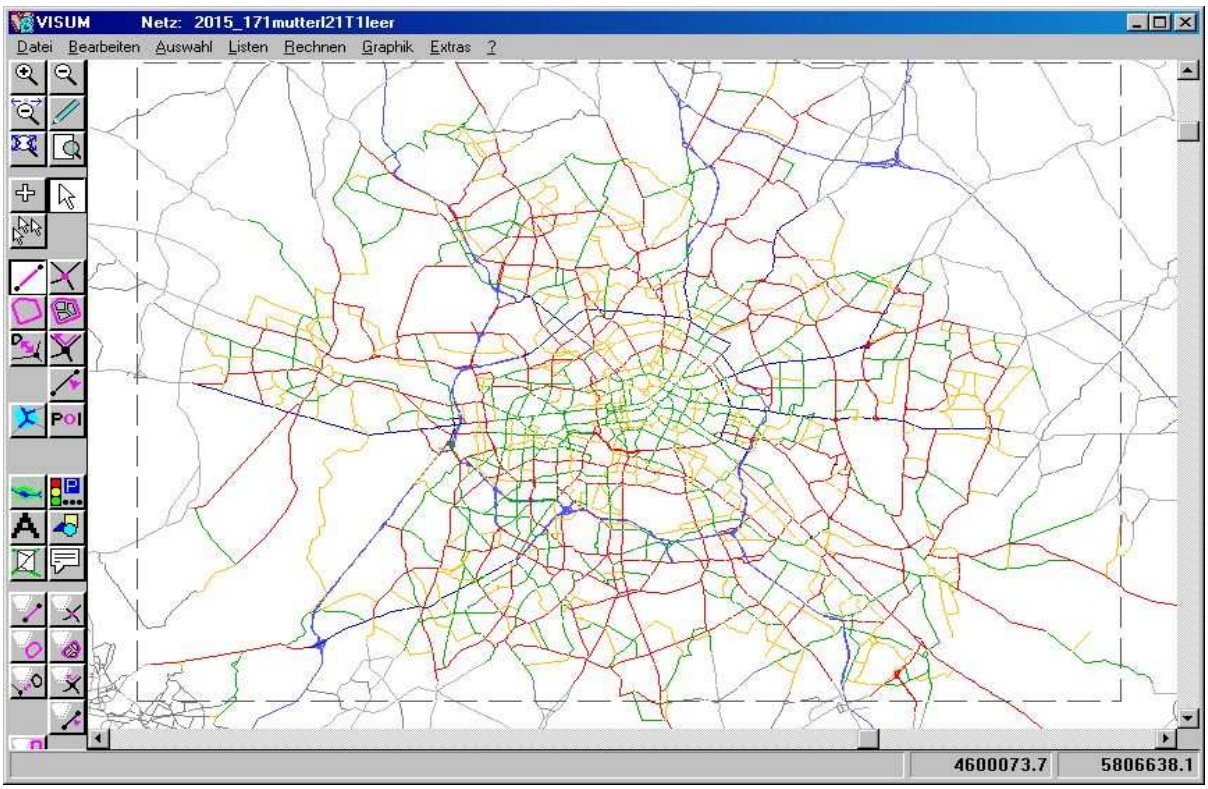

Figure 5: VISUM Network Model for Berlin[113]

[113] Source: Own compilation.

2.4.1.3 Demand Side: Trip-Matrices

In VISUM, travel demand is represented by fixed and normally symmetric matrices for the number of trips (from / to traffic zone) for all origin-destination (O-D) pairs. Thus, different transport demand segments (e. g. car and trucks) can be differentiated.[114] The structure of the network and the physical characteristics of the individual route sections determine the alternative routes for the travel demand of an origin-destination pair. As a rule, a mono-criteria approach is taken to model the simultaneous route choice of all road users.[115] This means that the different decision criteria for the choice of route, such as trip times, lengths of trips, tolls etc., are pooled together in one value, the so-called "generalized costs".[116] Along with link-specific criteria, such as a toll, average values of time and distance (VoT, VoD) must be specified for each demand segment. This enables a road user's route choice to be considered as an individual cost minimization problem. The choice of route for trips of different O-D relations, arising through the use of the same links, is interdependent. Therefore, assignment procedures that take account of capacity limitations usually work iteratively, starting from an often arbitrary initial solution of demand allocation on potential routes in the network.

However, in VISUM a change in the generalized costs e.g. due to new or expanded roads or a toll leads solely to a change of route choice behavior, not to changes in demand levels.[117] Because this assumption of a fixed demand is unrealistic for larger changes of generalized costs, we exogenously modeled these effects on demand levels. The procedures used are explained in the next sections.

2.4.1.4 Modeling the Effects of a Road Pricing Regime on Traffic

2.4.1.4.1 Cobweb Procedure for Determining Equilibrium with Elastic Transport Demand

For traffic models of the type described above, algorithmic assignment procedures are a necessary tool to balance traffic demand and network supply. Due to its economic foundation, some assignment approaches included in VISUM are suitable for our analysis. These assignment procedures induce a static Nash equilibrium. The Nash equilibrium is reached in a network, when the cost of travel on all routes used between each O-D pair is equal to the minimum cost of travel and all unused routes have

[114] For the practicality of functions restricting link-specific capacities, all demand segments are normed to so-called PCUs (Passenger Car Units). A car equals one PCU, a heavy truck usually equals 2-3 PCUs.

[115] Alternatively, for VISUM, there is also the bi-criteria assignment procedure TRIBUT, which works with frequency-spreading for time and distance cost rates. BARBIER-SAINT-HILAIRE ET AL. (1999). However, the requirements placed on the input data are very high here and calculation times are considerably longer than with classic mono-criteria assignment procedures.

[116] A more detailed description of these generalized costs follows in the next section.

[117] Usually VISUM is combined with fully-fledged demand models, like VISEM and VISEVA. Such models require much more detailed input data, and the economic interpretation of their results is more difficult. Hence we used a simpler modeling framework for our analysis.

equal or greater costs.[118] This corresponds to individual rational behavior, i.e. traffic should arrange itself on congested networks in that way.[119]

Technically, an iterative assignment procedure is used to converge to the static equilibrium state. This algorithm recalculates the travel speed on each network link according to the previous level of traffic assigned, and balances flows for each O-D pair within the available network capacity until the equilibrium is reached.[120] Unfortunately, and in contrast to the transport modeling software SATURN by the Leeds Institute for Transport Studies, there is no simple variable demand assignment procedure available in VISUM. This elastic assignment is considered necessary, as one expected effect of city road pricing should be an overall reduction in traveled vehicle trips. Therefore a simplified iteration procedure of the SATURN elastic assignment was applied for all of our VISUM simulations.[121] It follows the well known cobweb technique, which is depicted in Figure 6.

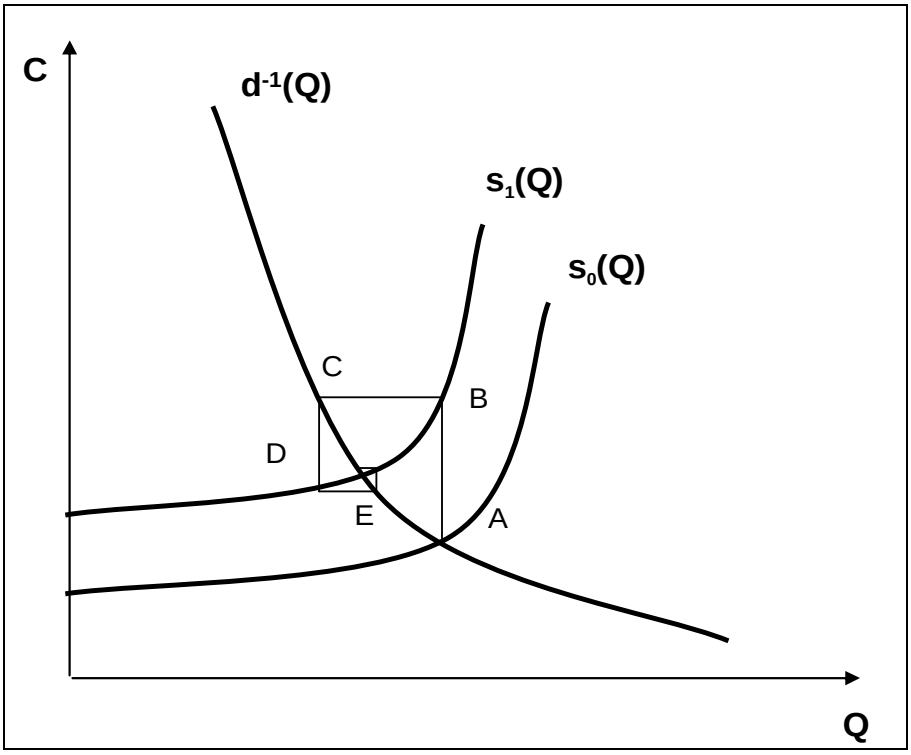

Figure 6: Cobweb Procedure to Balance Transport Demand and Supply[122]

[118] Cf. e.g. ORTUZAR / WILLUMSEN (2001).

[119] This is an example for an inefficient Nash equilibrium, i.e. a stable state, where rational individual decisions produce an unsatisfactory collective outcome, i.e. congestion.

[120] Cf. DfT (2002, p. 4/18).

[121] The procedure described is based on VAN VLIET / HALL (2002, pp. 7-24 f.) and DfT (2003, Appendix 13A, p. 21).

[122] Source: Own compilation, based on VAN VLIET / HALL (2002, p. 7-25).

Q is a vector representing the number of all trips in a multi-dimensional O-D matrix, C is a vector of the associated generalized trip costs, and $d^{-1}(Q)$ is the inverse demand function for Q. $s_0(Q)$ is the network supply (or network capacity / performance) function before the introduction of a toll, $s_1(Q)$ is the network supply function after the toll has been implemented, the toll itself is represented by the stretch AB. As shown in Figure 6, for an increase in trips, the trip average costs described by the network supply function $s_1(Q)$ rise due to congestion effects. Vice versa the demand for trips rises for a reduction of trip costs.

The cobweb procedure's starting point is an initial equilibrium between trip demand $d^{-1}(Q)$ and network supply $s_0(Q)$, excluding tolls (point A). This is realized with a first assignment of O-D-matrices to the network model. In the next step a toll is introduced, which alters the average trips costs and shifts the network supply function from $s_0(Q)$ to $s_1(Q)$ (point B). After the recalculation of trip average costs the O-D-matrices are adjusted according to assumed general cost elasticities (point C). The new O-D-matrices are assigned to the network again (point D). The whole procedure is repeated until the differences between the two steps cost or matrix updating become minimal (e.g. in point E). Convergence to the new equilibrium state occurs [123] when

$$\frac{\partial s_1}{\partial Q} < -\frac{\partial d^{-1}}{\partial Q}$$

This means that for achieving convergence with this approach the network supply function $s_1(Q)$ has to be comparatively elastic, as would be typical of less congested networks, or the trip demand $d^{-1}(Q)$ has to be relatively inelastic to the costs.[124]

For cost-induced adjustments of the trip demand a power function formulation was applied. It states that a cost rise should be reflected in a direct proportional demand decrease. Because of its simplicity and easy economic interpretation the power formulation is one of the most commonly applied functional types for elastic assignments, used for instance in SANTOS (2003) and MTCHELL ET AL. (2002). For their road pricing simulations SANTOS ET AL. (2001) alternatively tried an exponentially specified function, which yielded similar results.[125] Hence the use of a simple elastic demand function seemed to be appropriate for our analyses.

[123] VAN VLIET / HALL (2002, p. 7-26)

[124] ibd.

[125] Cf. SANTOS / ROJEY / NEWBERY (2001, p. 8).

Its functional form is:

$$q_{n+1}^{ij}(C) = q_n^{ij} * \left(\frac{C_{n+1}^{ij}}{C_n^{ij}} \right)^{\varepsilon}$$

where q_{ij} is the demand between the origin-destination pair i-j, C_{ij} is the associated generalized cost, ε is the elasticity parameter, and the indices n and n+1 stand for the current iteration step. The elasticity of demand regarding changes in generalized costs in its non-marginal formulation describes the percentage by which the trip demand decreases if generalized costs rise by one percent. Its value is determined by the sensitivity of trip demand to increases of cost. The applied empirical values are described below in the case studies of chapter 3 and 4.

The generalized cost parameter is defined as:

$$C_{ij} = VOT*t_{ij} + VOD*d_{ij} + c_{ij}$$

Where VOT and VOD are the values of time and distance respectively, t_{ij} is the realized travel time between origin i and destination j, d_{ij} is the regarding distance, and c_{ij} is the respective toll. Travel time and distance between two points of a network are outputs from VISUM, whereas the tolls are exogenous inputs. VOT and VOD are empirical average values, the role of which in the modeling and valuation process is also described in the case studies of the following chapter.

In practice, the cobweb procedure was carried out as follows: First the average trip costs per origin-destination relation and demand segment were determined in the VISUM model, before the toll (point A) and after the toll (point B). These cost values were imported into the mathematical software MATLAB with the relation-specific number of trips of the original user equilibrium. [126] Subsequently, with the assumed demand elasticity and function type, the new value for the number of trips after the toll was calculated (point C). The demand matrices obtained in this way were transferred to the VISUM model (incl. toll) and then assigned again to the network (point D). The changes in relation-specific costs were, in turn, taken from the VISUM model and imported to MATLAB for further adjustments to demand (point E). This process was continued until the differences between two consecutive iteration steps became minimal. As control parameters for the convergence of the iterations the network-wide average trip costs, and the region-specific values for number of trips,

[126] The program system MATLAB was chosen, above all, for its capability of processing a very large number of data records. The number of data records corresponded to the total of source-target relations in the respective VISUM model. These totalled between 1.1 m. and 1.7 m. records.

mileage, trip time and average speeds per demand segment were used. To determine the new equilibrium, five (with low cost elasticity) to ten (with high cost elasticity) iteration steps were normally necessary.

However, some of our toll simulations did not converge at all, because the trip demand was more elastic than the network supply. In the real world, again, a new, stable user equilibrium should be achieved, even if the respective adaptation processes take longer.[127] This appears possible, above all, if mixed strategies are applied by the road users. However, in this case, the cobweb procedure described cannot be used for mapping quantity reactions resulting from the introduction of a toll. Therefore, a regression-based methodology was developed, which allows of an approximation to the user equilibrium even if the cobweb procedure does not converge.

2.4.1.4.2 Estimation of a Network-wide Supply Function and Approximation of Equilibrium

Computation of a network-wide, power-based function for supply is a complementary method of determining the equilibrium after the introduction of a toll if the cobweb procedure does not converge. The network-wide demand function is already determined by assumptions on function type and cost elasticity, as well as the cost-quantity combination of the original equilibrium. But also for the supply function after the introduction of a toll, cost-quantity combinations are available after a few iteration steps, which allow of a regression estimate.[128] If both functions are known, the mathematical determination of the equilibrium point after introducing a toll is possible by equating the new supply function with the demand function.

This procedure was tested on simulation scenarios, for which the cobweb procedure described above could also be used. This meant that – as opposed to the non-converging scenarios – comparison data was available, which could provide information about the closeness to reality of the values calculated by means of the regression procedure. The procedure is explained in detail in Annex A.

In order to estimate the supply function, car and truck trips were pooled as vehicle journeys, truck journeys being weighted double, compared to car journeys; this corresponds to the internal assignment routines in VISUM. The weighted average costs per journey were calculated by dividing the sum of the total costs for time, distance and tolls, for both demand segments, by the total number of vehicle journeys.

[127] Until now, after the introduction of a toll, no tendency towards fluctuating, instable situations has been observed even with highly overloaded traffic systems, as shown by the example of the Congestion Charge in London.

[128] For this, it is not necessary for the iterations to converge.

The estimated user equilibrium for the traffic network after the introduction of a toll is at the intersection of the new supply and the demand function. It was calculated by equating supply and demand. The differences in the results for the alternative supply functions were minimal. This makes it clear that even with very few data points, a useful estimate of the network-wide supply function is possible; this saves valuable VISUM computing time. Further test calculations of other scenarios with a different number of data points confirm the results achieved here.[129]

In order to make a detailed evaluation of effects of the toll scenario on traffic, a VISUM assignment had to be carried out using the data calculated for the equilibrium point after toll. To do this, the demand matrices of the first two iteration steps were combined in a linear manner, in such a way that their sum corresponded to the calculated number of journeys in the equilibrium. As shown in Annex A, deviations between the key figures calculated iteratively and the regression-based values are very small. Therefore, it can be assumed that the procedure developed here for determining a user equilibrium by calculation represents a useful extension to the cobweb procedure. The precision of the prognosis of the regression procedure seems to be sufficient, especially for strategic planning. Above all, this method allows of statements to be made about the effects of a toll on traffic which are close to reality, even if the cobweb procedure does not converge.

2.4.2 Economic Assessment

2.4.2.1 Evaluation of Changes in the Capacity Utilization

The welfare effects of tolls obtained through higher average speeds in the network were calculated according to the methodology developed in NEWBERY (1990) and used by SANTOS (2004); the principle of this methodology is demonstrated in Figure 7.[130] The calculations are based on a comparison of the original equilibrium without a toll with the new user equilibrium after the toll.

[129] The regression was based on 5 data points for each of the four scenarios that were calculated with the procedure.

[130] Cf. NEWBERY (1990) and SANTOS (2004).

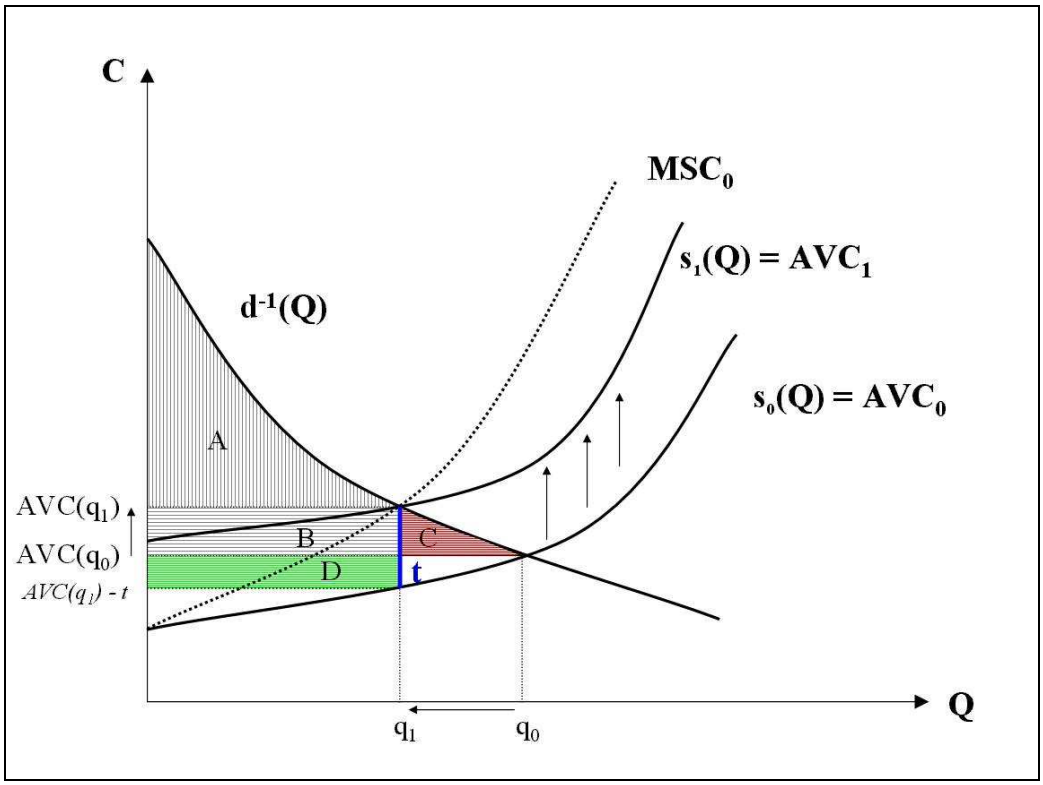

Figure 7: Measuring Welfare Changes Resulting from a Change of Network Capacity Utilization[131]

Due to the toll t, the travel offer became more expensive; this caused the offer function to shift upwards from s_0 to s_1. Due to this, the trip quantity declined from q_0 to the level q_1. The economic concept of social surplus was used to measure the welfare changes due to the introduction of a toll. Social surplus is defined as the sum of the differences between the willingness to pay for a service or a commodity and the actual price to be paid by all users. It describes the aggregated net benefit for the users. Graphically, the social surplus corresponds to the area below the demand function up to the equilibrium quantity, less the costs for the commodity.[132] The welfare gains can now be determined according to the following considerations: Before the introduction of the toll, the consumer surplus consisted of the areas A+B+C. After the introduction of the toll, the consumers retain net benefits amounting to A, while the city's or the county's toll revenues amount to B+D. In the standard economic model, the latter are regarded as pure transfer and hence as neutral for welfare considerations.[133] Thus the deadweight change due to the toll is A+B+D–(A+B+C) = D-C.[134], with area D

[131] Source: Own compilation based on NEWBERY (1990).

[132] Cf. VARIAN (2004, pp. 236 ff).

[133] Marginal costs of public funds are neglected here.

[134] Cf. also NEWBERY (1990, p. 40).

representing the road users' net advantage from increased average speeds, and area C representing the losses to social surplus due to cancelled trips.

More specifically, the calculation of welfare effects due to changes in capacity utilization was carried out as follows: First the difference between total costs before and after the toll was calculated for all origin-destination pairs and both demand segments (cars and trucks).[135] To do this, the relation-specific average costs per trip for both states of equilibrium (before / after toll) were multiplied by the respective number of trips. The toll itself as well as the tax portion of the distance costs (petroleum tax and VAT) were not included since they are also a pure transfer factor and thus do not affect welfare.[136] However, these system-wide totals of relation-specific net cost differences, before and after the toll override the deadweight effects, as the costs arising from now on for all journeys that are no longer made, are still included. These costs were, in turn, calculated relation-based and subtracted from the system-wide totals for cost differences before / after the toll. The intermediate result is the system-wide cost saving resulting from higher average speeds (area D in Figure 7). Subsequently, the loss in social surplus due to the reduction in journeys was calculated for all relations (area C in Figure 7).

If we ignore the existence of fuel taxes and VAT for a moment, the change of social surplus for a single O-D relation due to a toll can formally be written as: [137]

$$\Delta SS = SS_1 - SS_0 = AVC(q_0) * q_0 - (AVC(q_1) - t) * q_1 - \int_{q_1}^{q_0} d^{-1}(q)\, dq$$

As we chose the rather simple power formulation for the truck trip demand function, an analytical solution for the above mentioned integral is feasible. The demand function d(c) is defined as

$$d(c) = q(c) = q_0 * \left(\frac{c}{c_0}\right)^{\varepsilon}$$

with ε for general cost elasticity. The associated inverse demand function can then be expressed as

[135] The MATLAB program system was used, analogously to the demand modifications.

[136] Shadow costs for taxation are also not included in the calculation of welfare effects. However, these are likely to be comparatively low with distance-related costs such as petroleum tax.

[137] Although the notation is different, the basic approach to measuring the change of social surplus follows SANTOS (2004).

$$d^{-1}(q) = c(q) = c_0 * \left(\frac{q}{q_0}\right)^{1/\varepsilon}$$

Solving the integral of this function for the interval from q_1 to q_0 yields the following term:

$$\int_{q_1}^{q_0} d^{-1}(q)\,dq = \frac{c_0}{q_0^{1/\varepsilon}} * \frac{\varepsilon}{\varepsilon+1} * \left(q_0^{1+1/\varepsilon} - q_1^{1+1/\varepsilon}\right)$$

This term can replace the integral under the inverse demand function in the formula for the change of social surplus.

Due to the existence of fuel taxes and VAT, we must adjust the formula for the change of social surplus. These taxes must be included in the assignment calculations, because they are a substantial and decision-relevant part of the distance-dependent costs. Nevertheless, from the perspective of economic welfare analysis, these taxes only reflect a welfare neutral transfer from the network users to the government, and thus they have to be excluded from the monetary valuation of congestion costs.[138] So we have to replace the average private trip cost AVC_0 and AVC_1 in the formula for the change of social surplus with the social trip costs SC_0 and SC_1. They are defined as follows:

$$SC_n = VOT * t_n + (VOD - VAT - \text{fuel tax}) * d_n$$

In practice we had to deduct the taxes from the value of distance (VOD) used in our congestion valuation procedure. After some tests we decided to apply a simple triangle formula for the loss of social surplus, since these values only differ by 1-2 % from those of a numeric integration of the inverse demand function.

The welfare effect resulting from optimized capacity utilization is positive, if

(a) The costs per trip (excluding toll and taxes) decrease, and

(b) these cost savings are not overcompensated by the loss of consumer surplus.

In analogy to SANTOS (2004), possible avoidance reactions by car users in favor of public transport cannot be taken into account when calculating the deadweight effects.[139] With a relatively elastic public transport supply, an increase in consumer surplus compared with the basic case could be

[138] Cf. e.g. SANTOS (2004, p. 353).

anticipated in real life if the public transport demand curve shifts outwards and / or turns as a result of the toll. The extent of these effects depends on the additional (social) costs of demand for public transport and the strength of the substitution relation between public transport and motorized individual transport. For both of these factors, the urban agglomeration could not be taken into account within the scope of this study. Calculations are nevertheless possible, with results that are close to reality, for relatively low levels of cross-price elasticity between motorized individual transport and public transport and / or high additional costs for the use of public transport. However, there is a tendency to show excessive deadweight losses resulting from a reduction in consumer surplus due to fewer journeys by motorized individual transport.

2.4.2.2 Evaluation of Changed Air Pollution Levels

Due to the lack of an available conversion-dispersion model the valuation of reduced external environmental effects could not be conducted according to the impact-pathway-approach, as applied by e.g. BICKEL/SCHMID (2002). Hence our valuation procedure is based on a simplified method. The results for each simulation scenario are computed assuming monetary values per kilogram emission, differentiated for several harmful substances. These values come from the existing literature on environmental effects in urban areas,[140] the transfer method follows an approach used in SANTOS (2003). In addition, global environmental costs, i.e. reduction in greenhouse gas emissions, are considered.[141]

2.4.2.2.1 Adaptation of Emission Factors

The starting point for the valuation of external environmental effects is the change in traveled mileage due to the impact of different road pricing schemes and toll amounts. Theses values are computed by comparisons of different VISUM scenarios with and without tolling regimes. In the next step the reductions of environmentally harmful substances due this road pricing measures has to be estimated. These calculations are based on the German Handbook of Emission Factors, and on city-specific emission data, if available.[142] With changes of the average fleet composition from 1999 to 2004, taken from the German Handbook of Emission Factors (2004),[143] and the average speed of modeled truck flows from VISUM as input, these data were updated to the current situation. The intermediate results

[139] Cf. SANTOS (2004).

[140] MCCUBBIN / DELUCCHI (1999) and HOLLAND / WATKISS (2002).

[141] See section 2.1.2.2.

[142] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG (1999, p. 8).

[143] Cf. KELLER ET AL. (2004).

are emission amounts of a specific substance per kilometer traveled (e.g. g PM10/vkm). Table 12 contains exemplarily the basic data for the update of emission factors for trucks in Berlin.

Pollutant	**Change in Berlin Truck Fleet Emissions** (from 1999 to 2004)	**Pollution in g per Truck vkm 2004**
Carbon dioxide (CO_2)	99.51%	1,077.9026
Carbon monoxide (CO)	58.72%	1.3830
Nitrogen (di)oxide (NO_X)	72.67%	5.9671
Sulfur dioxide (SO_2)	30.16%	0.1021
Particulate matter (PM10)	52.87%	0.6180
Hydrocarbons (HC)	73.54%	0.8238

Table 12: Emission Factors for Average Trucks in Berlin 2004[144]

2.4.2.2.2 Valuation

As described in 2.1.2.1, the major share of environmental costs is caused by negative impacts on human health.[145] There is scientific consensus that damages due to airborne pollutants are directly proportional to their concentration levels.[146] In addition, it is generally assumed that no threshold exists below which the harmful effects for the population completely vanish. Analytically this can be described through linear dose-response-functions, which explain the dependence between concentration changes of a pollutant, and the adverse health effects caused.[147] Thus, from an economic point of view, the marginal damage costs of all airborne pollutants are linear.[148] Due to this fact a simple transfer of monetary values per ton of pollutant from existing studies to mileage-dependent vehicle emissions for the simulation scenarios is possible. A transfer of monetary values from existing studies should make sure these studies assume similar conditions regarding the exposed population to the ones assumed in the present analysis.[149]

[144] Sources: KELLER ET AL. (2004), SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999), own calculations.

[145] Cf. LINK ET AL. (2002, p. 19).

[146] FRIEDRICH / BICKEL (2001, p. 41), LINK ET AL. (2002).

[147] Complete sets of dose-response-functions for airborne pollutants can be found in FRIEDRICH / BICKEL (2001, pp. 56 f) and HOLLAND / WATKISS (2002, pp. 14 f.).

[148] See section 2.1.2.1.

[149] MCCUBBIN / DELUCCHI (1999, pp. 268 f.).

The study of MCCUBBIN / DELUCCHI (1999) contains external cost data for motor vehicle emissions at different regional levels of the USA.[150] We consider their values for the Los Angeles region, a large metropolitan area like Berlin, appropriate for this analysis. To comply with the PM10 data from the Berlin Emission Directory, the values of vehicle + upstream + road dust emissions were applied. For all other pollutants, only the monetary values for tailpipe emissions were taken into account. All monetary values from MCCUBBIN / DELUCCHI (1999) were updated from US$$_{1991}$$ to €$_{2003}$ using a conversion rate of 1.2583. This rate was derived from the historical purchasing power parity for national GDP [151] and the German consumer price index.[152]

An alternative toolkit for the estimation of external costs in urban areas can be found in HOLLAND / WATKISS (2002).[153] They use the impact-pathway-approach, developed by the EU project ExternE,[154] to obtain monetary values for airborne pollutants in different European regions. Because this database lacks values for CO_2, the estimation of the efficient market price for emission trade between so-called Annex-B countries of the Kyoto Protocol from CAPROS / MANTZOS (2000) was used additionally.[155] For the costs of PM10 the values for PM2.5 in HOLLAND / WATKISS (2002) were scaled down to 69%, according to the valuation of these pollutants in MCCUBBIN / DELUCCHI (1999). The values of €$_{2000}$ from HOLLAND / WATKISS (2002) were adjusted to the reference year 2003 by the multiplier of 1.0450, which reflects the German price index.[156] Table 13 shows the assessment basis for this project.

[150] Cf. MCCUBBIN / DELUCCHI (1999).

[151] Cf. OECD (2004).

[152] Cf. STATISTISCHES BUNDESAMT (2004).

[153] Cf. HOLLAND / WATKISS (2002).

[154] Cf. http://externe.jrc.es.

[155] Cf. CAPROS / MANTZOS (2000, p. 13).

[156] Cf. STATISTISCHES BUNDESAMT (2004).

Air Pollutant / € per t	**McCubbin / Delucchi (1999)**		**Holland / Watkiss (2002)**
	Low Estimate	High Estimate	Central Estimate
Carbon dioxide (CO2)	7	108	18
Carbon Monoxide (CO)	38	229	157
Nitrogen Oxide (NO_X)	8,395	100,120	4,285
Sulfur Oxide (SO_2)	44,631	289,489	100,425
Particulate Matter (PM10)	69,766	649,663	368,457
Hydrocarbons (HC)	651	5,537	2,926

Table 13: Cost Rates per Air Pollutant for the Monetarization of Environmental Effects[157]

The monetary values per ton of emission from HOLLAND / WATKISS (2002) fit well into the bandwidth of costs derived from MCCUBBIN / DELUCCHI (1999), only the value for NO_X seems to be rather low. This may reflect the fact that HOLLAND / WATKISS (2002) assume no population density effect for NO_X, as they link its impact mainly to secondary pollutants (ozone, nitrate aerosols), and hence calculate the same external costs for urban and rural areas.[158] The other main variations between both studies result from different statistical values of a life: While HOLLAND / WATKISS (2002) use 1 Mio. $€_{2000}$ per life, MCCUBBIN / DELUCCHI (1999) calculate with 0.5 Mio $US\$_{1991}$ to 4 Mio $US\$_{1991}$, depending on cause and type of death. Other sources for the existing differences may be slightly different dose-response-functions for certain health effects.[159] To cover the broad range of external cost estimations, all presented values will be used for the monetization. Due to its European focus, its relative up-to-datedness and plausible match with other estimations, the cost calculations of HOLLAND / WATKISS (2002) will be used as a kind of “best guess”.

The estimation results of both studies were combined with the calculated emission factors for the vehicle fleet.[160] This yields average monetary values per vehicle kilometer, which are presented in Table 14 exemplarily for trucks in Berlin.

[157] Source of data: MCCUBBIN / DELUCCHI (1999) and HOLLAND / WATKISS (2002), updated to the base year 2003.

[158] Cf. HOLLAND / WATKISS (2002, p. 13).

[159] Dose-response functions relate the quantity of a pollutant that affects a receptor (e.g. population) to the physical impact on this receptor (e.g. incremental number of hospitalizations). Cf. e.g. BICKEL/ FRIEDRICH (2001).

[160] Cf. Chapter 2.4.2.2.1.

Pollutant	MCCUBBIN / DELUCCHI (1999)		HOLLAND / WATKISS (2002)
	Low estimate	High estimate	
Carbon dioxide (CO_2)	0.007772	0.115982	0.019930
Carbon monoxide (CO)	0.000053	0.000318	0.000217
Nitrogen (di)oxide (NO_X)	0.050097	0.597428	0.025566
Sulphur dioxide (SO_2)	0.004555	0.029548	0.010250
Particulate matter (PM10)	0.043113	0.401468	0.227693
Hydrocarbons (HC)	0.000536	0.004562	0.002410
TOTAL	**0.106126**	**1.149305**	**0.286067**

Table 14: External Environmental Cost per Truck Kilometer in € (2003)[161]

2.4.2.3 Evaluation of Changed Noise Levels

Noise effects due to changed traffic flows and volumes were valuated using the impact-pathway-approach. Unfortunately, only for Berlin sufficient population data was available. For the measurement of locally changed noise levels we used the German standard model RLS90, which is available as an extra module in the VISUM traffic modeling suite. In addition, we obtained access to the local road traffic noise database, developed and maintained by the Berlin Senate Department for Urban Development. From this very extensive database, which covers about 7,500 links of the Berlin road network, we adopted the data for the local population exposed to road noise. Combining the population and the noise level data, we were able to quantify the physical impact of noise on inhabitants along the main parts of Berlin's roads.

For our valuation method we needed to calculate the noise indices (in dB(A)) L_{day} for daytime (7.00 to 19.00), $L_{evening}$ for the evening (19.00-23.00), L_{night} for night times (23.00-7.00).[162] In addition, we had to compute the composite indicator L_{den}. It is a descriptor of noise based on energy equivalent noise levels (L_{eq}) over a whole day with a penalty of 10 dB(A) for night time and an penalty of 5 dB(A) for evening noise. This composite indicator is defined as follows:[163]

[161] Source: Own calculations, based on MCCUBBIN / DELUCCHI (1999) and HOLLAND / WATKISS (2002).

[162] Due to this required time split the calculations of external noise effects could not be applied to some cordon scenarios with time-differentiated charges, as the time slices differ.

[163] Cf. EU Directive 2002/49/EU on the Assessment and Management of Environmental Noise, Annex I.

$$L_{den} = 10\lg * \frac{1}{24} * \left(12*10^{\frac{L\,day}{10}} + 4*10^{\frac{L\,evening}{10}} + 8*10^{\frac{L\,night}{10}} \right)$$

For the assessment of physical impacts on the population we used dose-response-functions from BICKEL / SCHMID (2002). These functions are based on research work of de KLUIZENAAR / PASSCHIER-VERMEER / MIEDEMA (2001) and express the expected change of risks for certain diseases due to altered noise levels. They are described in Table 15.

Endpoint	**Expectancy Value (per 1000 Adults Exposed)** [a)]
Myocard Infarction (MI), fatal (Years of Life Lost)	$0.084*L_{den} – 5.25$
Myocard Infarction non-fatal (Expected Cases of Morbidity)	$0.028* L_{den} – 1.75$
Angina Pectoris (Days in Hospital)	$0.168* L_{den} – 10.5$
Hypertension (Days in Hospital)	$0.063* L_{den} – 4.5$
Sleep Disturbance (Number of Cases)	$0.62* (L_{night} – 43.2)$ [b)]
[a)] Threshold is 70 dB(A) L_{den} except for [b)] 43.2 dB(A); Other assumptions: base risk of MI: 0.005; survival probability of MI: 0.7; Angina pectoris, base risk: 0.0015.	

Table 15: Exposure-Response-Functions for Noise Effects on Health and Sleep Disturbance[164]

Beside the calculation of these physical impacts of changed noise levels, monetary values for each endpoint are needed to calculate the change in total external noise costs. Again we selected values suggested by BICKEL / SCHMID (2002). These values were adjusted by the German consumer price index to take inflation into account. Deviating from their approach, we did not valuate more than one cost factor (e.g. hospital costs and productivity losses) related to one specific endpoint (e.g. fatal myocard infarction), but chose their total value per case. The values derived are shown in Table 16.

[164] Source: BICKEL / SCHMID (2002).

Endpoint	Total per Case in €
Myocard Infarction, fatal (7 years of life lost)	601,408
Myocard Infarction non-fatal (8 days in hospital)	26,125
Angina Pectoris (5 days in hospital)	16,315
Hypertension (6 days in hospital)	4,692
Sleep Disturbance (WTP + medical costs)	677

Table 16: Monetary Values (2003) of Noise Effects on Health and Sleep Disturbance[165]

Beside potentially positive health effects, lower annoyance levels are a result of tolls. If one assumes that people are completely unaware of the negative health effects of noise, as is done in research literature,[166] these annoyance effects have to be evaluated independently. Therefore BICKEL / SCHMID (2002) suggest a value of 16 € per reduced dB(A), per person and year for these effects. They derive this value from a hedonic pricing study of SOGUEL (1994). The proposed value fits well into the upper medium range of estimations in the relevant literature, as Table 17 shows. It gives an overview of some of the findings of noise cost studies based on the contingent valuation method. Hence, in this study we used an inflation-adjusted value of 17.06 € for the monetary valuation of diminished annoyance levels due to reduced traffic noise.

[165] Source: BICKEL / SCHMID (2002).

[166] Cf. e.g. BICKEL / SCHMID (2002) and NAVRUD (2002).

Study	**Location, Scenario, Year**	**Willingness to Pay (WTP) in €** per Reduced dB(A), Person and Year (in 2001 Prices)
POMMEREHNE (1988)	Basel (Switzerland), 50% reduction of perceptible noise level, 1988	**46.49**
SOGUEL (1994)	Neuchatel (Switzerland), 50% reduction of perceptible noise level, 1993	**28.17 – 33.24**
WIBE(1995)	Sweden, national study, elimination of noise annoyance, 1995	**12.95**
VAINIO (1995)	Helsinki (Finland), elimination of noise annoyance, 1993	**2.82 – 4.23**
NAVRUD (1997)	Norway, national study, elimination of noise annoyance, 1996	**0.96**
NAVRUD (2000)	Oslo (Norway), elimination of noise annoyance, 1999	**10.70 -15.21**
BARREIRO ET AL. (2000)	Pamplona (Spain), elimination of noise annoyance, 1999	**0.96- 1.41**
LAMBERT ET AL. (2001)	Region Rhone-Alpes (France), elimination of noise annoyance, 2000	**3.26**

Assumptions: Average level of existing noise = 60-65 dB(A), 50 % noise reduction is equivalent to 8 dB(A), 100 % noise reduction is equivalent to 10 dB(A), average household size of 2.13 persons.

Table 17: Results of Contingent Valuation Studies on Road Traffic Noise[167]

[167] Source: own calculations based on NAVRUD (2002), the above cited literature, and STATISTISCHES BUNDESAMT (2004).

3 Environmental Road Pricing for Trucks – An Empirical Analysis of Berlin

3.1 Introduction

3.1.1 Background and Objectives of this Study

In Berlin the emissions of nearly all airborne pollutants have been considerably decreased in the last 10 years.[168] The reduction of pollution has been caused by immobile sources, like private heating, as well as mobile sources, i.e. road traffic. In the road transport sector, technical and legal restrictions, like the mandatory introduction of the EURO norms for new cars and cleaner fuel standards, have succeeded in diminishing most of the adverse effects on humans and the environment. Current emission levels of lead, CO, benzene and sulfur dioxide are so low that the former problems caused by these pollutants can be considered as nearly solved.[169]

Nevertheless, due to newer medical evidence about the harmfulness of some airborne pollutants, tougher EU immission limits will come into force in the year 2010. This poses additional difficulties for the responsible public authorities, as the present higher immission limits for NO_X and PM10 were still exceeded in Berlin in 2004.[170] Due to the latter, the local authorities were required to draw up a local air quality plan.[171] This plan contains specific local measures to address these environmental problems. The transport sector as one of the main classic polluters of PM10 and NO_X is targeted, too.[172]

While traffic-induced air pollution should decline further within the next years, the importance of noise-related problems will rise. This is reflected by new legislation on the European level dealing with this issue, such as the EU directive 2002/49/EC on environmental noise. Beside the information of the public about noise exposure and its effects, a key requirement of this directive was to draw up binding action plans for larger cities to address noise issues by the year 2008.

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[168] This chapter is based on the results from WP 6.5 of the EU-funded project TELLUS ("Transport and Environment Alliance for Sustainability"), which itself is an integral part of the broader European CIVITAS Initiative ("Cleaner and Better Transport in Cities"). The study has benefited from presentations at the International TELLUS Conference on "Urban Road Pricing for Sustainable Cities" (Berlin, February 18, 2005), as well as from two internal project workshops. For in-depth discussions and providing data I am much obliged to the Senatsverwaltung für Stadtentwicklung Berlin, in particular Dr. Friedemann Kunst, Mr. Martin Lutz, Mr. Michael Neumann and Mr. Wolfgang Reichenbächer.

[169] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999, p.21).

[170] Cf. LUTZ (2004, p. 1).

[171] This is necessary according to §13 of 22. BImSchV, based on EU directive 96/62/EG. Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (2005).

[172] Cf. LUTZ (2004, p. 2).

If we consider the different vehicle classes' share of air pollution effects, the very strong negative impact of heavy trucks, compared to the other vehicle categories, becomes evident. As Figure 8 shows, trucks, representing only 4% of the total mileage, caused about 39 % of the PM10 emissions in Berlin (1999).[173] Roughly the same relation can be found between truck mileage and NO_X emissions.

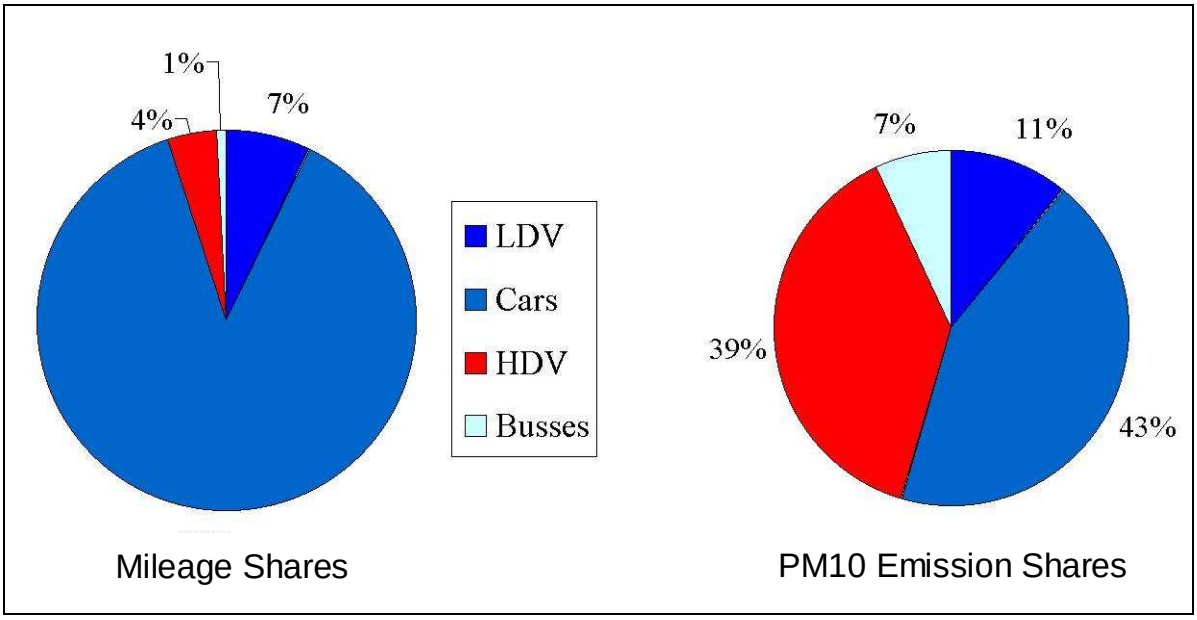

Figure 8: Mileage and PM10 Emission Shares of Different Vehicle Classes in Berlin 1999[174]

For traffic noise effects a similar relationship applies: The share of trucks in total traffic strongly influences the absolute noise level on a road link. For instance LINK ET AL. (2002) use a weight of factor 14 for trucks to compute a breakdown of noise costs on different vehicle categories, while a passenger car is weighted with factor one.[175] Hence a tolling system for trucks could be an adequate measure to efficiently reduce external noise and air pollution effects. Furthermore, as the technologically sophisticated German toll system for trucks on federal highways has been in operation for more than four years, an expansion of this scheme to an urban area like Berlin seems to be technically feasible.

This chapter analyzes the effects of an environmentally oriented road charging system for trucks in Berlin. Our approach takes into account the interdependency of the demand segments truck and

[173] As one environmental expert of the Berlin Senate Department stated, without any additional traffic-related instrument the achievement of the high air quality objectives in Berlin seems to be almost impossible (SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999, p. 8)).

[174] Source: SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999, p. 8).

[175] Cf. LINK ET AL. (2002, p. 139).

passenger car traffic. It is based upon recent empirical studies on other cities' experiences; amongst other things, we use data from the London congestion scheme to estimate general cost elasticities for truck trips.[176] The rest of the study is structured as follows: The first part of our report sketches the theoretical considerations necessary for the traffic modeling process and explains the selection of input values for our model. Section 3.3 describes the definition of scenarios and presents the benefit results of our simulations, before the final conclusions of this case study are drawn.

3.1.2 Internalization of External Effects in Urban Areas with Truck Road Pricing

From an economic point of view, the environmental and noise problems due to truck traffic are regarded as external effects: An individual economic activity induces changes in the welfare positions of other individuals without being reflected by corresponding changes in market prices. The relevant internalization costs, i.e. costs for the inclusion of the external effect into the price system, are the marginal external costs. Their characteristics differ for the various external effects, as described in section 2.1, which has direct consequences for the optimal design of a tolling system for trucks. The following paragraph summarizes the most important features of the external cost categories air pollution, noise and congestion, as these cost categories constitute the elements of our benefit analysis for truck road pricing. Moreover, we derive theoretically sound, but practical conclusions for the appropriate tolling structure of our simulation model.

External effects due to tailpipe emissions usually have constant marginal costs with regard to traffic mileage.[177] That means that a reduction in truck traffic mileage is accompanied by a proportional reduction in local external environmental costs. Typically external effects due to airborne pollutants vary greatly for different regions, depending, beside the level of traffic, on the geographical situation and the population exposed.[178] Therefore an economically efficient strategy to diminish local external effects due to exhaust emissions should ideally be directed at the most heavily used links of a street network in a densely populated area, such as an inner city. Disregarding its own investment and operating costs, a tolling system with differentiated tariffs for different vehicle classes seems to be the adequate implementation of this reduction strategy. A toll solely levied on the most polluting vehicle class, i.e. truck traffic, could be seen as a first realistic step on the road to this ideal. Furthermore, since marginal external air pollution costs remain constant with regard to traffic volumes a comparatively simple, volume-independent tolling structure for this cost category would suggest itself.

[176] Cf. SANTOS / SHAFFER (2004).

[177] Cf. section 2.1.2.1.

[178] Cf. ibd.

As damages due to traffic noise vary across different areas, they are most important in densely populated regions. Truck traffic accounts for a major share of its negative effects, so tolling this vehicle category could be justified for the same reason as in the case of air pollution effects. But, in contrast to exhaust emissions, traffic noise is characterized by decreasing marginal cost: The higher the existing level of traffic, the lower the noise costs of an additional vehicle. Hence reductions in external noise costs depend on the present traffic volume on a link: The same mileage reduction yields a high decrease of external noise costs for low levels of traffic, and low decreases in noise costs for high levels. This implies that efficient internalization strategies for noise effects should be directed at reductions of truck traffic mileage on links of the road network that are already less heavily used and are preferably situated in a densely populated region, such as a residential area. Due to the traffic volume dependency of marginal noise costs, a truck road charging system to diminish noise effects would require sophisticated non-linear tolls, i.e. charges would have to fall in proportion to an increase of present traffic volumes on a link for a first best solution. In addition, the optimal noise tolls would have to capture the different annoyance and damage levels at day time and night time respectively, which is not the case for air pollution costs. For a real world tolling application the complex requirements of such a first best noise toll are difficult to fulfill. If a charging system is to work properly, a simple structure of tolls is very important. A very sophisticated and differentiated pricing system might theoretically yield the best welfare results, but only a simple tariff structure with a high degree of transparency is likely to change real drivers' decisions about trips and their routing behavior in the long term. So we will simplify the above-mentioned optimal toll structure for our simulation study: The useful feature of a tolling structure differentiating between different times of day will be modeled; the volume dependency of tariffs will not explicitly be taken into account.

Most of the recent studies using a cost-benefit-analysis (CBA) framework to measure the effects of reduced transport externalities conclude that congestion costs are the most important external cost category.[179] That is why the inclusion of modified congestion cost levels in our welfare analysis seems to be necessary. Excessive congestion costs occur due to an inefficient overuse of untolled network capacities. From a certain point of road utilization, one additional vehicle trip slows down all other traffic users and increases their time costs. As each network user, in his decisions, ignores these additional time costs for all other drivers, the overall trip demand on an untolled road network will be too high compared to its optimal utilization. Due to the high invariability of network supply in combination with a high time dependency of traffic demand, marginal congestion costs are highest during the morning and evening peak hours, and small or non-existent during off-peak hours, e.g. night times. Hence, the temporal distribution of congestion costs is exactly opposite to that of external

[179] Cf. section 2.1.1.2.

noise effects. This indicates an inherent contradiction between the two aims, reduction of noise effects and lowering congestion levels, and underlines the importance of adequate target definitions for road charging systems. Especially the optimal tariff design will depend on the weight attached to each single aim. The core objective of this study is the estimation of the economic potential for the reduction of external noise and air pollution effects due to truck traffic through a road pricing system. That is why we will set our tolls according to these complementary targets, i.e. charging level and structures will be oriented towards the sum of marginal external costs for noise and air pollution due to truck traffic. Resulting changes in congestion cost levels will be expressed in monetary terms too, but they may occur only as side effects of this environmentally oriented truck charging scheme.

Disregarding its own installing and operating costs, a tolling system could help to diminish the external environmental and noise effects of truck traffic in an efficient way: The toll can precisely be applied to the most affected urban areas that would potentially benefit most from lower traffic volumes. Ideally, the former external effects are reflected in road charges and hence reintegrated in the market price system. The technologically sophisticated German toll system on federal highways has been in operation for more than four years; and long-term trends suggest even cheaper tolling devices and services for the future. This may facilitate a cost-effective expansion of the German highway tolling system for trucks to the city. The well-functioning London city toll scheme demonstrates the practicability of a charging application for metropolitan areas, even if the local charging zone is very limited (about 23 km^2), the system is technically simple, and the scheme is mainly directed at congestion effects.[180] For the local area of Berlin, the introduction of a highway toll could result in problems due to shifts from priced highways to the untolled major city network. A city charge for trucks could counterbalance those undesired effects. These reasons make the consideration of a truck road pricing system for Berlin particularly worthwhile.

The analytical basis for this study is the cost-benefit-analysis framework (CBA) laid down in section 2.4.2. Our evaluation methodology is based on the incremental changes of traffic levels due to a truck toll: We calculated the differences between the external cost levels before and after the introduction of the toll, while the total external cost levels of each of the single traffic equilibrium states were not considered in detail. Furthermore, we concentrated on a reliable and realistic calculation of welfare benefits due to reduced noise, air pollution and congestion cost levels. The cost side is not included in our analysis, because transferable information on cost data for charging systems is still rarely available.[181]

[180] Cf. SANTOS / SHAFFER (2004).

[181] Rare exceptions are DfT (2004b) and KÄFER (2005).

3.2 Modeling the Traffic Effects of Truck Road Pricing in Berlin

The modeling of traffic effects due to a road pricing system follows the methodology extensively described in section 2.4.1. One interesting feature of a real world transportation system is the interdependency between different transport demand segments using the same network, like passenger car and truck traffic. As stated above, one can expect a diminished demand for truck trips if freight transport costs rise due to a toll. If the truck trip demand reacts in this way to a charge, as a side effect the average speeds for all network users will rise. Hence, higher average speeds imply, ceteris paribus, diminished average costs for most of the passenger car trips. This should lead to an increase of the untolled passenger car traffic. If this rebound effect is not taken into account, an overestimation of possible benefits due to lower congestion levels is likely. That is why we integrated the interdependency between different network users in our assignment approach.

3.2.1 Assignment Approach Using Interdependent Demand Segments

The concrete assignment approach was as follows: First, a multi-user-class equilibrium assignment with both demand segments, truck and private car traffic, was conducted. The result was a user equilibrium between supply and transport demand before tolls. Then the toll for trucks was introduced into the network supply model. This changed the trip costs for trucks. Using general cost elasticities, the truck trip demand of each O-D relation was adjusted downwards. In the next step this new truck O-D matrix and the original private car matrix were commonly assigned to the network again, which yielded altered route choices and changed cost data for each demand segment and each origin-destination pair of the network. After this, the truck and the passenger car matrix were adjusted simultaneously upwards to take into account the new – hypothetically – lower average trip costs (supply) data. After re-assigning both adjusted O-D matrices, the demand segments were adjusted again to the altered (higher) average trip costs, which were caused by the increased congestion effects. This process was repeated until the differences in traffic and cost levels between two steps of the assignment became negligible for both demand segments. While a simple approximation to equilibrium without taking into account the rebound effect on private car traffic was reached after just four assignment steps,[182] the number of necessary steps using our more elaborate approach varied greatly for different elasticity values. Not surprisingly, a higher truck general cost elasticity value produced longer iterations, i.e. more iteration steps.

[182] This complies with the minimum of three converging iterations proposed for simple elastic assignments by the British Department of Transport. Cf. DfT (2003, Appendix 13A, p. 21).

3.2.2 Input Values for the Modeling Process

3.2.2.1 Values of Time and Distance

The choice of the input parameters Value of Time (VOT) and Value of Distance (VOD) is of outstanding importance for the study results: The relation between VOT and VOD determines the route choice of each demand segment, which is one of the main outputs of the traffic modeling process. If the VOT is high compared to the VOD, the users of the transport system will prefer the time-shortest paths over distance-shortest paths. Fast but long routes, for instance, such as motorways, will be favored over slower, but shorter routes.

For the internal route choice routines of the simulation software, the choice of the absolute values of time and distance for each user class is of minor importance. Nevertheless, these absolute values strongly influence the inertia of the modeled trip demand reactions. Higher absolute trip costs before tolls would reduce the relative weight of an additional road charge. This would result in a weaker trip demand reaction in our model, despite constant general cost elasticity values. Furthermore, the valuation results for congestion costs depend especially on the absolute value of time, because these benefits after the introduction of a toll occur primarily due to reduced time costs for the remaining users. Hence, the values of time and distance must be carefully chosen and validated.

The assignment procedures applied use separate but uniform values of time and distance for each demand segment. This common method uses and refines the approach of studies like MITCHELL ET AL. (2002) and SANTOS (2003), as the specific features of truck traffic, such as higher values of time and distance are explicitly taken into account. Even though an alternative assignment method of VISUM is able to represent stochastic distributions of values of time (VOT)[183], the lack of local data and the much more time consuming calculation runs discouraged us from the use of this approach for our study.

3.2.2.1.1 The Value of Time and Distance for Trucks

To provide an overview of common values of time (VOT) for trucks in Europe, Table 18 summarizes and updates data from LINK ET AL. (1999):

[183] This is the TRIBUT module. Cf. BARBIER-SAINT-HILAIRE ET AL. (1999).

Country	VOT in €/h (2003)
Portugal	5.90
Finland	6.80
Greece	9.00
Netherlands	10.80
United Kingdom	13.80
Italy	15.10
Ireland	15.70
Spain	18.60
Luxemburg	18.70
Denmark	23.70
Sweden	24.30
Germany	32.00
France	33.20
Austria	33.40
Belgium	33.60
Switzerland	69.60

Table 18: Value of Time for Trucks in European Countries[184]

The broad bandwidth of VOT for similar countries is remarkable: For instance the values for the Netherlands or the United Kingdom are below the VOT of Spain, and even the VOT for Luxemburg is below the average European value of 22.80 €/h. In contrast to this, the VOT for Germany, France, Austria and Switzerland are in the upper range, some of them more than doubling the median of 18.65 € for all countries. This can hardly be explained by regional cost differences; instead variations in the accounting cost approaches are likely. Unfortunately, truck values of distance for Europe show a similar heterogeneity, which again can not be described by inherent differences, like differing fuel taxes. That is why we took a closer look at related simulation studies and reviewed recommendations of national administrations dealing with the valuation of transport benefits. The results are summarized in Table 19.

[184] Source: LINK ET AL. (1999, p. 111), own calculations.

Study	VOT in € per Hour	VOD € per 100 km	Relation VOT/VOD
ROTHENGATTER / DOLL (2001)	45.00	52.00	0.87
TROYER (2002)	23.39	33.46	0.70
DfT (2001)	12.37	90.00	0.14
This Study	**28.00**	**40.00**	**0.70**

Table 19: Value of Time and Distance for Trucks in Different Studies - Relation between VOT/VOD[185]

Table 19 suggests the use of a wide range of VOT and VOD for truck traffic in similar studies. While for example the British DEPARTMENT FOR TRANSPORT (1998) recommends comparatively high distance costs,[186] the German and Austrian studies apparently use rather high time costs for trucks. Hence, the resulting relationship between VOT and VOD as the main determinant of route choice is far from being stable across studies. Nevertheless, for this study we decided to choose input values of **28.00 € per hour for VOT and of 40 € per 100 km for VOD** according to Table 19. These values were chosen to approximate the recent German and Austrian studies by ROTHENGATTER / DOLL (2001) and TROYER (2002), taking into account the absolute values of time and distance as well as their relation to each other.

Furthermore, we cross-checked the total costs for a hypothetical urban truck trip at an assumed average speed of 20 km/h and an average trip length of 20 km with the available basic data and our selected VOT and VOD. The reason for this calculation is the great importance of total truck trip costs as the basic parameter for the calculation of demand reactions via general cost elasticities. The results are shown in Table 20.

[185] Sources: ROTHENGATTER / DOLL (2001), TROYER (2002), DfT (2001), own calculations.

[186] See DfT (2001). The suggested VOD could only partly be explained by the comparatively high taxes on diesel in the UK. The consumer costs per liter of diesel are about 50% higher than e.g. in Germany (see e.g. http://www.theaa.com/allaboutcars/fuel/). According to the approach of DfT (2001) the fuel component accounts for about 2/3 of the total distance costs, which would justify a higher VOD of about 133 % compared to the levels assumed in German studies. As Table 20 indicates, the actual difference is between 170% and 270%.

Study	Time Costs in € per Trip	Distance Costs in € per Trip	% Time Costs	% Distance Costs	Total Costs in € per Trip
ROTHENGATTER / DOLL (2001)	45.00	10.40	81 %	19 %	55.40
TROYER (2002)	23.39	6.70	78 %	22 %	30.08
DfT (2001)	12.37	18.00	41 %	59 %	30.37
This Study	**28.00**	**8.00**	**78 %**	**22 %**	**36.00**

Table 20: Value of Time and Distance for Trucks in Different Studies – Total Trip Costs [187]

Interestingly, although the absolute values of time and distance as well as the relative weight of VOT and VOD differ widely between the studies, the studies tend to converge to similar results for the total costs of a typical urban truck trip. Our selected VOT and VOD for truck trips, as well as the derived total costs for an urban truck trip fall into the plausible ranges of this test, which indicates that the selected values are appropriate.

3.2.2.1.2 The Value of Time and Distance for Passenger Cars

A model of interdependent truck and private car traffic requires detailed data on VOD and VOT of both demand segments. In contrast to the truck segment there has been a broader consensus on the range of these values for passenger car traffic in research literature, as shown in Table 21.

Study	VOT € per h	VOD € per 100 km	Relation VOT/VOD
SANTOS (2003)	10.11	17.70	0.57
MITCHELL ET AL. (2002)	8.40	14.00	0.60
TROYER (2002)	6.64	10.78	0.62
This Study	**8.40**	**14.00**	**0.60**

Table 21: Value of Time and Distance for Passenger Cars - Relation between VOT/VOD[188]

The absolute VOT and VOD used for private car traffic in the studies quoted do not differ much. More importantly, despite larger regional differences in the study areas the relationship between these parameters seems to be a stable one, at around 0.6. This encouraged us to update the VOT and VOD for this study to **8.4 € per hour and 14 € per 100 km**.

[187] Sources: ROTHENGATTER / DOLL (2001), TROYER (2002), DfT (2001), own calculations.

[188] Sources: SANTOS (2003), MITCHELL ET AL. (2002), TROYER (2002), own calculations.

Not surprisingly, the calculation of the total costs of a hypothetical urban passenger car trip, of an average length of 10 km and an average speed of 25 km per hour yielded quite similar results for all studies, as Table 22 below indicates. The constant relative share of time and distance costs respectively in all studies is also remarkable. Hence, the selected values should allow of modeling realistic routing behavior in this study.

Study	Time Costs in € per Trip	Distance Costs in € per Trip	% Time Costs	% Distance Costs	Total Costs in € per Trip
SANTOS (2003)	4.04	1.77	69 %	31 %	5.81
MITCHELL ET AL. (2002)	3.36	1.40	71 %	29 %	4.76
TROYER (2002)	2.66	1.08	71 %	29 %	3.74
This Study	**3.36**	**1.40**	**71 %**	**29 %**	**4.76**

Table 22: Value of Time and Distance for Passenger Cars – Total Trip Costs[189]

One last measure used in this study for the evaluation of VOT and VOD is the relation between VOT and VOD of the different traffic demand segments. This comparison should ensure the internal consistency of the used data for truck and private car traffic. In addition, it forms the basis for a realistic valuation of congestion effects, taking into account the rebound effects of unpriced car traffic. Unfortunately we only know one further study dealing with both vehicle classes, i.e. trucks and private cars. For comparison between their values and ours, see Table 23.

Study	Value of Distance	Value of Time
Relation	Private Car / Truck	Private Car / Truck
TROYER (2002)	0.28	0.32
This Study	**0.3**	**0.35**

Table 23: Relation of the Values of Time and Distance between Passenger Cars and Trucks[190]

The VOT and VOD data we selected appear to be in line with the existing data. As Table 23 also shows, the simplification usually applied in modeling truck traffic of equating one truck with 2 or 2.5 standardized passenger car units (PCU)[191] seems to be rather inappropriate. If the derived data is correct, VOT and VOD for a truck trip are about 3 times higher than for a passenger car trip. Taking additionally into account the slower average speeds of trucks and the presumably longer average trip

[189] Sources: SANTOS (2003), MITCHELL ET AL. (2002), TROYER (2002), own calculations.

[190] Sources: TROYER (2002), own calculations.

[191] Cf. MITCHELL ET AL. (2002) and SANTOS (2003).

distance, this makes a strong case for the separate modeling of both demand segments, as done in this study.

3.2.2.2 Generalized Cost Elasticities of Urban Traffic

3.2.2.2.1 Literature Review: Cost Elasticities of Urban Freight Transport

To specify the demand function in power formulations for the assignment procedure, an empirical elasticity value is needed. As one can see from the next figure, taken from the extensive review of GRAHAM / GLAISTER (2002),[192] a broad range of results for road freight elasticities exists.

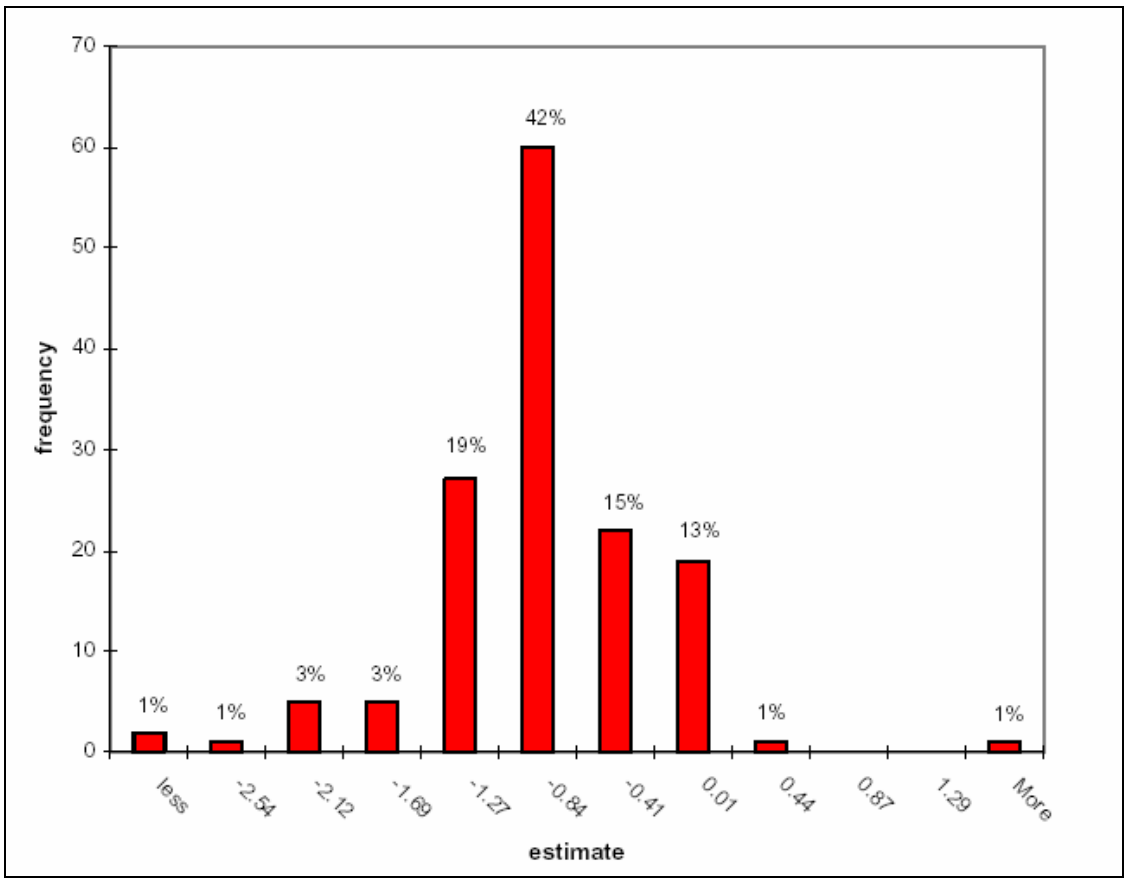

Figure 9: Price Elasticities of Demand for Road Freight Services[193]

Beside the obvious deviations in regional market coverage (e.g. urban vs. intercity transport) between the studies, GRAHAM / GLAISTER (2002) state that the following factors are mainly attributable for this large bandwidth:[194]

[192] Cf. GRAHAM / GLAISTER (2002).

[193] Source: GRAHAM / GLAISTER (2002, p. 44).

- Differences between functional models estimated
- Variations in the type of data used (e.g. aggregate or disaggregate)
- Differences in the level and definition of commodity group aggregation
- The use of different demand specifications

However, GRAHAM / GLAISTER (2002) find surprisingly high elasticities for road freight transport in their review. Mainly this is due to the fact that most studies analyze intercity transport with much better substitution choices for shippers than in urban transport. For the resulting elasticity value the reference point used is also essential: BEUTHE (2001) and BJORNER (1999) both show that the price elasticity regarding tonnage is nearly half the price elasticity regarding ton kilometers.

We are neither aware of any empirical study using the required reference point, an elasticity of truck trips regarding changes in generalized costs, nor an analysis dealing explicitly with urban freight transport price or cost elasticities. Nevertheless, many authors assume a very low elasticity for urban truck transport. In the following Table 24 values proposed for the elasticity from the scientific literature are summarized:

Study	**Elasticity High**	**Elasticity Low**
UPI (1988), according to SCHNIER (1999)	-0.12	
ECOPLAN (1992), according to SCHNIER (1999)	-0.20	-0.10
DIW ET. AL. (1994), according to ROTHENGATTER / DOLL (2001)	-0.20	-0.10
SCHNIER (1999)	-0.10	-0.05
ROTHENGATTER / DOLL (2001)	-0.10	-0.05
TROYER (2002) (Interurban Transport)	*-0.30*	*-0.15*

Table 24: Assumed Generalized Cost Elasticities for Urban Truck Trips[195]

In the light of poor substitution possibilities for most of the urban truck traffic the elasticity values quoted seem to be reasonable at first. But now, as recent traffic counting data from the introduction of the London Congestion Charging Scheme have become available, a validation or falsification of these assumed elasticities is possible.[196]

[194] Cf. GRAHAM / GLAISTER (2002, p. 32).

[195] Sources: SCHNIER (1999), ROTHENGATTER / DOLL (2001), TROYER (2002).

[196] First calculations regarding the generalized cost elasticities for individual car trips in London can be found in SANTOS / SHAFFER (2004).

3.2.2.2.2 Estimation of Generalized Cost Elasticities for Urban Car and Truck Trips

To estimate the general cost elasticities of truck trip demand, we analyzed the changes in trip volume due to the London congestion charges of 5 GBP per work day, following the approach suggested by SANTOS/SHAFFER (2004). Their calculations are methodologically sound, and are based on the most recent data from a comparable European capital with similar structures to Berlin. That is why we used the findings of SANTOS/SHAFFER (2004) as direct input for the reactions of the passenger car demand segment. Its basic assumptions and main results are described in Table 25 below:

Parameter	**Value**
Occupancy Rate	1.35
Average Car Trip Length (km)	11.7
Number of Trips per Day	2
VOT per Person (pence/min)	8.6
Time per Trip (min)	47
Time Savings per Trip (min)	6
VOD (pence/km)	12.3
General Costs per Day (GBP)	13.82
Toll (GBP)	5.00
Time Benefits (GBP)	1.40
Reliability Benefits (GBP)	0.35
Change in General Car Trip Costs (GBP)	+3.25
Change in General Car Trip Costs (%)	+23.50
Change in Car Trip Demand (%)	-31.00
General Cost Elasticity for Car Trips	**-1.32**

Table 25: General Cost Elasticities for Private Car Trips in London[197]

The general monetary values for VOT and VOD in this study are based on data from the TfL on London specific time costs, and the recommendations of DfT (2001). They are quite similar to data used in other studies.[198] The calculated general cost elasticity of - 1.32 explicitly refers to the short-term vehicle operating costs, hence it excludes the fixed costs. For our purposes this is the relevant base, as fixed costs like insurances and depreciation do not influence route choice.

[197] Source: SANTOS / SHAFFER (2004).

[198] Cf. Table 21.

Unfortunately the data base for urban truck trips in London is much weaker than for passenger car traffic. Therefore we had to make reasonable assumptions about some parameters of the calculation, like average truck trip distance and number of truck trips to the charging zone per day. In addition, to get a realistic picture of the truck demand reaction to the London Congestion Charge, we had to vary some of these key parameters. Our base assumptions and the main results are presented in Table 26.

Parameter	**London and UK**	**Alternative**
Number of Truck Trips per Charging Day before the Toll	31,585	31,585
Number of Truck Trips per Charging Day with the Toll	27,878	27,878
Average Urban Truck Trip Length in km	27.16[199]	12.15[200]
Average Truck Time Costs in EUR per Hour	12.37	28.00
Average Truck Distance Costs in EUR per km	1.01	0.40
Toll per Day in EUR	7.14	7.14
Number of Daily Truck Trips in Charging Zone	2	2
General Costs per Incoming Truck per Day before the Toll in EUR	93.28	49.63
General Costs per Incoming Truck per Day with the Toll in EUR	99.81	55.66
Increase in General Costs per Truck per Day	7.00%	12,14%
Decrease in Truck Trips per Day	13.30%	13.30%
Generalized Truck Cost Elasticity with regard to Trips	**-1.90**	**-1.10**

Table 26: Parameters for Calculating General Cost Elasticities for Truck Trips in London[201]

Even using the selected conservative input parameters, our calculations result in surprisingly high elasticities. The single calculations differ, beside the chosen VOT and VOD, mainly in the average trip distance. Of course, as shown in Table 26, a longer average trip distance results in higher running vehicle costs. Hence the estimation yields higher general cost elasticities for the same demand decrease. The same is true if the number of daily trips to and from the charging zone is higher than

[199] The average trip distance was estimated using data from the national Transport Statistic Bulletin for transports within London (DfT (2004a)). The annual freight performance (tkm) was divided by the annual amount of goods lifted (t), which results in a volume weighted average trip distance for freight traffic within London. As long-distance freight traffic from or to other areas than London is excluded here, this value could rather underestimate the real but unknown average trip distance for trucks in London.

[200] BRACEWELL (2000) reports of an average trip distance for light trucks of 8.5 km, and 15.8 km for heavy trucks in Vancouver, Canada. We compute here with an average of both values.

[201] Sources: DfT (2001), DfT (2004a), SANTOS / SHAFFER (2004), TfL (2004).

assumed, or if the rather small calculated time benefits for trucks [202] (or reliability benefits not captured) should be substantial in reality.

There is the possibility that lower truck trip demand is not only a result of the higher transport costs due to road charges, but also e.g. of a lower demand for transport due to external cyclical economic factors. That is why we compared the overall transport statistics for the year 2002 (before the toll) and the year 2003 (after the introduction of the pricing system). Table 27 shows the tonnage and performance of goods transport to and from London for these years.

Measure	From London to UK (outside London)	To London from UK (outside London)	Within London	TOTAL
Lifted Goods 2002 (mn. t)	31	41	51	123
Lifted Goods 2003 (mn. t)	33	52	44	129
Performance 2002 (mn. tkm)	3,617	5,233	1,404	10,254
Performance 2003 (mn. tkm)	3,724	5,882	1,195	10,801

Table 27: Development of Freight Transport to, from and within London[203]

The best measure for analyzing the development of freight traffic is the tonnage lifted, because it is distance independent. As one can see from Table 27, the total tonnage of freight traffic involving the London area rose from 123 Mio. t in 2002 to 129 Mio. t 2003, so seasonal effects are not likely to disturb our calculations. Interestingly the demand for freight transport within London decreased in this period, in contrast to the demand for transports to and from London. This could be a direct effect of the toll, which is a main cost component for short inner-city trips, but becomes negligible on longer distances.

Adopting our estimations, but at the same time staying in line with the research quoted, we decided to use as input values for our simulation scenarios a rather large range of general cost elasticity values for truck trips from **– 0.5** to **– 1.5**.

With the selection of these values a broad spectrum of truck demand reactions to a toll is covered, which should improve the reliability of our conclusions on welfare gains due to a truck charging system.

[202] As the surrounding areas have similar traffic conditions as before the introduction of the toll, and only a small share of between 10% and 20% of the average truck trip takes place in the congestion charging zone, the calculated time benefits due to higher average speeds in the charging zone are almost negligible. For comparison, TfL (2004) reports average time savings of 6 min for a basket of 5.000 passenger car journeys after the introduction of the congestion charge, which in the calculations of SANTOS / SHAFFER (2004) results in time benefits of 1.40 GBP per trip.

[203] Sources: DfT (2004a).

3.2.3 Data Adjustments and Calibration of the Base Model

The main objective of a calibration procedure is to ensure a good match between the VISUM base supply and demand data and reality. First we had to adjust the 24h forecast O-D matrix for all traffic in Berlin to match reference counting points and speeds already included in the network model, Additionally, we manually added counting data. After deducting the truck matrix from the 24h forecast O-D matrix, we reduced the resulting private car trip matrix stepwise to exclude the forecast effect. The achieved match was good, with a correlation coefficient of 0.91 between modeled flows and reference counting data. This model was used as a 24h reference case for our simulations.

For the analysis of time differentiated tolls it was necessary to derive three separate sub models from the 24h network model, each representing the network supply during a different period of day (7.00 – 19.00), evening (19.00-23.00) and night (23.00-7.00). As the explicit objective of this procedure was to model a whole 24 hour period, the original road capacity on each link (in max. vehicles per hour) was reduced for each sub period to the share of its duration, i.e. 12/24 for the day sub model, 4/24 for the evening sub model, and 8/24 for the night sub model. The respective demand matrices were adapted accordingly, too. We compiled time-differentiated traffic counting data from the Berlin Senate Department for Urban Development to split the 24h O-D matrices into three time slices. The next graph shows the average share of truck and passenger cars in Berlin during a whole work day, which were used to split the 24h demand matrices. Not surprisingly the truck traffic share is comparatively high at night times, as a substantial number of long-distance transports uses this relatively uncongested time period.

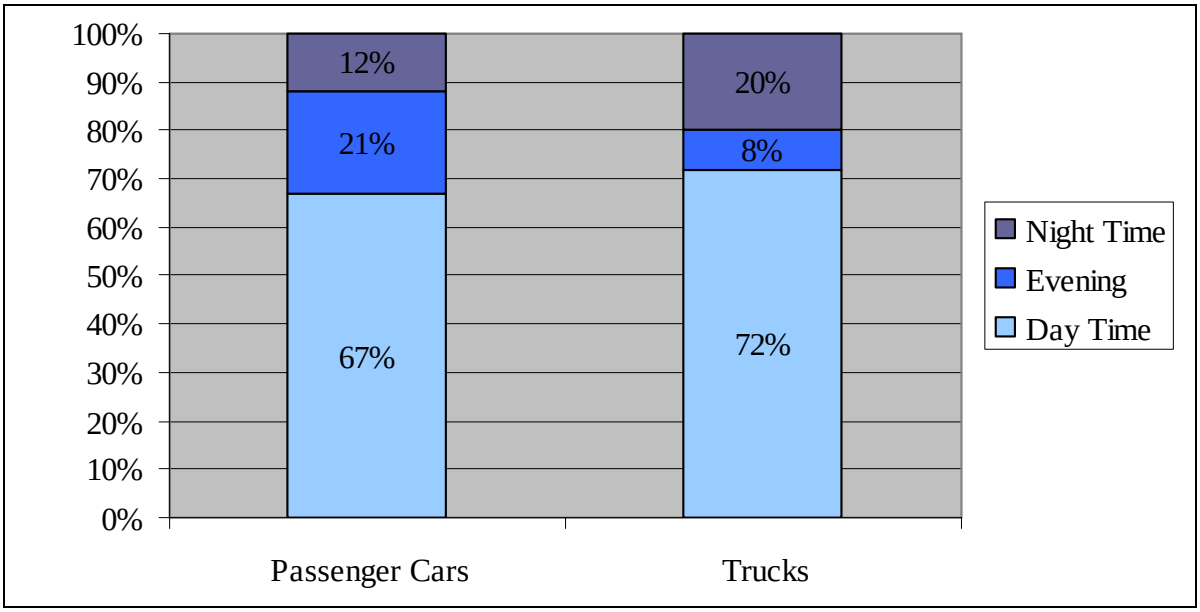

Figure 10: Share of Truck and Passenger Car Traffic in Berlin during Different Times of Day[204]

Tests on the combined modeled truck and passenger car flows as well as on the time-weighted average speeds revealed very high correlations of about 0.99 and very low absolute deviations (+ 0.23% higher passenger car volumes, -1.63% lower truck volumes) between the original 24h model and the combination of the three sub models. This supports the usefulness of the matrix split operation described before.

Even if some features of the real world traffic situation should not be fully captured by our model, some characteristics of our approach help to diminish potential difficulties: First of all, the daily mileage delivered by the VISUM model for the reference case was scaled up to match the annual mileage data for trucks from the Berlin Emission Directory for Transport.[205] This ensures realistic ranges for the global values of traveled vehicle kilometers for all scenarios. Secondly, our truck simulations function as incremental models, i.e. we consider only changes of network flows between two different states of the model. Preliminary calculations show that as long as the overall generalized costs of an O-D-pair are approximately proportional to the modeled tolls, numerical variations of the VOD and VOT in a medium range leave the extent of route choice changes nearly unaffected. These factors suggest the assumption that the modeled traffic flows are sufficiently in line with observed data to suit our research purposes.

[204] Source: Own compilation based on data from the SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN.

[205] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999).

3.3 Simulation Results

3.3.1 General Aspects of Scenario Building and Selection

Due to its isolated geographical position with only about 100 entry possibilities,[206] the Berlin region might well be an ideal starting point for an urban road pricing system in Germany. Our truck tolling zone includes the metropolitan area of Berlin, as shown in Figure 11. In our simulation scenarios we levy distance-based, time-differentiated charges for trucks with more than 3.5 tons gross weight on all roads of the tolling area, except federal highways (Bundesautobahnen; BAB). The exclusion of the latter road category from additional truck charges has three reasons: First, they are already charged by the German highway toll of about 12.4 ct per vehicle kilometer, thus reducing the potential for additional noise and air pollution oriented charges. Second, motorways in Berlin often lead through sparsely populated areas; if not, they are usually equipped with noise protection walls, so at least a noise toll does not make sense on these links. Third, even if it is still unclear whether German states (as Berlin) are eligible to introduce locally adapted road charges, they have no authority to toll the federal road network. In Figure 11 the main toll roads of Berlin's network are marked in blue, while the federal highways without the additional city toll are depicted in red.

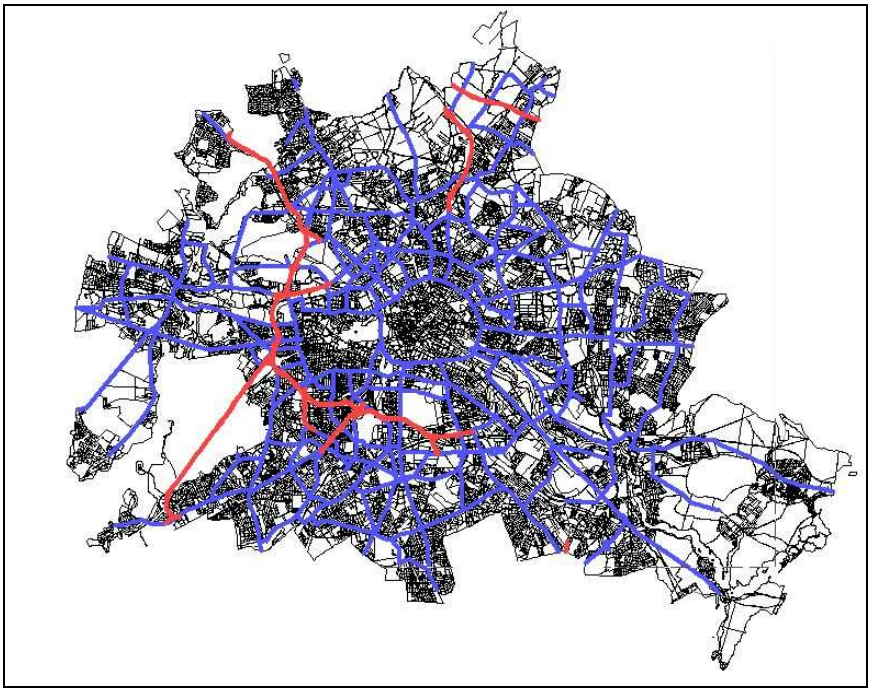

Figure 11: Berlin Road Pricing Area[207]

[206] Cf. FOLKERTS (2004).

[207] Source: VISUM-Screenshot.

In all our simulation scenarios the toll on German federal highways, introduced on 1 January 2005, is included. Due to the delayed implementation of this toll,[208] there is still a lack of evidence concerning shifting movements of truck trips to the secondary city network, as no new traffic counting data is available yet. Hence model adaptations to real-world shifting effects have been impossible so far, and it is difficult to predict these movements accurately. Nevertheless, it seems necessary to include these effects in our analysis. The scenarios with just a highway toll serve as comparators for all other city road pricing scenarios. Applying this approach, it is possible to distinguish between the effects of highway and city tolls analytically. Figure 12 summarizes the steps of our modeling process.

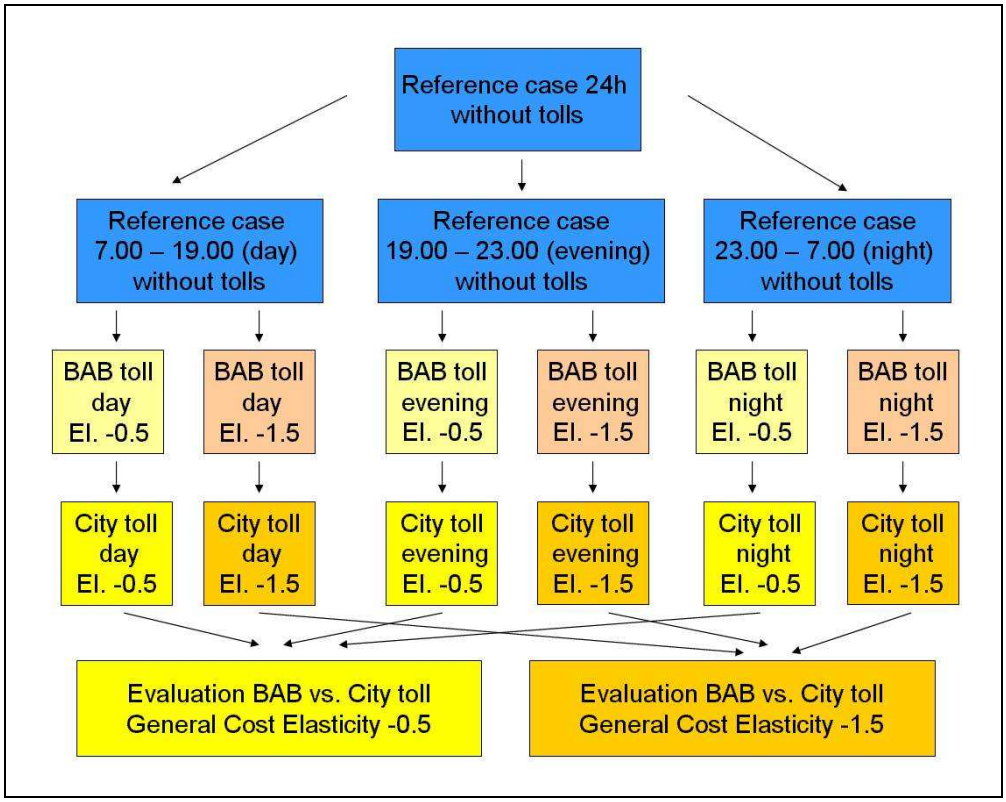

Figure 12: Scenario Building and Modeling Stages[209]

A road pricing scenario in VISUM depicts an average workday only, but for valuation purposes it was found suitable to aggregate the available data to annual values. The number of working days per year was calculated using data from the Berlin Emission Directory Transport (2001), which contains the mileage for trucks in 1999: 539.08 million vehicle kilometers.[210] Assuming a constant level of truck

[208] Originally the start of the German Highway Toll for trucks was scheduled for January 2003. Due to numerous technical problems it was postponed repeatedly.

[209] Source: Own compilation.

[210] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (1999, p. 8).

traffic until 2003, this annual figure was divided by the daily mileage from the reference case in VISUM, resulting in 265 working days for truck traffic scenarios. By multiplying the reduction of truck mileage for each scenario, annual numbers are projected. The figure of 265 working days seems to be reasonable. In her road pricing study, for instance, SANTOS (2003) assumes 250 working days for both truck and car passenger traffic.[211] If we consider mainly the truck traffic, this number could be even higher, because pickup and delivery tours usually run on Saturdays, too. Nevertheless, to match a reliable number for the overall annual truck mileage, 265 working days were assumed for all of our calculations.

3.3.2 Base Scenarios: German Highway Toll

First of all, the base scenarios including the German highway toll were simulated. A charge of 8.82 ct per truck kilometer was assigned to all federal highways in our network model. This value is based on the average truck toll on highways of 12.4 ct/vehicle km. It was scaled down by 28.9% to take the share of vehicles between 3.5 and 12 t gross weight into account,[212] which are not obliged to pay the toll, but are included in our truck trip matrix. Then the elastic assignment procedure[213] was applied for the assumed general cost elasticities of -0.5 and -1.5.[214] Table 28 summarizes the basic results for Berlin regarding truck mileage and trip numbers for these scenarios.

[211] Cf. SANTOS (2003, p. 10).

[212] This value is derived from the overall mileage for the different vehicle classes in Germany 1997, cf. ROTHENGATTER / DOLL (2001, p. 26). Possible differences between highways and other types of road were neglected.

[213] Cf. section 3.2.1.

[214] Cf. section 3.2.2.2.2.

Scenario	Truck Variables	Time of Day			TOTAL
		Day	Evening	Night	
Reference	Number of Trips (in million)	27.12	3.01	7.53	37.67
	Mileage (in Million vehicle km)	379	44	115	538
	Average Trip Length in km	13.97	14.62	15.31	14.29
Highway Toll with ε = - 0.5	Number of Trips (in million)	25.99	2.93	7.15	36.08
	Change of Number of Trips	-4.17%	-2.74%	-5.05%	**-4.23%**
	Mileage (in million vehicle km)	363	42	110	515
	Change of Mileage	-4.07%	-4.25%	-4.77%	**-4.23%**
	Average Trip Length in km	13.98	14.40	15.35	14.29
	Change of Average Trip Length	0.11%	-1.55%	0.30%	**0.00%**
Highway Toll with ε = - 1.5	Number of Trips (in million)	24.18	2.79	6.68	33.65
	Change of Number of Trips	-10.86%	-7.41%	-11.31%	**-10.67%**
	Mileage (in million vehicle km)	338	40	103	481
	Change of Mileage	-10.82%	-8.81%	-11.00%	**-10.69%**
	Average Trip Length in km	13.97	14.40	15.36	14.29
	Change of Average Trip Length	0.05%	-1.52%	0.36%	**-0.02%**

Table 28: Changes in Annual Truck Mileage and Trip Numbers due to the German Highway Toll[215]

The introduction of the German highway toll reduces the annual truck mileage as well as the number of truck trips within Berlin in our model in the order of about 4 % (for ε = - 0.5) or 11 % (for ε = - 1.5) respectively. At first sight this reduction of local truck mileage is a somewhat surprising result: The diminished number of truck trips to and from Berlin due to the toll apparently more than makes up for shifting movements to the secondary road network. This is supported by an almost unchanged average truck trip distance within Berlin of about 14 km. Nevertheless, a closer look reveals great differences in regional changes of truck traffic flows. Figure 13 shows the additional traffic for the case of ε = - 0.5. The more heavily used links are marked in red, the lesser used roads are marked in green, and the positions of the federal highways in Berlin are depicted in blue.

[215] Source: own calculations.

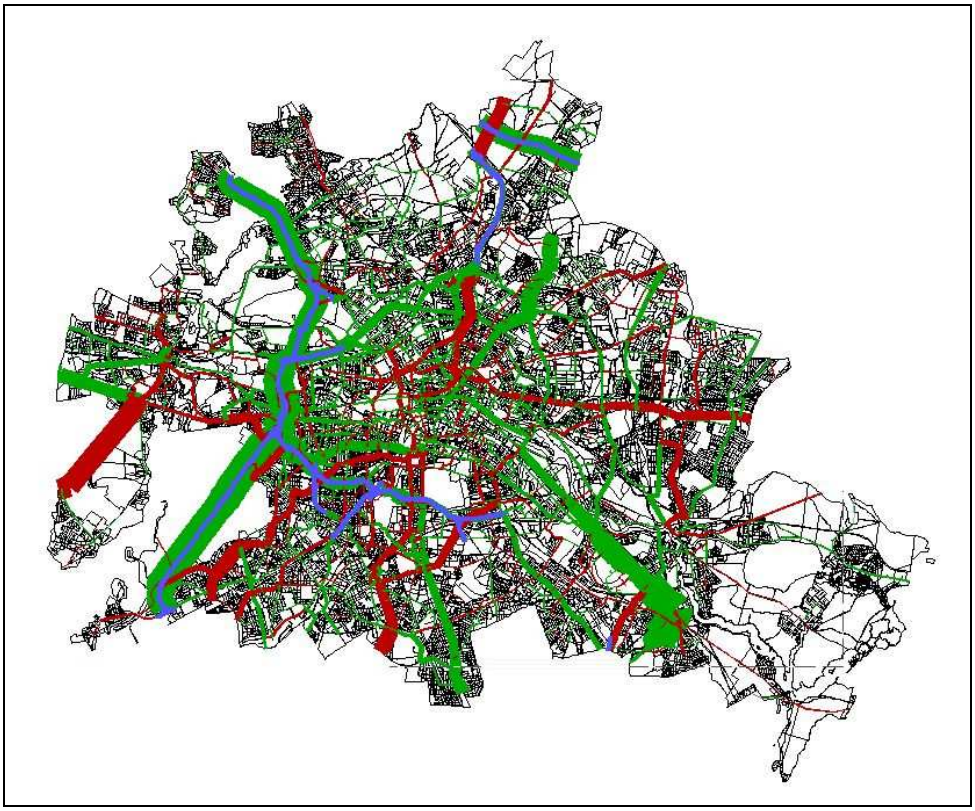

Figure 13: Changes in Truck Traffic in Berlin during Day Times due to the German Highway Toll[216]

As one can see from Figure 13, the truck demand segment reacts to the tolling in our model by substituting routes involving federal highways for shorter, but potentially slower alternative routes through the city. In Figure 14 the regional distribution of changed truck traffic levels is categorized by area and road type, respectively.

[216] Source: VISUM-Screenshot.

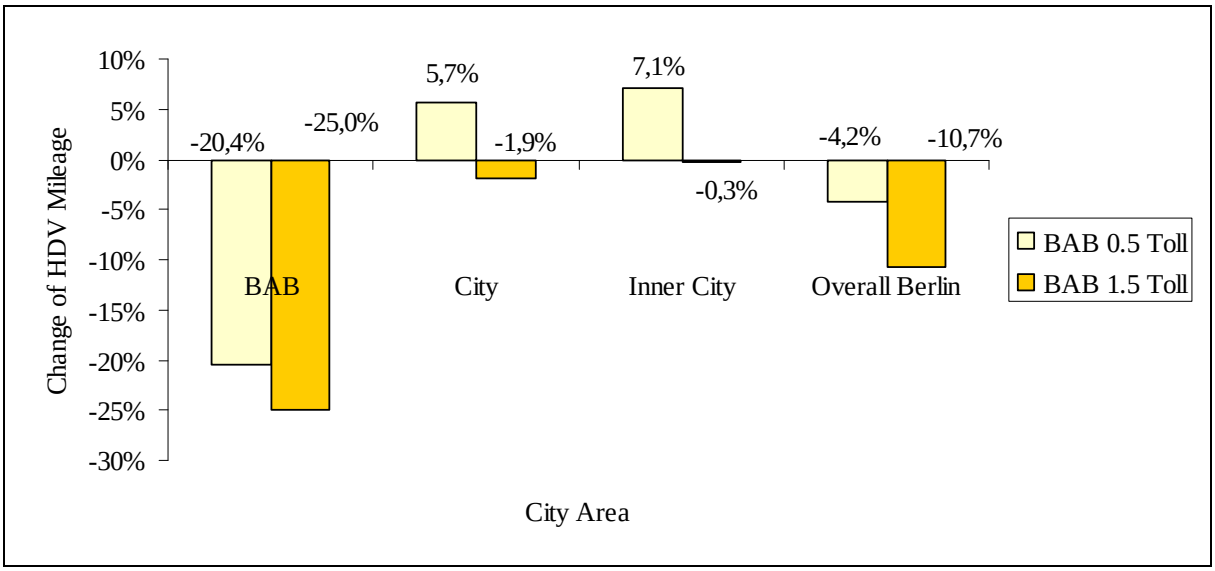

Figure 14: Regional Distribution of Changes in Truck Mileage in Berlin due to the German Highway Toll[217]

As stated in Figure 14, the sharp decline of mileage on the federal highways dominates the toll effects on total truck mileage within Berlin in both scenarios. For the tolling scenario with ε= - 1.5, the net effect of re-routing behavior and trip reduction is negative for all areas of Berlin considered, even if the truck mileage decrease in the city area is almost negligible. In the alternative scenario (with ε= -0.5), the trip reduction of the toll is smaller, causing stronger re-routing effects. The final result is a rise in truck traffic of between 5 and 7 % in the city areas which are most sensitive to noise and exhaust emissions. This is a first hint that a charging system could be an approbate measure to counterbalance possible side effects of the federal highway toll.

A side effect of the German truck toll on federal highways is a slight rise in urban passenger traffic, caused by higher average speeds on the Berlin road network. The increase of private car mileage is depicted in Figure 15.

[217] Source: own calculations.

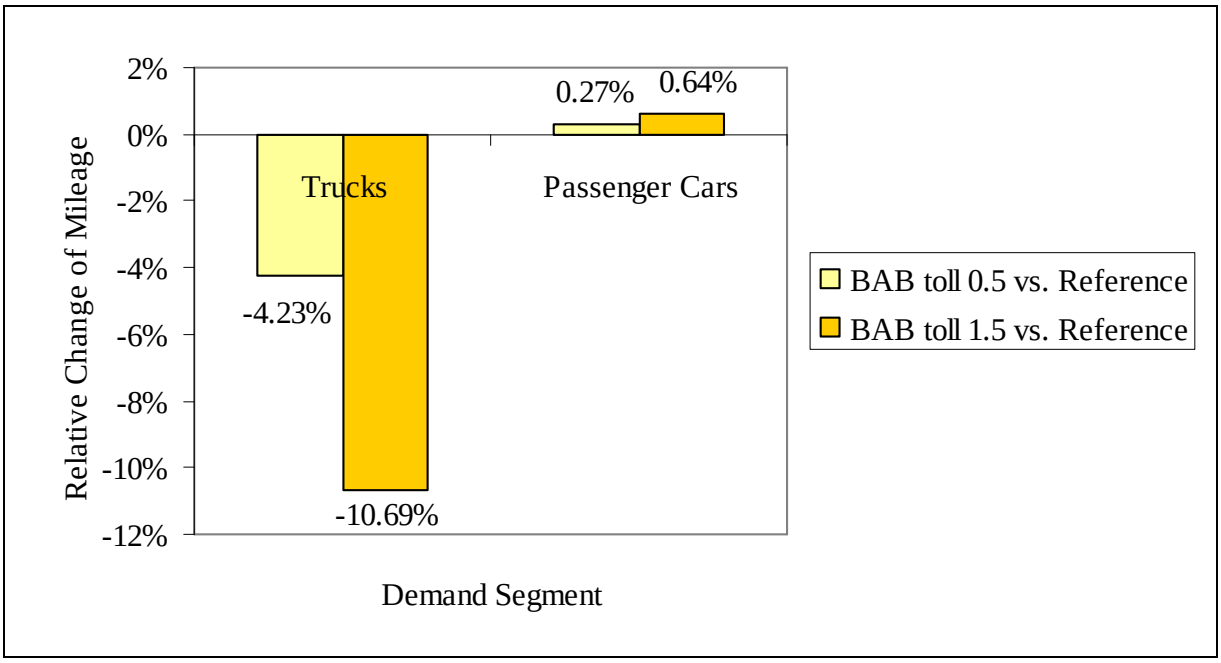

Figure 15: Relative Change in Annual Mileage per Demand Segment due to the German Highway Toll[218]

The reaction of private car users to lesser truck traffic seems to be almost negligible at fist sight. But these relatively small changes do not capture the fact that the vast majority of urban transport users are passenger cars. As the graph in Figure 16 shows, the reduction of urban truck mileage due to the toll is offset to a large extent [219] by a rise of passenger traffic. From an economic point of view, this should still yield some environmental benefits, as less polluting private car traffic replaces more polluting truck traffic. But it becomes clear that neglecting the interdependency between both demand segments in the modeling process would tend to overstate the improvements of the congestion situation due to the federal highway toll. This strongly supports our modeling procedure described in section 3.2.1.

[218] Source: own calculations.

[219] Due to different characteristics (e.g. average speeds, specific emissions, etc.) the mileage of both demand segments is not directly comparable.

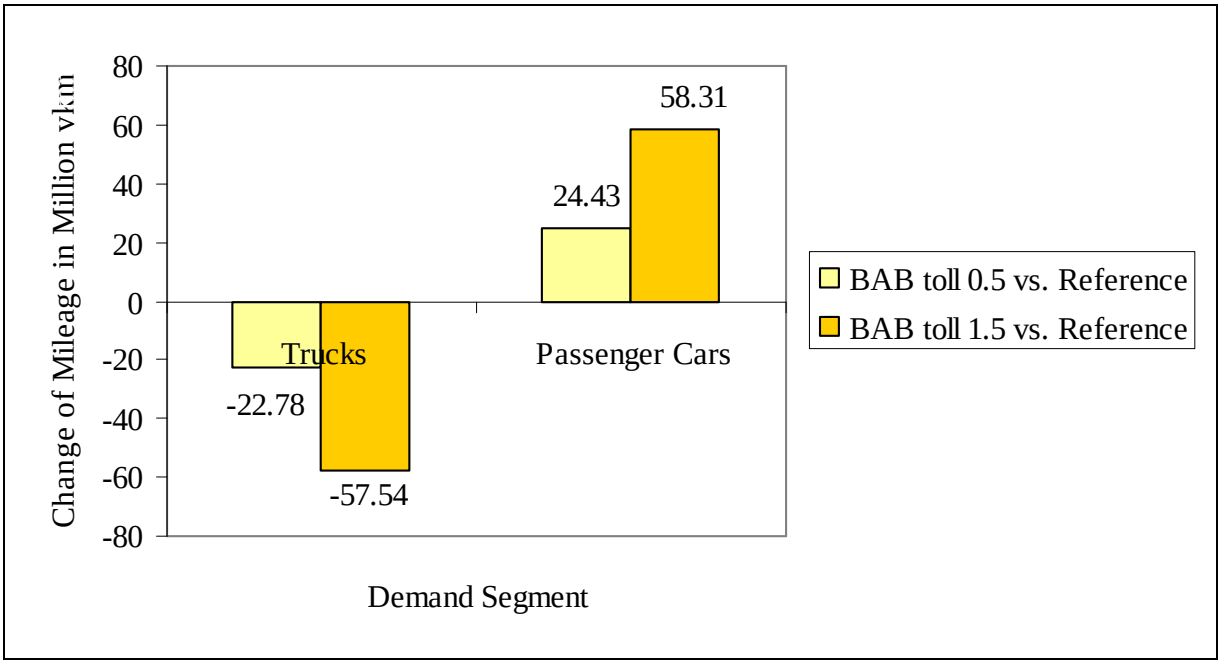

Figure 16: Absolute Change in Annual Mileage per Demand Segment due to the German Highway Toll[220]

3.3.3 Structure of the Metropolitan Road Pricing System for Trucks in Berlin

As mentioned above, the scenarios including only the German Highway Toll are the benchmarks for all other simulation scenarios. A separate environmental valuation was not considered useful, because the main objective of creating these scenarios was to distinguish between the effects of highway and urban charges for trucks analytically.

The city toll amounts modeled are based on estimations of marginal external noise and air pollution costs of truck traffic in Berlin. The values are derived mainly from the Berlin specific case study of BICKEL / SCHMID (2002), conducted for the EU project UNITE.[221] They are in line with our own estimations of marginal air pollution costs per truck vehicle kilometer as calculated in section 2.4.2.2, as well as with international research literature.[222] Table 29 gives an overview of the ranges of external cost estimations for noise and air pollution effects caused by truck traffic in urban areas.

[220] Source: own calculations.

[221] Cf. BICKEL / SCHMID (2002).

[222] Cf. e.g. INFRAS/IWW (2000), UNITE (2002), SANSOM ET AL. (2001).

Source	Marginal Air Pollution Costs (in ct / vkm)	Marginal Noise Costs (in ct / vehicle km)		
		Day Times	Evening	Night Times
BICKEL / SCHMID (2002) – Berlin	15.46	8.18	10.84	24.88
BICKEL / SCHMID (2002) – Stuttgart	23.28	27.46	36.52	83.44
INFRAS/IWW (2000) – high volume	22.81- 54.09	11.69		27.49
INFRAS/IWW (2000) – low volume	22.81- 54.09	24.71		58.20

Table 29: Marginal External Air Pollution and Noise Costs (2003) for Urban Truck Traffic in Europe[223]

The reported estimations were adjusted to our base year 2003 using the German CPI.[224] Since the publication of these studies the share of cleaner trucks in the urban truck fleet, i.e. those complying with the Euro norms III and IV is likely to have risen further. Hence the true external air pollution costs could be in the lower range of estimations. Unfortunately a differentiation of truck charges according to vehicle classes (Euro norms) is not possible within our modeling framework, but all modeled charges can be seen as an average of real world differentiations between newer and cleaner trucks and their more polluting counterparts.

As can also be seen from Table 29, noise costs for different times of day vary greatly. This supports our modeling of a time-differentiated noise toll. The theoretically useful additional differentiation of noise tolls between roads with lower traffic volumes (and higher charges) vs. roads with a high utilization (and lower charges) conflicts with the objective of creating an easy and understandable pricing structure. In addition, such a tolling structure could cause undesired congestion effects dominating on highly used links at times of day which would require the lowest noise tolls.[225] We applied a simplified uniform pricing structure for all road types of **30 ct** per truck km at **day times**, **40 ct** in the **evening**, and **60 ct** at **night**. As symbolized by the overlapping areas of the air pollution and noise tolls in Figure 17, some uncertainties about the right toll amounts can be reduced due to a simple averaging effect by applying combined noise and air pollution charges.

[223] Sources: updated from BICKEL / SCHMID (2002) and INFRAS/IWW (2000).

[224] Using data sets from http://destatis.de, we applied a factor of 1.0663 for the update from base year 1998 to 2003 (BICKEL / SCHMID (2002)) and a factor of 1.1322 for the update from base year 1995 to 2003 (INFRAS/IWW (2000)).

[225] See section 2.1.2.3.

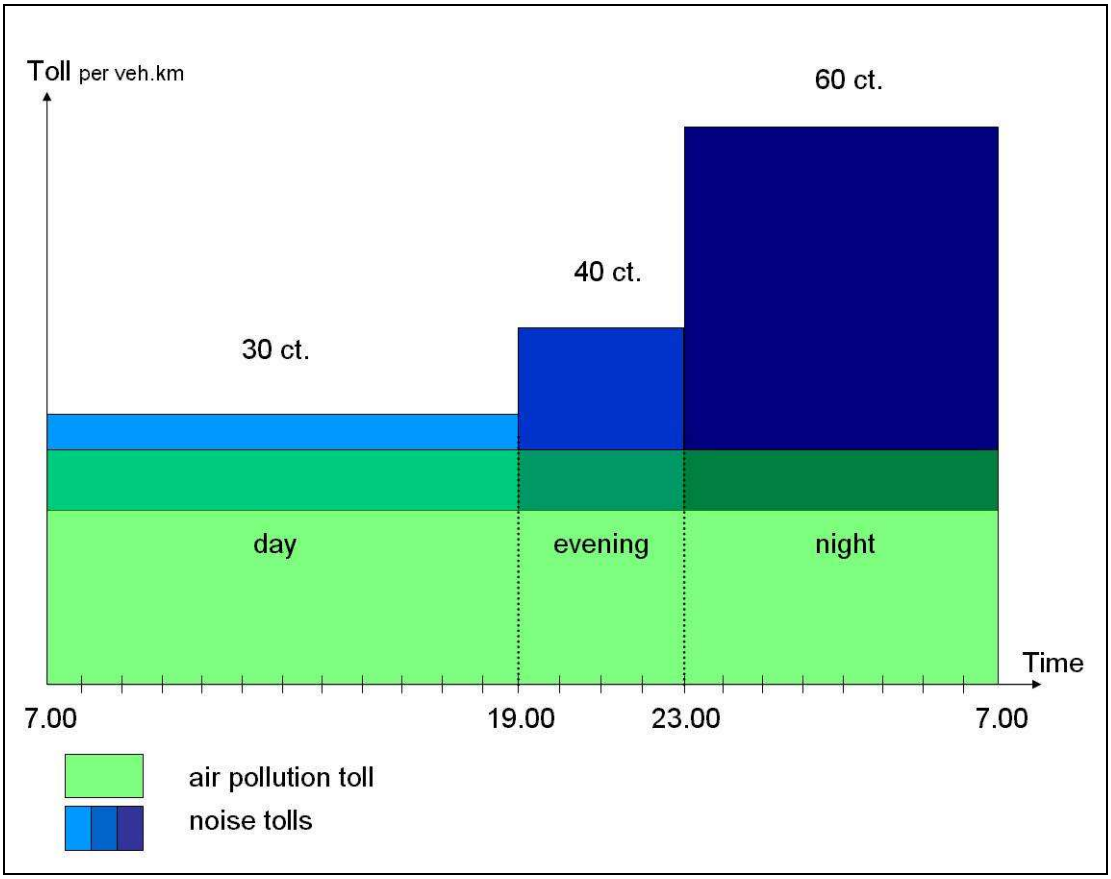

Figure 17: Structure of a Time-Differentiated Truck Charge in Berlin[226]

3.3.4 Traffic Effects of a Time-Dependent Metropolitan Toll in Berlin

The effects of time-differentiated city road charges for the truck demand segment are summarized in Table 30. All relative changes refer to a comparison with the highway toll scenarios.

[226] Source: Own compilation.

Scenario	Truck Variables	Time of Day			TOTAL
		Day	Evening	Night	
City Toll with ε = - 0.5	Number of Trips (in million)	25.83	2.91	7.04	35.78
	Change of Number of Trips	-0.61%	-0.80%	-1.58%	-0.82%
	Mileage (in million vehicle km)	340	40	104	483
	Change of Mileage	-6.57%	-6.34%	-5.52%	-6.33%
	Average Trip Length in km	13.14	13.59	14.74	13.49
	Change of Average Trip Length	-6.00%	-5.59%	-4.00%	-5.55%
City Toll with ε = - 1.5	Number of Trips (in million)	23.83	2.71	6.38	32.92
	Change of Number of Trips	-1.45%	-2.83%	-4.48%	-2.17%
	Mileage (in million vehicle km)	311	37	94	442
	Change of Mileage	-7.93%	-8.47%	-8.71%	-8.14%
	Average Trip Length in km	13.06	13.57	14.68	13.41
	Change of Average Trip Length	-6.57%	-5.80%	-4.43%	-6.10%

Table 30: Changes in Annual Truck Mileage and Trip Numbers due to the City Toll in Berlin[227]

As anticipated, truck mileage declines considerably due to the comprehensive city toll system, i.e. by about 6-8 %. The decrease of truck trips during a certain time of day, as shown in Figure 18, is about proportional to the modeled toll, with a stronger demand reaction for the higher elasticity. This is in line with our expectations and seems to be reasonable.

[227] Source: Own calculations.

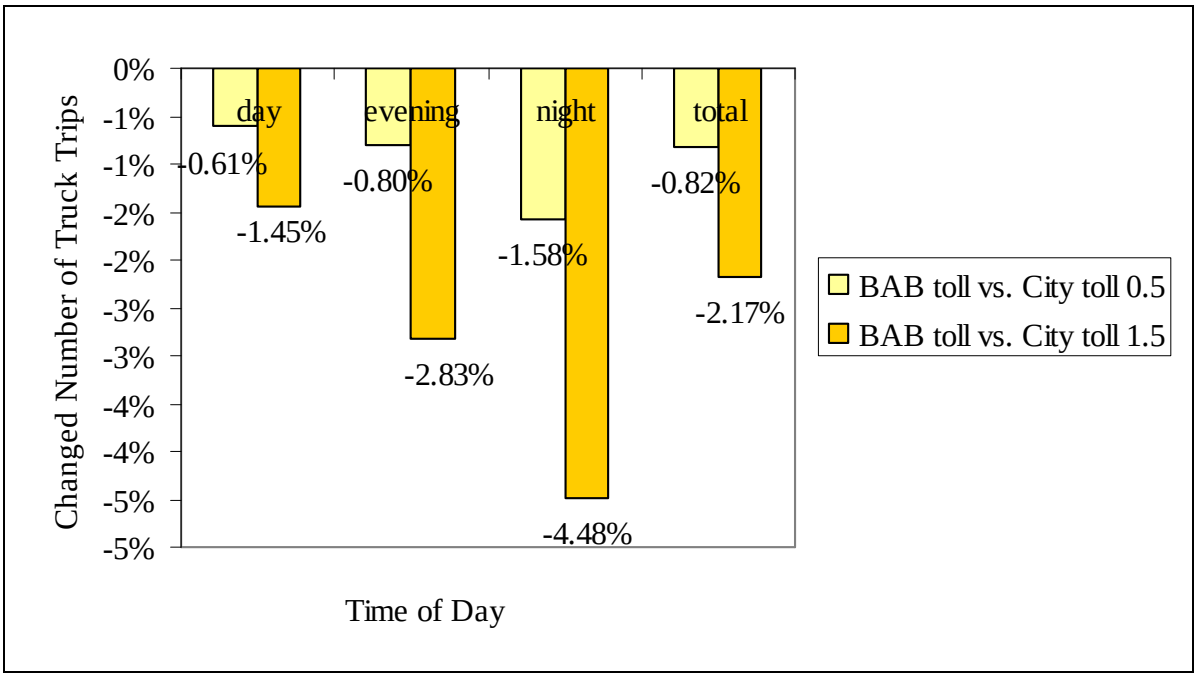

Figure 18: Temporal Distribution of Reduced Numbers of Truck Trips in Berlin due to the City Toll[228]

The overall reduction of truck mileage in our model on the one hand results from the reduced number of truck trips, on the other from a decreased average trip distance by about minus 5-6 %. The latter is a strong hint that re-routing effects due to city tolls are significant. This can be confirmed by an analysis of the spatial distribution of changed truck traffic, provided in Figure 19.

[228] Source: Own calculations.

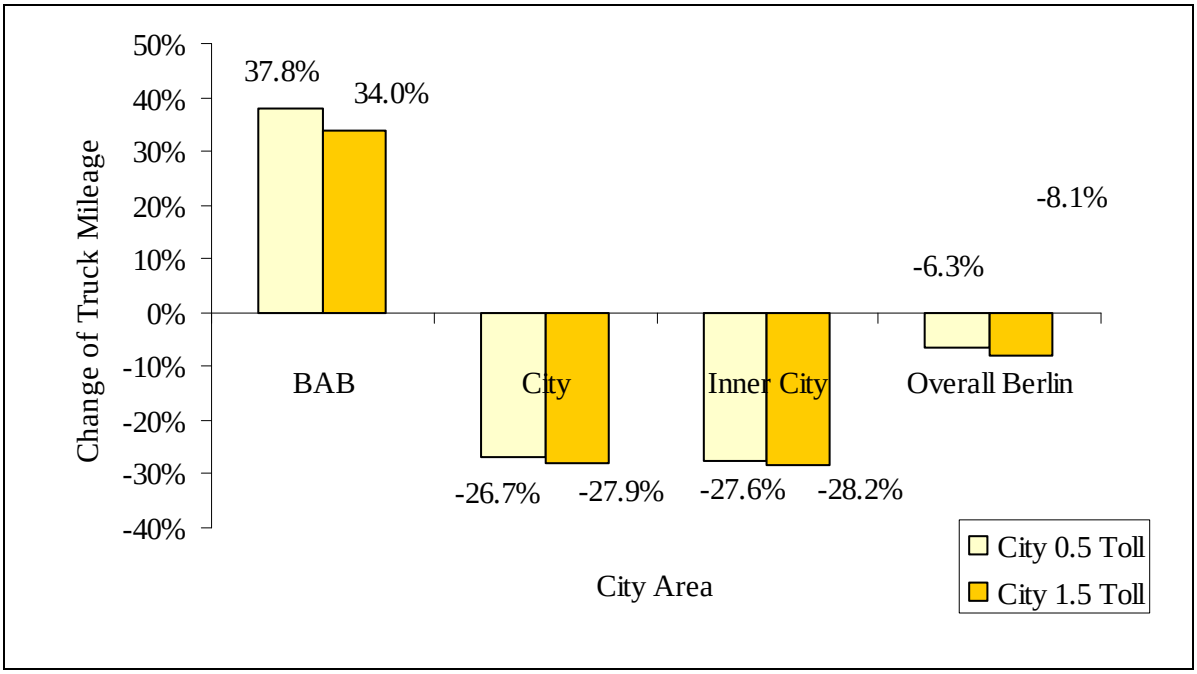

Figure 19: Regional Distribution of Changed Truck Mileage in Berlin due to the City Toll[229]

As indicated by Figure 19, the truck demand segment reacts to a city toll with considerable shifts (+34-37% in terms of mileage) to faster and lower-priced routes including federal highways. Furthermore, our model predicts that possible shifting movements to the city road network due to the German highway toll could completely be reversed. In line with the objectives of our time-based differentiation of tolls, the truck reduction effect in the most sensitive zone, the inner city of Berlin, is largest at night times, as shown in Figure 20.

[229] Source: Own calculations.

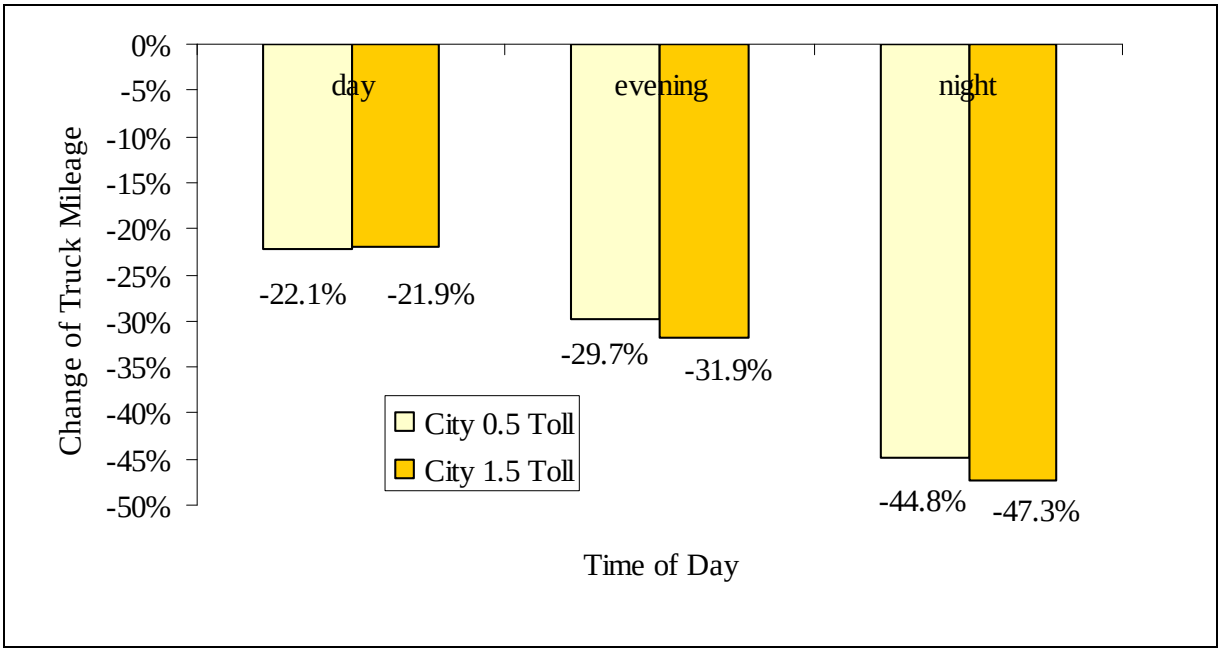

Figure 20: Reduced Truck Mileage in the Inner City of Berlin due to the City Toll[230]

The reduction of lower truck mileage by 6-8%, shown in Figure 19, induces better travel conditions for private car traffic on the Berlin road network. As a consequence the private car demand segment increases its performance by about 0.39 – 0.49% in terms of traveled mileage, and 0.25-0.32% in terms of trips. Figure 21 shows that the induced increase in mileage of private car demand even slightly exceeds the reductions in truck mileage. Besides the higher number of trips, this can be explained by an increased average car trip length due to the decreased average trip time costs in the network. So some environmental and noise benefits will occur due to the substitution of truck by private car traffic, while positive congestion effects will be limited due to the missing toll for the passenger car demand segment.

[230] Source: Own calculations.

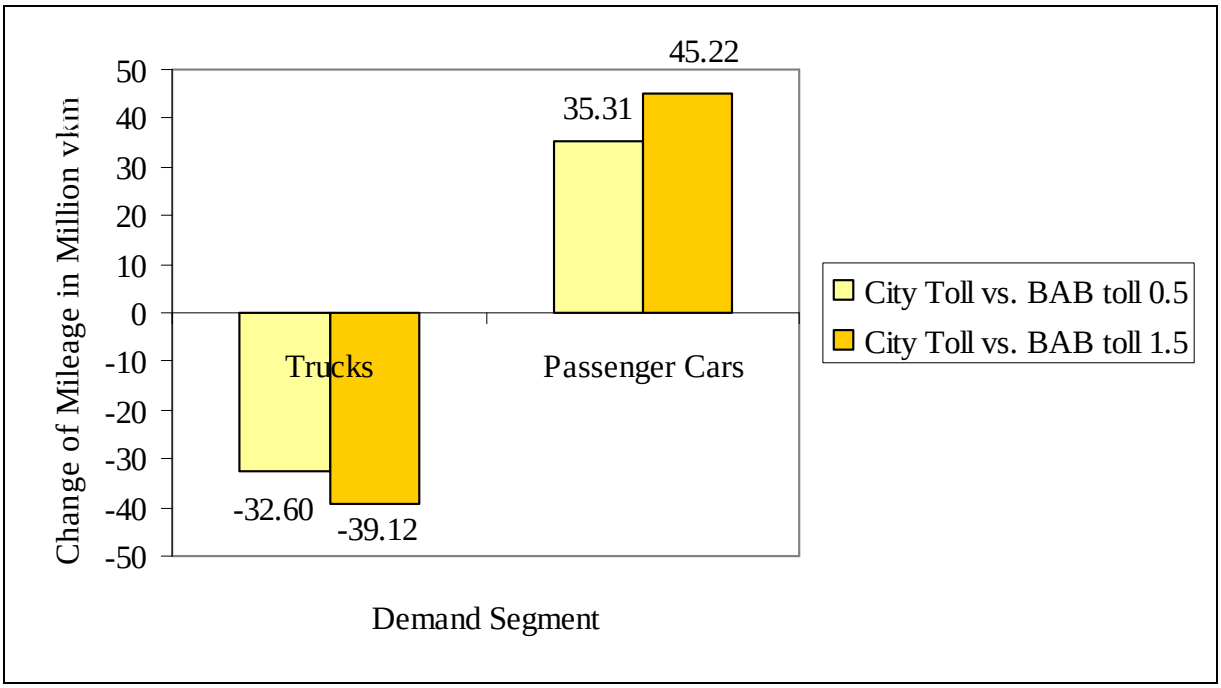

Figure 21: Absolute Change in Mileage for Passenger Cars and Trucks in Berlin due to the City Toll[231]

3.3.5 Revenues from the Toll Scenarios

In our study the realization of revenues is only a side effect of the analyzed environmentally oriented road charging system for trucks. Nevertheless, in times of tight public budgets, the possible income from the introduction of such a charging scheme is of great interest for politicians and other decision makers. Figure 22 shows an estimated breakdown of revenues for the examined city tolling system for trucks.

[231] Source: Own calculations.

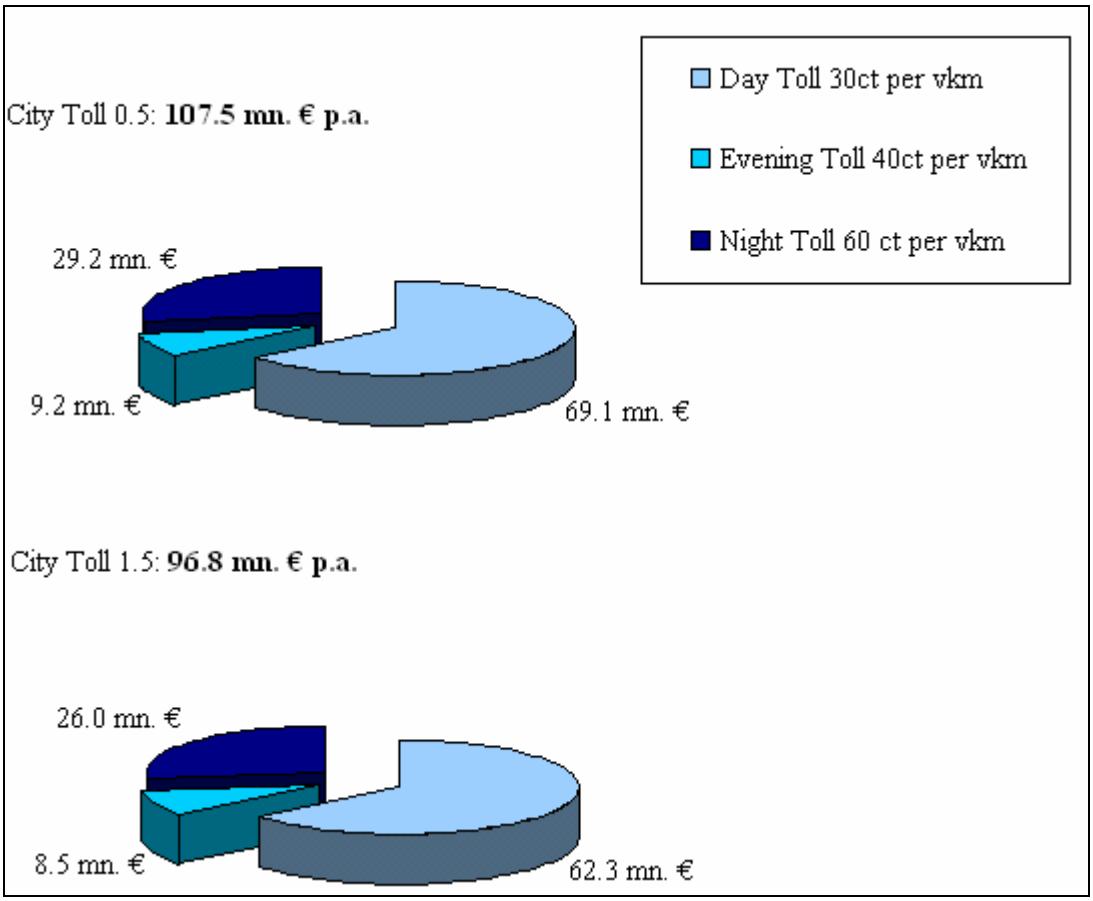

Figure 22: Revenues of a Truck City Toll in Berlin[232]

Not surprisingly, the revenues will be lower if the truck demand reacts more elastically, i.e. with fewer trips and less mileage. The share of revenues during day times of about 64% reflects the current temporal distribution of truck traffic in Berlin.[233] The higher tolls per vehicle kilometer in the evening and night are partly balanced by the greater reductions of truck mileage during these times. In a city with large financial difficulties like Berlin, the toll revenue of between 96.8 and 107.5 million € p.a. might contribute to easing its budgetary burdens. Independent of the benefits, this would favor the introduction of a truck pricing scheme.

[232] Source: Own calculations.

[233] Cf. Figure 10: Share of Truck and Passenger Car Traffic in Berlin during Different Times of Day (p. 69).

3.3.6 Benefits of a Time-Dependent Metropolitan Toll in Berlin

3.3.6.1 Benefits due to Reduced Air Pollution

The major objective of this study is to analyze the potential of a tolling system for trucks for the reduction of negative external environmental effects. As described in section 2.4.2.2.1, we calculated the monetary benefits of the reductions of truck traffic using Berlin specific fleet data, and estimations of monetary values for harmful substances from research literature. Table 31 provides an overview of likely benefits due to reduced local air pollutants and greenhouse gases, based on the estimates of MCCUBBIN / DELUCCHI (1999) and HOLLAND /WATKISS (2002).

Our lowest annual environmental benefit estimations range between 3.3 and 9.7 million €. As expected, the toll-induced substitution of truck traffic by passenger traffic is on the whole beneficiary, because the emission potential of a private car is much lower than that of a truck. As Table 31 indicates, the additional burden due to private cars is about 4 % of the benefits of decreased truck mileage.

The application of the high estimations of MCCUBBIN / DELUCCHI (1999) yields the absolute upper limits of the environmental benefit estimations of our study. As Table 31 indicates, these benefits could reach up to 36.0 – 43.1 million € p.a. This sounds much, but even assuming benefits of this order doubts remain as to whether the implementation and operation costs of a city-wide road pricing system for trucks are justified in economic welfare terms.

Taking into account the advances in the evaluation of external environmental effects, we consider the recent benefit estimations based on HOLLAND / WATKISS (2002) the most reliable.[234] Our results derived from their work are also presented in Table 31. The value of environmental benefits ranges between 9.0 and 10.7 million € per year.

[234] Further reasons for relying mainly on the estimates of HOLLAND / WATKISS (2002) can be found in section 2.4.2.1.

Scenario	Passenger Car	Truck	Total Benefits in € p.a.
MCCUBBIN / DELUCCHI (1999) Low Estimate			
City Toll with ε = - 0.5	-130,823	3,454,283	**3,323,461**
City Toll with ε = - 1.5	-167,559	4,143,724	**3,976,166**
MCCUBBIN / DELUCCHI (1999) High Estimate			
City Toll with ε = - 0.5	-1,418,070	37,443,129	**36,025,060**
City Toll with ε = - 1.5	-1,816,274	44,916,409	**43,100,135**
HOLLAND / WATKISS (2002) Median Estimate			
City Toll with ε = - 0.5	-352,975	9,320,048	**8,967,073**
City Toll with ε = - 1.5	-452,093	11,180,238	**10,728,145**

Table 31: Environmental Benefits in € p.a. according to MCCUBBIN / DELUCCHI (1999) and HOLLAND / WATKISS (2002)[235]

Bearing in mind the geographical comprehensiveness of the system, and the comparatively high tolls levied, the resulting positive environmental effect seems to be rather limited.

3.3.6.2 Benefits due to Diminished Noise Levels

In this section, we analyze whether the targeted reductions of noise cost can contribute significantly to the benefits of the charging system. Beside the decrease of airborne pollutants, the reduction of noise is the other major objective of the charging system under scrutiny. As expected, the lower truck mileage and the changed vehicle mix results in lower noise levels on about 75% of all considered links in the Berlin network. Figure 23 indicates the changes in noise levels on these links in terms of the composite indicator L_{den}.[236]

[235] Sources: MCCUBBIN / DELUCCHI (1999), HOLLAND / WATKISS (2002), own calculations.

[236] For the definition of this indicator see section 2.4.2.3.

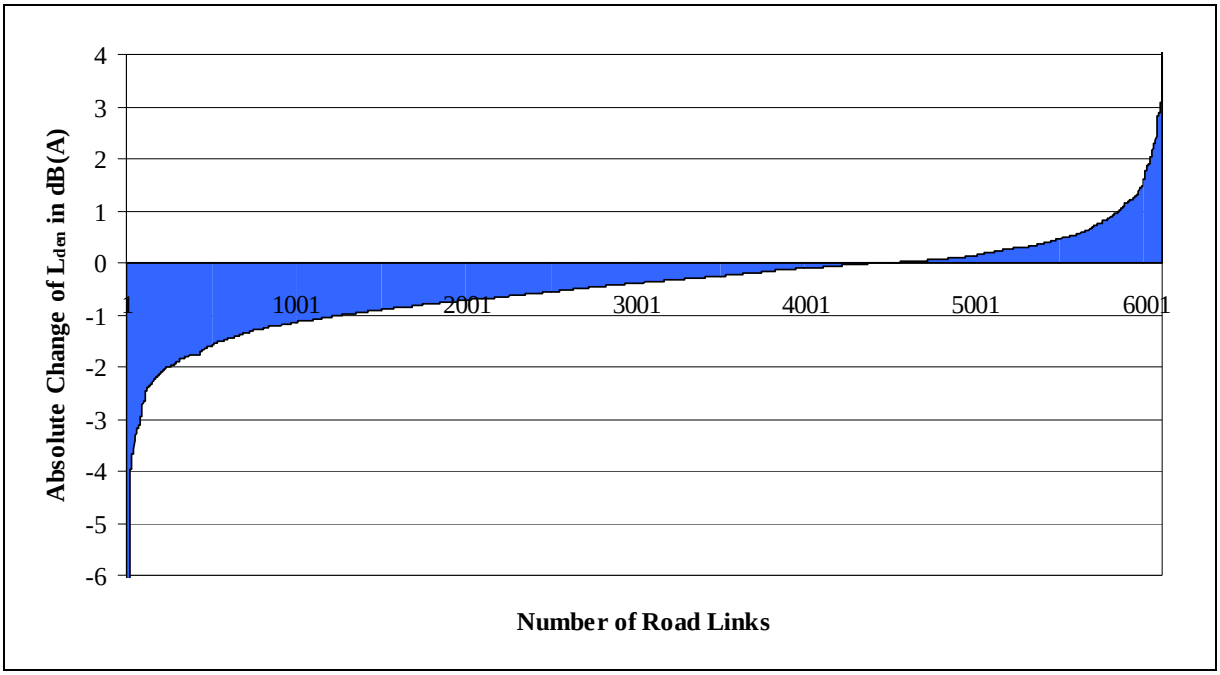

Figure 23: Changed Noise Levels L_{den} due a Truck City Toll (ε = - 1.5)[237]

The considerable decrease in terms of truck mileage due to the toll results in minor reductions of noise related health risks. The regarding risk changes, expressed in number of statistical cases, are displayed in Table 32.

Reduced Adverse Noise Effects	City Toll with ε = - 0.5 No. of Cases p.a.)	City Toll with ε = - 1.5 (No. of Cases p.a.)
Infarction fatal	- 2.583	- 2.847
Infarction non-fatal	- 6.026	- 6.643
Angina Pectoris	- 7.231	- 7.972
Hypertension	- 0.760	- 0.725
Sleep Disturbance	- 176.510	- 188.417

Table 32: Changes of Risks for Health Effects due to Reduced Traffic Noise (in Annual Cases)[238]

As one can see from Table 32, the annual number of (fatal plus non-fatal) infarctions could be decreased by 8-9 cases with the proposed toll, which yields benefits of about 1.7 and 1.9 million € p.a. The contribution of the other risk reductions to the overall benefit is rather small, about 125,000 € p.a. for reduced sleep disturbance and 130,000 € p.a. for diminished risks of Angina Pectoris, while the

[237] Source: own calculations.

[238] Source: own calculations, based on BICKEL / SCHMID (2002).

benefits of fewer cases of Hypertension are negligible. Beside these changes in health costs, the reduced annoyance levels are an important component of the benefits due to reduced traffic noise. They account for benefits of between 2.44 and 2.61 million € p.a. Figure 24 summarizes the welfare effects of diminished noise levels in consequence of the truck tolls.

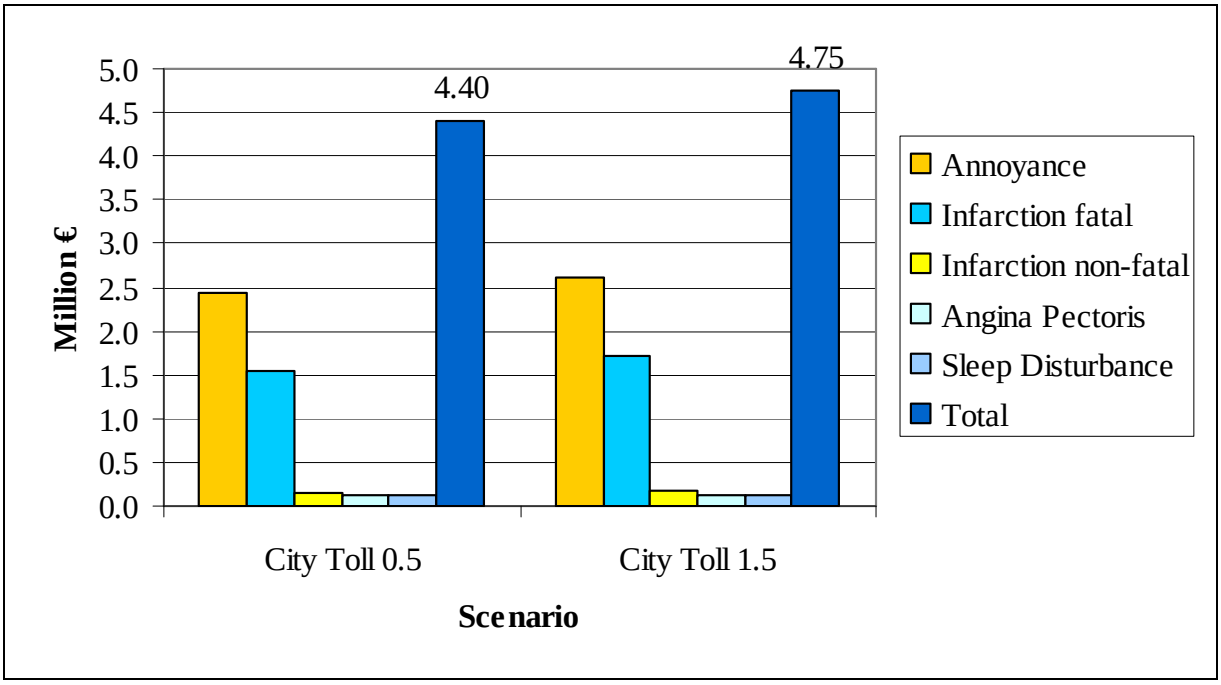

Figure 24: Sources of Benefits due to Reduced Noise Levels [239]

Despite the explicit noise orientation of the charging structure, the achieved welfare increases of between 4.4 and 4.8 million € p.a. are rather low, especially if we take the installation and operational costs of such a tolling system into account. While the introduction of differentiated tariffs for links with high or low traffic volumes respectively might increase these benefits a little, we are skeptical about the appropriateness of tolls as a measure for reducing noise levels in general. Alternative policy instruments, like speed limits, night bans for truck traffic in certain areas, or the repair of degraded road surfaces could achieve similar or better results more effectively.

3.3.6.3 Benefits due to Changed Congestion Levels

As a side effect of the introduction of the truck charges, congestion levels changed. In contrast to the targeted reductions of noise and air pollution effects, the direction of this change is a priori unclear. Two possible scenarios go to confirm the ambiguity of the issue: first, the reaction of private car traffic to higher average speeds and hence lower average trip costs could wipe out positive congestion effects

[239] Source: own calculations, based on BICKEL / SCHMID (2002).

due to lower truck traffic levels. Second, the benefits of a (small) increase in average network speeds due to fewer truck trips can be more than counterbalanced by (larger) direct losses of social surplus due to cancelled truck trips with a net user benefit. In Figure 25 the toll-induced changes in congestion costs and benefits for both demand segments are shown.

As expected, the passenger car segment greatly profits from the higher average speeds on the network, and the truck demand segment experiences losses of social surplus. In the scenario assuming the (in absolute terms) lower generalized truck cost elasticity -0.5, there remains a slight positive net effect of 3.8 million € p.a., as less truck trips with a positive net utility are cancelled than in the scenario assuming the higher elasticity. The latter yields slightly negative congestion costs of - 0.7 million € p.a.

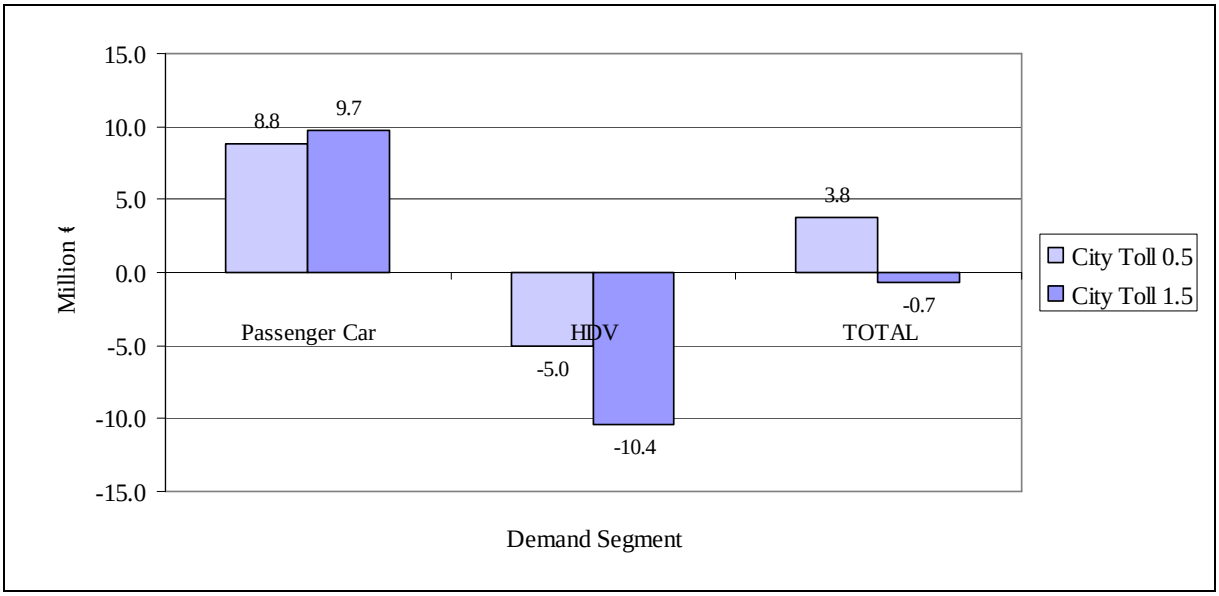

Figure 25: Demand Segment Specific Costs and Benefits due to Changed Utilization Levels[240]

As expected, the passenger car segment greatly profits from the higher average speeds on the network, and the truck demand segment experiences losses of social surplus. In the scenario with the (in absolute terms) lower generalized truck cost elasticity -0.5, there remains a slight positive net effect of 3.8 million € p.a., as less truck trips with a positive net utility are cancelled than in the scenario with the higher elasticity. The latter yields slight negative congestion costs of - 0.7 million € p.a.

[240] Source: own calculations.

If we consider the temporal distribution of these demand segment specific benefits and costs in Figure 26, the reasons for the negative welfare effects of the truck segment become clearer. During day times, usually the most congested time period, both demand segments benefit from the substantially higher average network speeds as a result of less truck traffic. In contrast to this, the potential for increases of the network speeds is limited at night times. At this time the traffic volume is already low, which implicates rather high average speeds. While the limited decrease of average trip costs still creates substantial benefits for the private car segment, the high night time tolls of 60 ct per vehicle km reduces the truck trip demand apparently beyond efficient quantities. This is reflected by losses in social welfare in the truck segment of about 6.5 or 10.8 million € p.a. respectively. Taking into account the noise benefits of 4.4 - 4.8 million € p.a., which can mainly be attributed to lower truck traffic levels at night, the applied night toll level of 60 ct per kilometer seems to be too high from an economic perspective.

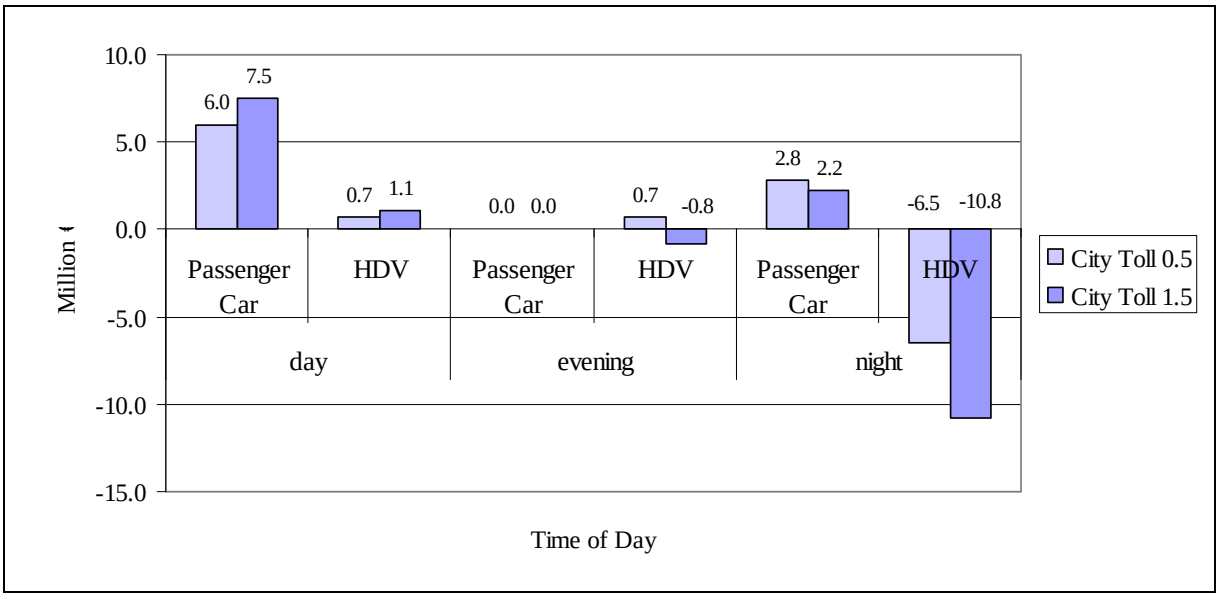

Figure 26: Period Specific Costs and Benefits due to Changed Congestion Levels[241]

3.4 Conclusions

Figure 27 summarizes the main findings of our study. With a welfare effect of +9.0 million € p.a. or +10.7 million € p.a. respectively, reduced air pollution levels dominate the overall benefits. This is in line with the common objectives of the TELLUS project and this study. Despite a pricing structure explicitly dedicated to the reduction of noise effects, the benefits from decreased health risks and annoyance levels due to traffic noise are comparatively small, ranging between 4.4 and 4.8 million €

[241] Source: own calculations.

p.a. Taking into account the ambivalent congestion effects, the analyzed road charging system for trucks may achieve total benefits of between 14.7 and 17.2 million € per year.

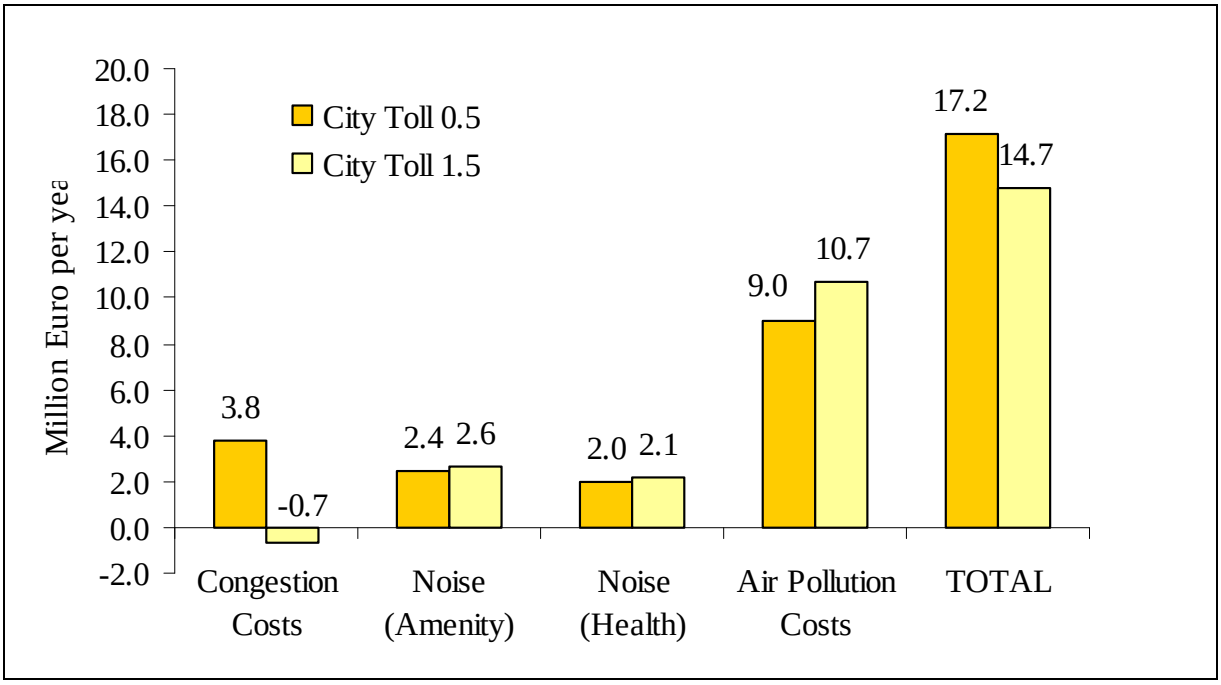

Figure 27: Overall Benefits of a Truck City Toll due to Reduced Externalities[242]

In comparison to the installation and operational costs the potential welfare gains achieved through the toll seem to be rather small: The installation of tolling and enforcement equipment for an extension of the German highway toll GNSS system to the whole metropolitan area of Berlin might cost about 200 million €.[243] If, moreover, we consider the fact that air pollution burdens are likely to decrease further due to the gradual renewal of urban truck and car fleets within the next few years, the implementation of the environmentally oriented truck charging system cannot be recommended without any adjustment.

While the question may be raised whether it is reasonable at all to direct a road pricing system to noise issues, there is no doubt about the overall usefulness of an urban road charging scheme. Instead of combining the two objectives of reducing noise and air pollution, it should rather pursue the complement targets of congestion relief and reduction of air pollution. If these two objectives were bundled, a further exclusion of private cars from the tolling system, as assumed for this study, could not be justified: While truck traffic is the major source for noise and air pollution, large parts of

[242] Source: own calculations, based on HOLLAND / WATKISS (2002) and BICKEL / SCHMID (2002).

[243] Cf. for some rough estimations WINTER / HIRSCHHAUSEN (2005).

external congestion costs are caused by private car traffic. Furthermore, the increasing scarcity of public funds will lead to a greater importance of user financing in the future. From this perspective, the inclusion of the private car segment as the main user of urban road networks into a user charging system seems to be necessary, too. This case will be analyzed in chapter 4.

4 Cordon and Distance-dependent Pricing: Berlin and Stuttgart Compared

4.1 General Context and Scenario Definition

In order to estimate the effects of a toll for optimizing capacity use in agglomerations we have developed simulations for the metropolitan areas of Berlin and Stuttgart. The focus of the analysis was on the welfare effect of road pricing through more efficient use of capacity. The Berlin road system is radial and focused on the monocentric center of the city. By contrast, the network around the metropolitan area of Stuttgart has a mesh structure. These network configurations correspond to different distributions of transport demand: Berlin transport is dominated by O-D traffic between the center and the periphery. In contrast, transport in Stuttgart features many more relations between different sub-centers. Due to these characteristics road pricing solutions covering only the city center should be more suitable for Berlin. In the monocentric town a reduction of transportation will lead to an disproportionate increase of average speed in the core network. By contrast, mesh networks such as Stuttgart's should benefit by comprehensive tolling schemes that rely on distance-related fees; in this case, there are fewer incentives to modify route decisions in an inefficient way.

For both agglomerations we have analyzed road pricing with different tolling areas and different tariff schemes. On the one hand, this was a cordon-toll for the respective city center, the Stuttgart "city basin", and the "great dog's head" in Berlin. Another scenario features a distance-dependent toll for the entire city area. For Berlin we additionally considered two sub-scenarios, exclusive and inclusive of federal highways.[244] Technology-wise, for the cordon-toll, DSRC- and/or camera-based systems can be applied; in contrast, distance-related solutions will require a satellite-based tolling system which could be implemented only in the medium- and long-term. For road pricing scenarios with distance-dependent tolls, which we also analyzed with respect to financial aspects,[245] the fee was based on the annual expenses of the city of Stuttgart for motorized individual traffic (MIV) or – more generally – the total transport system costs, including public transportation, bicycle traffic, and pedestrians.[246] If we distribute these costs among the motorized individual transportation of Stuttgart, we obtain values

[244] The federal highways A8 and A81 represent the north-western and southern borders of the city Stuttgart respectively, and there are no further highways within the city area. Most of the traffic on these routes is interregional and transit, hence a city road pricing solution including these highways would have to cope with a lot of occasional users. This seems hardly feasible. Hence we decided to exclude the highways at Stuttgart's border from the tolling area.

[245] Cf. BECKERS ET AL. (2007).

[246] Cf. DOBESCHINSKY / TRITSCHLER (2006). In addition to annual expenses of 123.7 mn. € for motorized individual transport and 379.0 mn. € for further transport in 2004, we estimate the costs of the tolling system at about 30-50 % of the revenues.

of about 8 ct/vehicle-km (vkm) and 24 ct/vkm, respectively. In order to compensate for the toll-related reduction of demand, we have set the tolls at 10 ct/vkm and 25 ct/vkm, respectively, for private cars. For trucks the tolls were multiplied by 3.

In the case of the cordon-toll we also introduced a time-differentiation in order to obtain congestion reduction in the peak periods of the morning (6-10am) and in the afternoon (3-7pm). In the mid-peak period (10am – 3pm) half of the peak-toll is charged, whereas in the evening and night (7pm – 6 am) no toll is levied. The level of the cordon-toll was calibrated through the fees of established road pricing solutions: between 2-3 € per entry in the cordon at peak times.[247] We doubled these fees for trucks in order to take into account the stronger effect of heavy vehicles on congestion.

For the interpretation of scenarios we used three different spatial categories:

- the inner city of Berlin and Stuttgart,
- the entire city area within its official borders,
- the entire model corresponding to the metropolitan areas.

4.2 Data Adaptation and Calibration of the Base Cases

We used current 24h-VISUM models of the respective metropolitan area,[248] provided by the Senate Department of Urban Development (Senatsverwaltung für Stadtentwicklung) in Berlin, and the Department of City Planning and Urban Renewal (Amt für Stadtplanung und Stadterneuerung) in Stuttgart. These base models were developed for city planning purposes in the “real world”, and are thus characterized by a very high degree of detail. In particular, the network models include about 20 road types of different capacity, and 11 (Stuttgart) or 17 (Berlin) different speed-flow functions of the BPR type.[249] In addition, these network models include all valid speed restrictions, one way rules and other specific regulations such as bus lanes. Using this local knowledge of the real transport situation, the supply side in the initial models of Stuttgart and Berlin is represented in great detail.

Nonetheless, we had to modify the existing models on the demand side, which required a gradual recalibration of the models. These modifications included adapted Value of Time (VoT) and Value of

[247] Practically, in VISUM 50% of the cordon toll tariff under consideration was charged for both entry and exit. This was necessary to maintain the symmetry of entering and exiting trips during the cobweb procedure. Nevertheless, the results can also be interpreted as effects of a purely entry-related toll, as traffic participants will always consider their total trip costs for both travel directions.

[248] For the structure and general functionality of these models see section 2.4.1.1.

[249] For the definition of this type of volume-delay functions see section 2.4.1.2.

Distance (VoD) rates for the trip demand, the aggregation of different demand segments, and the time-of-day differentiation of the models for time-specific tolls. For the VISUM-model of Stuttgart we had to proceed all modifications, whereas for Berlin we used a recalibrated 24h-VISUM model based on the EU-project TELLUS.[250] In the latter case we only added time differentiation. Hence, the following section describes mainly the adaptation for the VISUM model of Stuttgart.

4.2.1 Adaptation of Value of Time (VoT) and Value of Distance (VoD) for Trips

In the initial models the generalized costs for trip demand, which are the basis of the route choice, only relied on the projected trip time. Since the time costs account for about 70% of the total costs of private car trips in European metropolitan areas (see Table 33), this assumption can produce realistic simulation results. In particular, when looking at the effects of spatially restricted toll-free road expansions, the relative reduction of travel time on alternative routes should play the dominant role in the individual route optimization of traffic participants.

Study	Time Costs in EUR per Trip	Distance Costs in EUR per Trip	% Time Costs of Total Costs	% Distance Costs of Total Costs	Total Costs in EUR per Trip
SANTOS (2003)	4.04	1.77	69.5	30.5	5.81
MITCHELL ET AL. (2002)	3.36	1.40	70.6	29.4	4.76
TROYER (2002)	2.66	1.08	71.1	28.9	3.74

Table 33: Composition of Generalized Costs for an Average Car Trip in Urban Areas[251]

Things change when looking at larger-scale transport policy measures; here changing travel distances also need to be considered. In these cases, alternative routes may not only have lower time costs due to higher average speeds, but also higher distance costs due to increased trip lengths. In addition, large-scale measures affect the trip costs of a large number of O-D relations resulting in a high interdependency of spatially differentiated trip demand. A correct modeling of these route choices is particularly needed to establish realistic network-wide forecasts. The explicit modeling of distance costs is particularly important for the trade-off between shorter, but slower routes and longer, but faster connections (e.g. highways). For traffic assignments without tolls the absolute values of time (VoT) and distance (VoD) matter less than the relation between these cost categories.

[250] Cf. WINTER / HIRSCHHAUSEN (2005).

[251] Sources: SANTOS (2003), MITCHELL ET AL. (2002) and TROYER (2002), plus own calculations. We assumed an average trip distance of 10 km and an average speed of 25 km/h, which is typical for car trips in urban areas.

When toll solutions are analyzed using VISUM, toll payments also have to be taken into account as an element of the generalized cost of the individuals transported (in addition to distance- and time-related costs). In order to model the effects of relative cost changes upon demand caused by the introduction of a toll, we need realistic absolute values for the VoT and VoD in VISUM. As Table 34 suggests, the relation of VoT and VoD for private car transport, used in British (SANTOS [2003], MITCHELL ET AL. [2002]) and Austrian studies (TROYER [2002]) are similar. For this reason we used the median of the cost estimates of the existing analyses, as shown in Table 34.

Study	**Value of Time (VoT) in EUR/h**	**Value of Distance (VoD) in EUR/100 km**	**Relation VoT/VoD**
SANTOS (2003)	10.11	17.70	0.57
MITCHELL ET AL. (2002)	8.40	14.00	0.60
TROYER (2002)	6.64	10.78	0.62
Used in this Study	**8.40**	**14.00**	**0.60**

Table 34: Values of Time and Distance for Car Trips from the Literature[252]

For the demand segment of heavy trucks (> 3.5 t) data are less clear. VoT and VoD vary significantly between different studies.[253] For our simulations we relied particularly on German (ROTHENGATTER / DOLL [2001]) and Austrian (TROYER [2002]) analyses, as shown in Table 35.

Study	**Value of Time (VoT) in EUR/h**	**Value of Distance (VoD) in EUR/100 km**	**Relation VoT/VoD**
ROTHENGATTER / DOLL (2001)	45.00	52.00	0.87
TROYER (2002)	23.39	33.46	0.70
DEPARTMENT FOR TRANSPORT (2001)	12.37	90.00	0.14
Used in this Study	**28.00**	**40.00**	**0.70**

Table 35: Values of Time and Distance for Heavy Truck Trips from Research Literature[254]

[252] Source: SANTOS (2003), MITCHELL ET AL. (2002), and TROYER (2002) and own calculations.

[253] However, it is interesting to see that the total costs for urban truck transports do not differ significantly using these different values, see WINTER / HIRSCHHAUSEN (2005).

[254] Source: ROTHENGATTER / DOLL (2001), TROYER (2002), and DfT (2001) and own calculations.

4.2.2 Recalibration of the 24h-VISUM Model

Following the adaptations of VoT and VoD the 24h-model of Stuttgart was recalibrated to obtain a realistic point of departure. We aggregated the seven demand segments of Stuttgart into two: private cars and trucks, in order to reduce calculation times. The main approach of calibration was a gradual rescaling of total demand for private cars and trucks. A relation specific adaptation would have been too demanding, given more than 1.1 million of O-D relations. The introduction of distance costs into the model diminishes the role of time costs, thus, given a constant O-D demand, we expect an increase in travel times when compared to the initial model. This leads to lower average speeds of the adapted model when compared to the base model. In order to ensure a good, region specific correlation with the base model for the three variables mileage, travel times, and average speed, we reduced the number of car and truck trips in the process of recalibration iteratively. The results, in totals for cars and trucks, are shown in Table 36.

Area	Model	Daily Mileage in vkm	Daily Travel Times in veh.h	Average Speed in km/h
Stuttgart City	Initial Model (24 h)	8,551,837	316,581	27.01
	Recalibrated Model	8,087,610	309,921	26.10
	Deviation	*-5.43 %*	*-2.10 %*	*-3.40 %*
Stuttgart Inner City	Initial Model (24 h)	2,284,935	114,200	20.01
	Recalibrated Model	2,162,572	109,445	19.76
	Deviation	*-5.36 %*	*-4.16 %*	*-1.24 %*

Table 36: Key Figures for the Initial Model (24h) and the Recalibrated Model of Stuttgart[255]

The results suggest a sufficient approximation of the recalibrated model to the initial model. One has to take into account that an increase of mileage through an increase of modeled trips would lead to a disproportionate increase of travel times in the network. This in turn implies reduced average speeds, so that the simultaneous approximation of all three initial variables is limited. However, this is not too important for the interpretation of the toll simulations, since we particularly compared the state of results with or without tolling (rather than the traffic on single links before the introduction of the toll).

Another calibration parameter is the difference in link-specific average speeds between the initial and the recalibrated model (see Table 37). The recalibration leads to a very good approximation of the

[255] Source of the data: accounting data in VISUM as well as own calculations.

link-specific average speeds in the initial model. This is a notable result, because changes in link-specific average speeds are very important for the assessment of the effects of the toll.

Area of Stuttgart	Analyzed Road Links	Total of Link-Specific Average Speeds	Correlation Coefficient between Base Model and Recalibrated Model
City Area	All	+0.07 %	0.994
Inner City	All	+0.65 %	0.994
City Area	Only Used	+0.07 %	0.976
Inner City	Only Used	+0.65 %	0.973

Table 37: Link- and Area Specific Differences of Average Speeds between Initial Model and Recalibrated 24h-Model for Stuttgart[256]

In addition, traffic count data for 161 road links of Stuttgart's network model are available. This enables checking the approximation of both the initial and the adapted model to reality. Table 38 summarizes this comparison between the real world traffic count data and both models.

Indicator	Model	Cars	Trucks	Total
Correlation Coefficient	Initial Model (24 h)	0.985	0.971	**0.986**
	Recalibrated Model (24 h)	0.975	0.950	**0.976**
Deviation from Traffic Count Data	Initial Model (24 h)	+3.75 %	+4.99 %	**+3.81 %**
	Recalibrated Model (24 h)	-2.42 %	-7.52 %	**-2.63 %**

Table 38: Fitting of Stuttgart's Initial and Recalibrated Model to Traffic Count Data[257]

The correlation coefficient between the traffic count data and the modeled transport flows deteriorates slightly in the course of calibration, from 0.986 to 0.976. Nonetheless, the approximation to the real traffic flows can be considered as very good. This is also supported by the low difference between the sum of all traffic count data per demand segment, and the respective traffic flows in the recalibrated model. In the recalibrated model this difference of -2.63% over the two demand segments is even smaller than in the initial model (+ 3.81%). Therefore, we used this recalibrated 24h-VISUM model of Stuttgart to derive time-of-day-differentiated VISUM-models, as explained in the next section.

[256] Source of data: traffic count data in VISUM as well as own calculations.

[257] Source of data: traffic count data in VISUM as well as own calculations.

4.2.3 Structure of Time-Differentiated VISUM-Models

In order to simulate the effects of time-differentiated tolls it was necessary to work with a finer time distribution. We defined four time intervals (or time "slices"), for which the transport flows were modeled separately. In order to do so, we assumed that the time slices are independent of each other, and can therefore be simulated separately. Implicitly it was assumed that the deviations of starting times from one interval to the next would neutralize each other.[258] We defined the following time intervals:

- morning (6-10 am)
- noon (10 am – 3 pm)
- afternoon (3-7 pm)
- night (7 pm – 6 am)

A more detailed time-of-day differentiation, e.g. in the form of 3h intervals, was rejected after looking at traffic count data for Berlin and from INFAS / DIW (2004). It seems that in recent years the former strong peaks of time-of-day dependent transport demand in the morning and the afternoon have been weakened.[259]

Table 39 shows a comparison between data from INFAS / DIW (2004) and traffic count data for a selected road link of the inner city of Berlin.[260] Apparently, the average values for Germany from INFAS / DIW (2004) characterize the daily distribution of traffic fairly well. For this reason, we segmented the 24h-demand matrices according to the more general data from INFAS / DIW (2004).

[258] Using time interval specific cross elasticities this somewhat problematic assumption could be avoided within the existing modeling framework. However, until now empirical elasticities of this type are not available.

[259] These adaptations can also be interpreted as a reaction of demand to congestion. Flexible working hours and less attachment to a physical workplace may also have favored these developments.

[260] We also analyzed the time-of-day distribution of traffic on other road links, which in general yielded similar values as those published in INFAS / DIW (2004).

Time Interval	Average Car Traffic in Germany (in %), according to INFAS / DIW (2004)	Average Car Traffic in Berlin, Greifswalder Straße (in %), according to Traffic Count Data (2004)
6 am - 10 am (4h)	23.2	23.6
10 am - 3 pm (5h)	26.5	26.5
3 pm - 7 pm (4h)	27.2	25.4
7 pm - 6 am (11h)	23.1	24.6

Table 39: Time-of-Day Distributions for Private Car Traffic according to INFAS / DIW (2004) and Traffic Count Data for a Selected Major Road Link in Berlin[261]

Subsequently we adapted the road capacity proportionally to the duration of each time interval (morning and afternoon 4/24h, noon 5/24h, night 11/24h). After the assignment of differentiated demands to the time-of-day related sub-models we calculated the resulting mileage, travel times and average speeds for each sub model. Using further gradual adaptations of road capacities we readjusted the sub models in order to reproduce the recalibrated 24h model in total. A scaling factor of 1.29 for all time-dependent network capacities yielded the closest approximation to the original 24h model. The results are summarized in Table 40.

Area	Model	Mileage in vkm	Travel Times in h	Average Speed in km/h
Stuttgart City	Recalibrated Model (24h)	7.739.766	298.472	25.93
	Sum of All Time Slices	7.756.618	302.679	25.63
	Deviation	*+0.2 %*	*+1.4 %*	*-1.2 %*
Stuttgart Inner City	Recalibrated Model (24h)	2,100,527	106,656	19.69
	Sum of All Time Slices	2,126,010	108,780	19.54
	Deviation	*+1.2 %*	*+2.0 %*	*-0.8 %*

Table 40: Comparison of Key Figures between Recalibrated 24h Model and Time-of-Day Differentiated Models in Stuttgart[262]

It becomes evident that the time-differentiated models come very close to the 24h model of traffic in Stuttgart. In addition, the time-distribution of average speeds in the inner city and the entire agglomeration of Stuttgart look plausible, as shown by Figure 28. Similar adaptations were made on

[261] Sources: INFAS / DIW (2004), traffic count data of the Senate Department of Urban Development Berlin, own calculations.

[262] Sources: Data from VISUM and own calculations.

the recalibrated 24h model of Berlin. This also yielded a close approximation between the 24h model and the sum of the time slices, as shown by Table 41 and Figure 28.

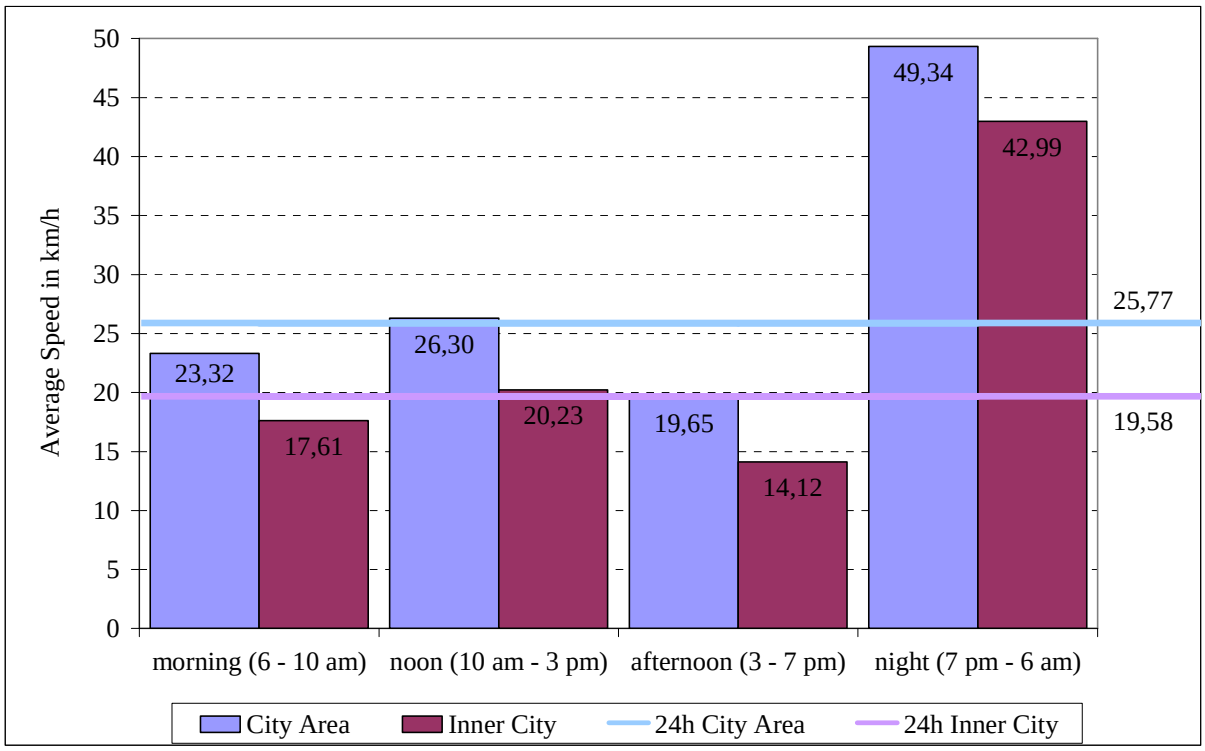

Figure 28: Comparison of Average Speeds between Recalibrated 24h Model and Time-of-Day Differentiated Models in Stuttgart[263]

The absolute level and the distribution of average speeds in Table 41 and Figure 29 shows that the differences between the time intervals are significantly less important in Berlin than in Stuttgart. This suggests that traffic in Berlin faces much less congestion problems. In addition it is remarkable that – contrary to Stuttgart – there are almost no differences in their travel speeds between the inner city and the rest of the city. Only at nighttime, approx. free flow speed, we observed larger deviations. This reduces the potential of welfare-enhancing tolls as an instrument to optimize dynamic capacity use.

[263] Source: author's diagram.

Area	Model	Mileage in vkm	Travel Times in h	Average Speed in km/h
Berlin City	Recalibrated Model (24h)	34,356,532	1,083,796	31.70
	Sum of All Time Slices	34,521,774	1,083,661	31.86
	Deviation	*+0.5 %*	*+/-0.0 %*	*+0.5 %*
Berlin Inner City	Recalibrated Model (24h)	7,663,786	239,202	32.04
	Sum of All Time Slices	7,675,543	243,505	31.52
	Deviation	*+0.2 %*	*+1.8 %*	*-1.6 %*

Table 41: Comparison of Key Figures between Recalibrated 24h Model and Time-of-Day Differentiated Models in Berlin [264]

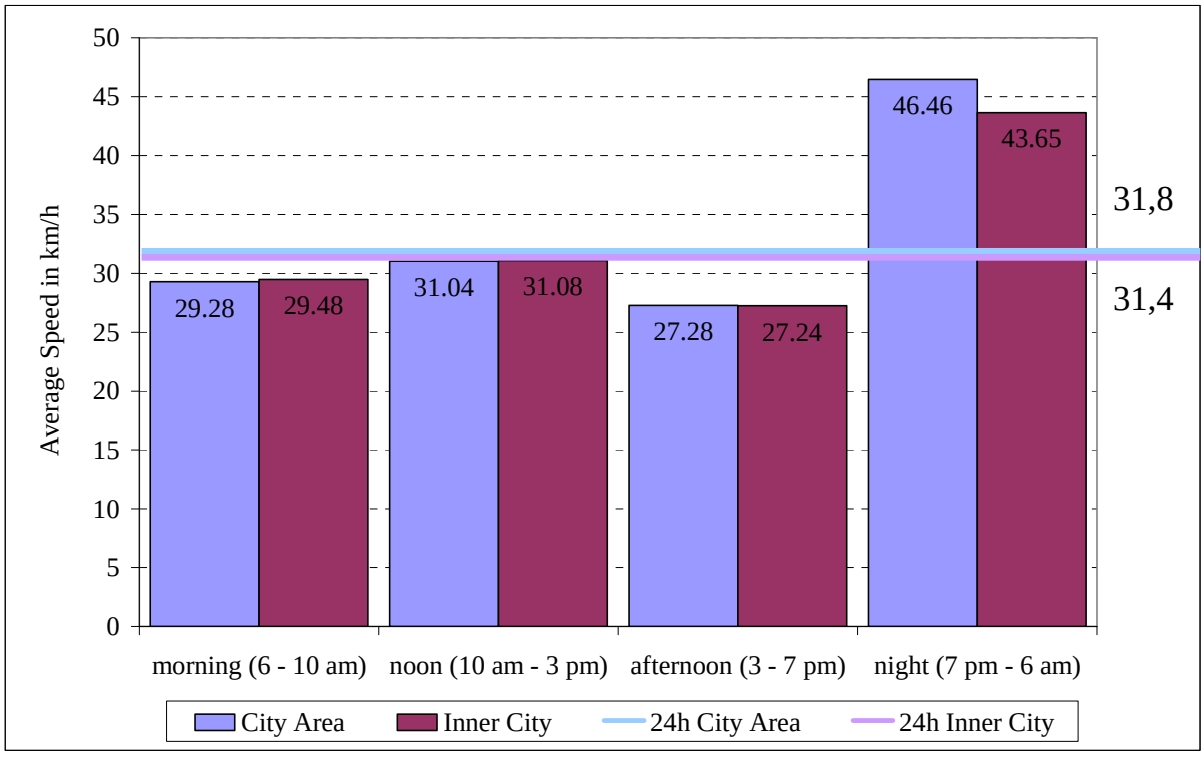

Figure 29: Comparison of Average Speeds between Recalibrated 24h Model and Time-of-Day Differentiated Models in Berlin[265]

[264] Source of the data: traffic count data in VISUM as well as own calculations.

[265] Source: author's diagram.

4.2.4 Generalized Cost Elasticities to Represent Demand Adaptation

As explained in section 2.4.1.3, VISUM performs assignments using fixed demand matrices. When assessing the effects of small network changes, one can obtain plausible results using fixed demand, because changes in the route choices of traffic participants may override other adaptation options for trip demand. However, when analyzing more complex changes of transport supply, we also have to take into account the quantity effects of demand which are caused by individual changes of user costs. This includes increased traffic through toll-free capacity expansion in the network, but also reduced traffic due to the introduction of a toll for individual motorized travel. We used an iterative procedure to take into account demand effects for individual trips. We attached demand functions to the existing private car and truck demand matrices using empirical data on reactions of demand segments to changes of generalized costs (time costs + distance costs + tolls).[266]

For a realistic modeling of the changing traffic flows in agglomerations, we should require a relation-specific differentiation of cost elasticities, in order to model different substitution patterns of spatially disaggregated demand, e.g. with respect to public transport. In our study, this differentiation turned out not to be possible, similar to the models of SANTOS (2004) and MAY / MILNE (2002). Table 42 shows the values for generalized cost elasticities of trip demand that have been used in research literature, or real-world analyses.[267] Due to the broad variance of the empirical values, we used two different generalized cost elasticities for both demand segments: -0.5 and -1.5. This range covers a large spectrum of the values occurring in research literature, and thus ensures a broad validity of the results.

Source	Demand Segment	Generalized Cost Elasticity	Comment
SANTOS (2002)	Car	-0.3 to -0.7	Assumption
SANTOS (2004)	Car	-1.32	Calculations based on London data
TROYER (2002)	Truck	-0.15 to -0.30	Assumption
WINTER / HIRSCHHAUSEN (2005)	Truck	-1.10 to -1.90	Approximate calculations based on London data

Table 42: Generalized Cost Elasticities for Car and Truck Trips in Research Literature[268]

[266] This approach largely corresponds to the method used in SATURN, applied by MAY / MILNE (2004) and SANTOS (2004); it is explained in section 2.2.1.

[267] Further values for generalized cost elasticities can be found in WINTER / HIRSCHHAUSEN (2005).

[268] Source of the data: SANTOS (2002), SANTOS (2004), TROYER (2002), and WINTER / HIRSCHHAUSEN (2005).

4.3 Road Pricing in Berlin

4.3.1 Structural Data of Berlin

In the entire metropolitan area of Berlin / Brandenburg there are about 4.4 million inhabitants in an area of 5.370 km². The population of the city area of Berlin is about 3.4 million inhabitants in an area of 892 km².[269] These data show that the metropolitan area of Berlin/Brandenburg is monocentric, at least from a macroscopic perspective.[270] This type of agglomeration is characterized by long commuting distances and a comparatively high concentration of residential population and jobs in the center of the region.[271] Although the number of commuters between Berlin and Brandenburg has increased continuously over the last few years, the total volume of commuters between Berlin and its surroundings is low when compared to other large cities in West Germany.[272] This can be explained by the large area of the city of Berlin itself, and the high concentration of the population that lives within the city itself (about 80%). Commuting trips within the city can be as long as 20 km. The trend towards delocalization from the city into the periphery and the neighboring regions of Brandenburg is likely to continue. This implies an increasing average commuting distance and also increased traffic levels within the (inner) city of Berlin.[273]

Compared to other large cities Berlin has a low rate of motorization. In 2006 1.42 million private vehicles were registered, of which 1.23 million were private cars, and 94,000 motorcycles.[274] This corresponds to a motorization of 360 private vehicles per 1,000 inhabitants. West Germany's large cities feature a much higher motorization, such as Munich (544), Stuttgart (531), or Duesseldorf (518).[275] In Berlin 38% of all travel is done by car, another 27% is done by public transport, 10% by bicycle, and 25% walking.[276]

Hence, the transport situation for private motorized vehicles in Berlin is good. Repeated congestion within the road network is rare. By national as well as international standards, Berlin has a high

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[269] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (2003, p. 83), and for the population data of Brandenburg LDS (2006, S. 4).

[270] Cf. SIEDENTOP ET AL. (2005, p.87). Contrary to the larger metropolitan area of Berlin / Brandenburg the city of Berlin is still polycentric, with high densities in the downtown area as well as in peripheral areas of the outer city; it also characterized by a mixed use of land (see BERLIN SENATE DEPARTMENT OF URBAN DEVELOPMENT, 2003, p. 83).

[271] Cf. SIEDENTOP ET AL. (2005, p. 87) and BECKERS ET AL. (2007, p. 259).

[272] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (2003, p. 83).

[273] Ibid, p. 95.

[274] Cf. STATISTISCHES LANDESAMT BERLIN (2006).

[275] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (2003, p. 84).

[276] Ibid. p. 63.

quality transport infrastructure, with significant capacity reserves. This has been strengthened by significant infrastructure investments since 1990.[277]

The parking situation, including public and private parking, in the center of Berlin is comfortable, which favors destination traffic by commuters and shoppers. In the denser inner-city residential areas there is a certain scarcity of parking lots (even though motorization is low), leading to significant searching traffic for parking locations.[278] Parking fees in public spaces are € 1/h on average, and € 2/h in areas with a high short-term parking demand. This is relatively low, compared to other large German cities, such as Munich (€ 2.50/h), and Hamburg (€ 2/h).[279]

Public transportation and public rail transportation in Berlin are very well developed. Berlin features a network of 2,004 km consisting of bus-, metro-, tram-, city train and regional rail traffic. The city train and metro network of 440 km contributes particularly to the intensive use of public transport in Berlin. On average, each Berliner uses the public transport 335 times per year (Hamburg: 285). The modal split is about 60:40 in favor of the so-called "environmental alliance" of public transport, public rail transport, bicycle and walking, versus private motorized transport.[280] This, too, contributes to the fact that the transport system in Berlin is rarely suffering from road congestion.

4.3.2 The Model

For this study we used a VISUM network model of Berlin provided by the Senate Department of Urban Development Berlin (Senatsverwaltung für Stadtentwicklung Berlin). It consists of 33,600 road links with 17 different speed-flow functions of the BPR type. The demand mesh of the model includes 1,324 traffic cells, which represent the spatial distribution of origins and destinations of trips in the network. This yields about 1.75 million possible O-D-relations for the model (1,324x1,324). The road network is represented in Figure 30.

[277] Cf. SENATSVERWALTUNG FÜR STADTENTWICKLUNG BERLIN (2003, p. 84).

[278] Ibid p. 37 f.

[279] Ibid p. 84.

[280] Ibid.

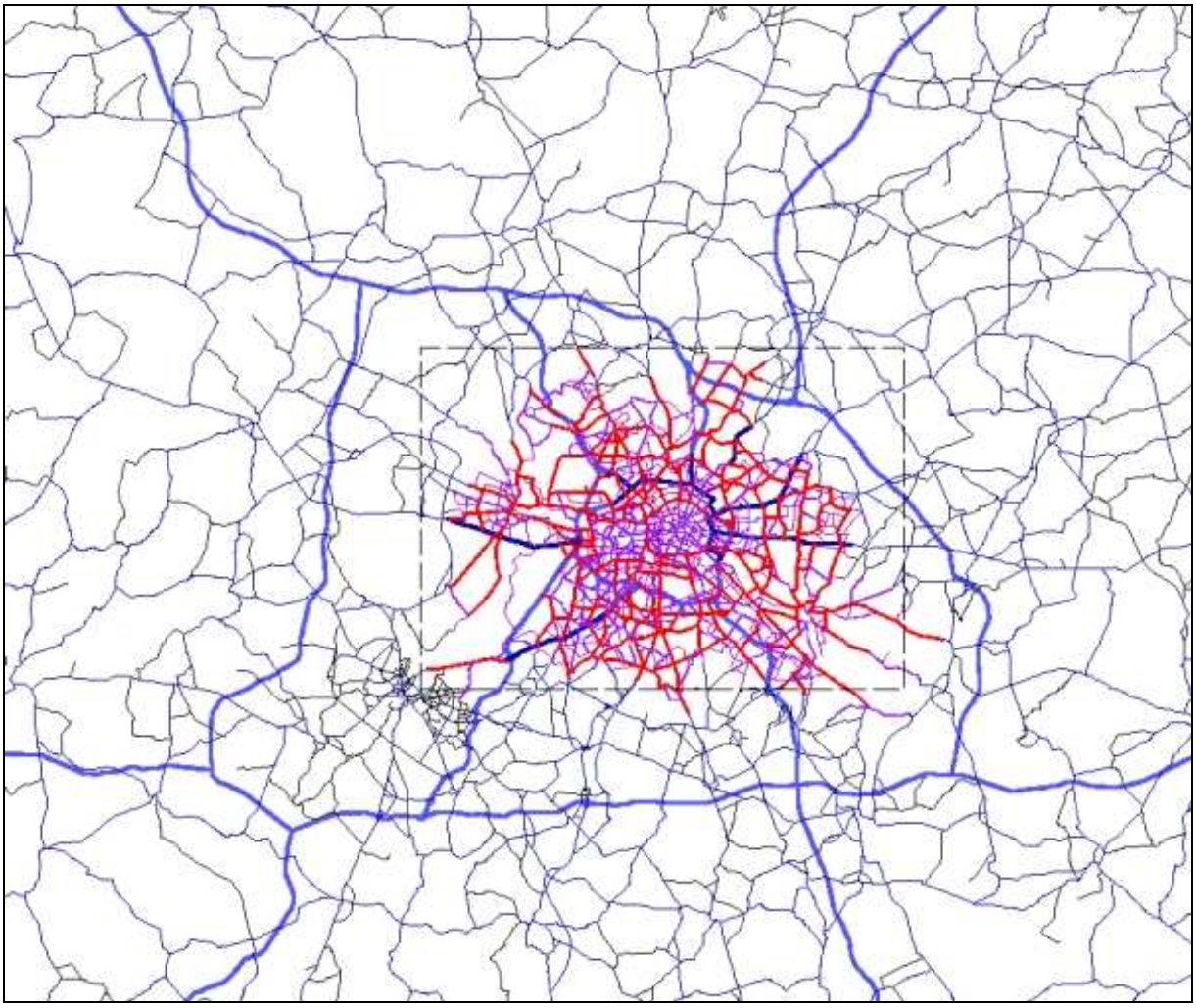

Figure 30: VISUM Network Model of the Metropolitan Area of Berlin[281]

4.3.2.1 Scenario 1: Time-Differentiated Cordon Tolls for the Center of Berlin

Figure 31 shows the situation of the cordon-ring in Berlin, marked in green. It corresponds to the entire inner-city within the city train ("S-Bahn") ring, the so-called "big dog's head" („großer Hundekopf").

[281] Source: Screenshot of the Berlin VISUM network model.

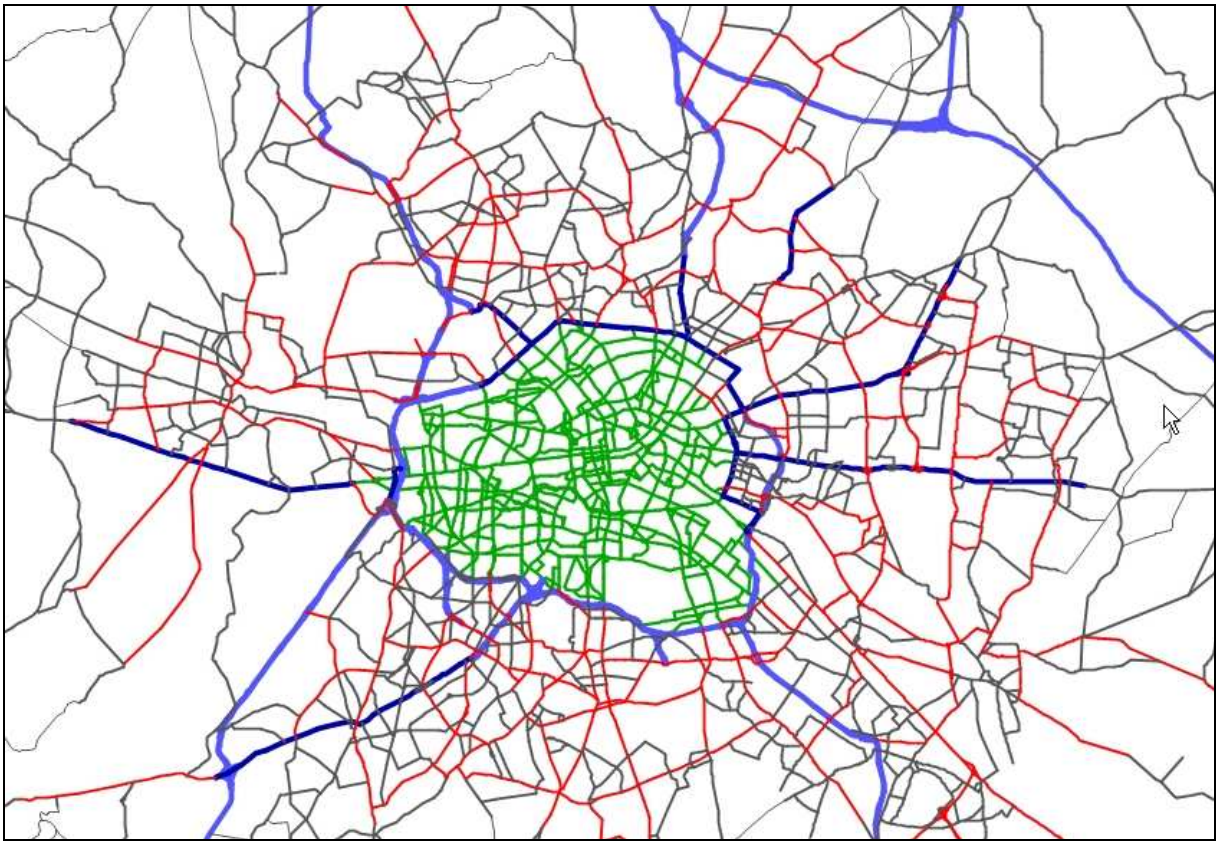

Figure 31: Cordon Tolling Area in the Inner City of Berlin[282]

Table 43 summarizes the transport implications of cordon pricing with a peak tariff of € 2 per entry into Berlin. This pricing regime leads to a reduction of car trips into the cordon area by 3.2% and 7.2% respectively. Both the total mileage and the travel times in the inner city decrease more than proportionally. The number of truck trips into the cordon area is only marginally reduced, because the cost increase of the toll is low in comparison to the total cost of these trips. Nonetheless the route choice is also optimized in this segment of trucks, leading to overall lower trip volumes and trip times within the cordon area.

[282] Source: Screenshot of the Berlin VISUM network model.

Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Demand Segment**	**Change in %**				
			Number of Trips	**Mileage**		**Travel Times**	
			Tolling Zone	**Tolling Zone**	**City Area**	**Tolling Zone**	**City Area**
2 / 1 / 2	-0.5	Cars	-3.17	-10.60	-1.90	-16.25	-2.55
4 / 2 / 4	-0.5	Trucks	-0.23	-14.18	-0.58	-19.73	-0.97
2 / 1 / 2	-1.5	Cars	-7.18	-15.28	-4.66	-22.88	-6.90
4 / 2 / 4	-1.5	Trucks	-0.46	-14.45	-0.43	-22.25	-2.21

Table 43: Implications of Time-of-Day Differentiated Cordon Tolls with a Peak Tariff of 2.00 EUR per Entry in Berlin[283]

In both demand segments there are considerably larger reductions in travel times than in travel distances. This implies higher average speeds for the cordon area as well as for the total road network in Berlin. For the lower of the two cordon tariffs we observed an increase of average speeds of 6.7%-9.9% within the cordon area, and of 0.7%-1.8% in the entire Berlin road network. Figure 32 shows the changes of average speed in the toll area with a peak cordon-toll of € 2 per entry. The increase of speed during peak times in the morning and in the afternoon is stronger than in the off-peak period around noon, which has the lower cordon-toll. Nonetheless the average speed during the afternoon peak remains lower than at other times, even after the introduction of the cordon-toll.

[283] Source: author's diagram.

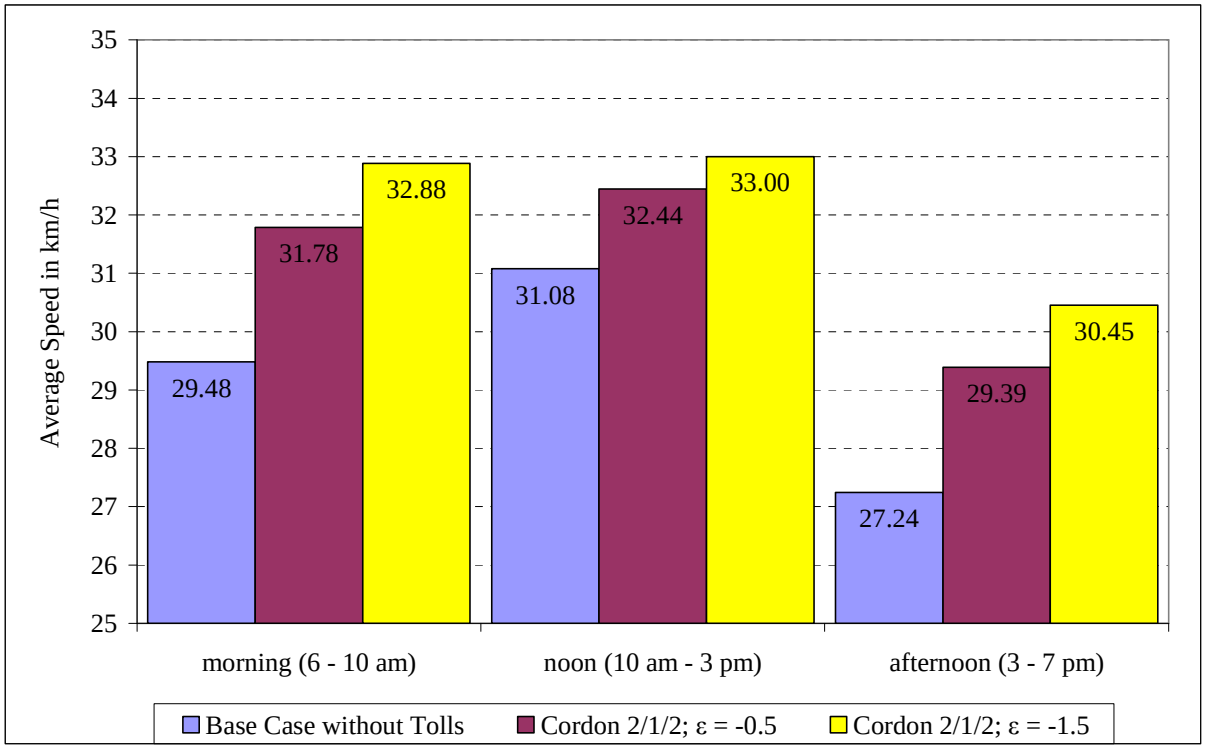

Figure 32: Changes in Average Speeds in the Tolling Area due to a Time-Differentiated Cordon Toll with Peak Tariffs of 2.00 EUR per Entry in Berlin[284]

Table 44 summarizes the traffic effects of a time-differentiated cordon-toll with a peak tariff of € 3. As expected, there is a larger reduction of trips compared to the lower peak tariff. This reduction is 4.5 %-9.7 % for car trips. There is also a disproportionately large reduction of trip times in this scenario, corresponding to higher average speeds. As in the cordon-toll scenario with the lower peak tariff, we also find average speed increases in the entire city of Berlin. This implies that the reduction of trips due to the introduction of the toll largely compensates for negative effects on transport due to changing routes, e.g. in order to avoid the tolling area. Nonetheless one can also imagine higher average costs per trip (exclusive of toll and taxes): these can result from longer travel distances implied by these modified route choices.

The increase of average speed for the high peak tariff is between 9.3%-13.5% for the cordon area, and 0.7%-3.1% for the entire Berlin road network. Figure 33 shows the time distribution of the changes in average speeds in the cordon area.

[284] Source: author's diagram.

Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Demand Segment**	**Change in %**				
			Number of Trips	**Mileage**		**Travel Times**	
			Tolling Zone	**Tolling Zone**	**City Area**	**Tolling Zone**	**City Area**
3 / 1.5 / 3	-0.5	Cars	-4.49	-14.02	-2.64	-21.30	-3.37
6 / 3 / 6	-0.5	Trucks	-0.41	-21.10	-0.78	-28.03	-0.92
3 / 1.5 / 3	-1.5	Cars	-9.74	-20.30	-6.42	-29.78	-9.25
6 / 3 / 6	-1.5	Trucks	-0.77	-21.71	-0.66	-31.13	-2.77

Table 44: Implications of Time-of-Day Differentiated Cordon Tolls with a Peak Tariff of 3.00 EUR per Entry in Berlin[285]

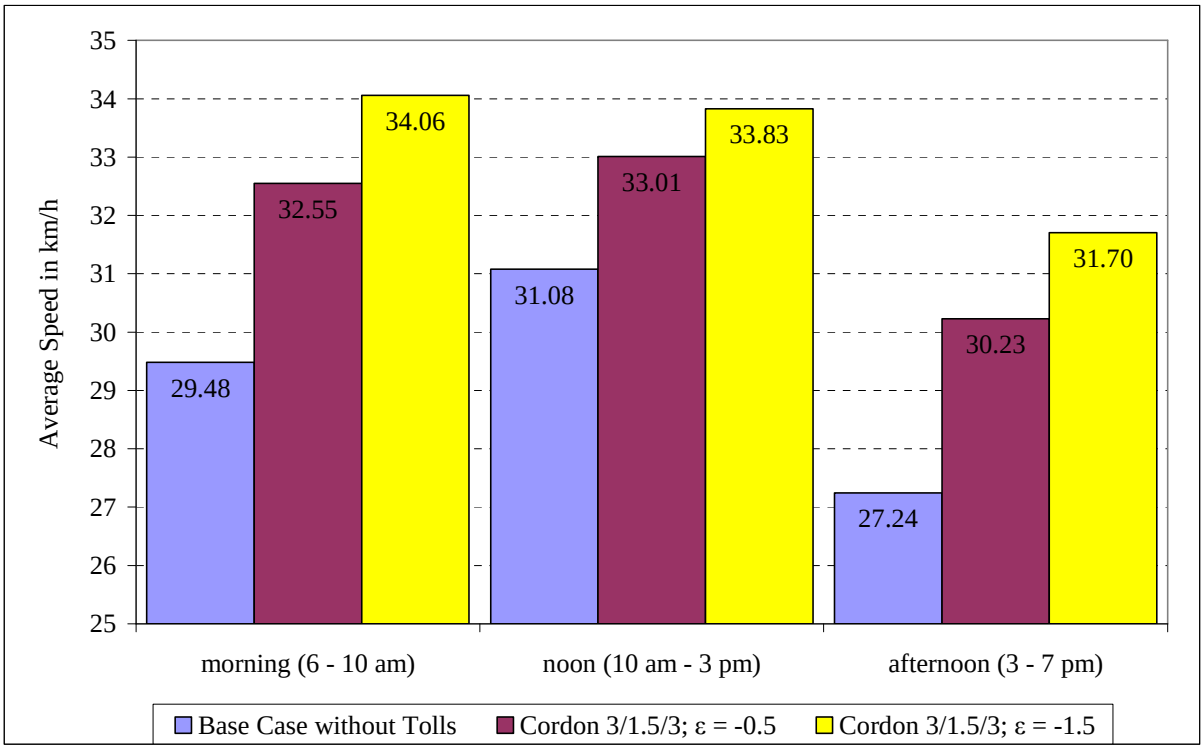

Figure 33: Changes in Average Speeds in the Tolling Area Due to a Time-Differentiated Cordon Toll with Peak Tariffs of 3.00 EUR per Entry in Berlin [286]

In comparison to the lower peak-tariff the average speeds have significantly increased again, even though the initial average speeds, i.e. before the introduction of tolls, are high already. These large

[285] Source: author's diagram.

increases, given already low capacity utilization in the base scenario, can be explained by the structural specifities of the Berlin road network, and the related demand structure. Compared to other international cities, the center of Berlin features a large number of main corridors with high average free-flow speeds.[287] Thus, despite short travel times in the center, there is a large potential for a further decrease of travel times. In addition, the road network in Berlin is a ring-radial network. This is typical of monocentric metropolitan areas, and leads to a high concentration of O-D-traffic between the center and the periphery along main corridors. The sensitivity to congestion of such networks increases with the proximity to the center. When this traffic is reduced by a toll in the center, the risk of congestion in the center is reduced disproportionately. This leads to high increases in average speeds in the core network, compared to the periphery.

1	2	3	4	5	6	7	8	9
Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Change (in 1,000 EUR)**						
		User Cost Reduction before Tolls ./. after Tolls (excl. Taxes and Tolls)		**Social Surplus**		**Total Welfare Effect by Reduced Congestion**		
		Cars	**Trucks**	**Cars**	**Trucks**	**Cars**	**Trucks**	**Total**
2 / 1 / 2	-0.5	-10,615	+4,168	-6,699	-53	-17,314	+4,114	-13,200
2 / 1 / 2	-1.5	+21,760	+15,149	-15,726	-123	+6,483	+15,025	+21,508
3 / 1.5 / 3	-0.5	-17,062	+5,105	-13,801	-95	-30,863	+5,010	-25,853
3 / 1.5 / 3	-1.5	+28,400	+20,326	-30,852	-215	-2,453	+20,110	+17,657

Table 45: Welfare Effects of Changed Capacity Utilization due to a Time-Differentiated Cordon Toll in Berlin (per annum)[288]

Table 45 shows that cordon-pricing in Berlin leads to positive welfare effects of truck transport, whereas in the private motorized segment, positive welfare effects only occur in the case of strong demand reactions to changing trip costs (cost elasticity of -1.5). The long-distance truck transport benefits disproportionately from higher average speeds, which are mainly due to reduced local private motorized transportation. As for the demand for private motorized transport, mainly shorter trips are abandoned. This is indicated by the low average costs of cancelled private trips (€ 4.41-4.50), compared to the net costs of a trip before the introduction of the toll of € 7.71. This

[286] Source: author's diagram.

[287] This is the reason why the average speeds in the inner city of Berlin are often higher than in the peripheral roads with lower capacities, e.g. residential areas outside the city center.

[288] Source: author's diagram.

result seems plausible with respect to the local borders of the cordon-toll: the costs for shorter trips into the center increase disproportionately. Even though the average speeds increase significantly, the positive welfare effects for motorized private transport are still low. Table 45 shows that in the case of low demand elasticity (-0.5) the net average costs per trip increase. The reasons for this phenomenon are rerouting behavior and detours, as shown by the increase of the average trip length by 1-2% for the entire model of the metropolitan area. This rerouting of trips can be interpreted as the direct effect of a locally limited toll. In the specific case of Berlin, the federal highways, not tolled in these scenarios, are in the periphery of the cordon areas; they may be good substitutes with free capacities for the formerly used roads in the inner-city. The first result, therefore, is that the cordon toll systems studied here are unlikely to be useful to optimize road capacity utilization in Berlin. Whether a different tariff structure or a different cordon-region would change these results is doubtful, in particular with respect to the investment and operation costs of a tolling system, which have not been taken into account so far.

Table 46 summarizes the main results of the monetary assessment of the environmental effects of the cordon-toll solutions for Berlin. We have averaged the different assumptions on the demand reactions.[289] Due to lower travel volumes in Berlin the environmental effects are always positive; they are between € 2.9-13.4 mn per year for the lower cordon-toll, and between € 4.0-18.6 mn per year for the higher toll. Even considering other values for the monetarization of the cordon-toll solutions, we assume that the improved environmental quality is insufficient to justify the investment and operational costs of such a road pricing system.

Table 47 summarizes the welfare effects of the analyzed cordon-scenarios for Berlin, excluding the costs of raising the toll. In addition, Table 48 shows the revenues of different cordon-toll solutions. Even though considerable revenues can be raised, the introduction of a cordon-toll is not suggested, due to economic welfare criteria.

[289]The same procedure has been applied for the other simulation scenarios.

Tolling Scenario	Change of Mileage in the City Area in %		Local Environmental Effects in Million EUR p. a.								
			Low Estimate			High Estimate			Medium Estimate		
	Cars	Trucks	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	-3.28	-0.51	+2.60	+0.28	+2.88	+10.38	+3.03	+13.41	+5.19	+0.74	+5.93
3 / 1.5 / 3	-4.53	-0.72	+3.59	+0.40	+3.99	+14.34	+4.29	+18.59	+7.17	+1.05	+8.22

Table 46: Evaluation of the Local Environmental Effects Due to Cordon Tolls in Berlin[290]

Tolling Scenario	Welfare Effects in Million EUR p. a.								
	Environmental Quality			Capacity Utilization			TOTAL		
	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	+5.2	+0.7	+5.9	-5.4	+9.6	+4.2	-0.2	+10.3	+10.1
3 / 1.5 / 3	+7.2	+1.1	+8.3	-16.7	+12.6	-4.1	-9.5	+13.7	+4.2

Table 47: Categorized Welfare Effects of Cordon Tolls in Berlin[291]

Tolling Scenario	Welfare Effects in Million EUR p. a.			Revenues in Million EUR p. a.		
	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	-0.2	+10.3	+10.1	201.3	18.1	219.4
3 / 1.5 / 3	-9.5	+13.7	+4.2	276.0	26.8	302.8

Table 48: Welfare Effects and Revenues of Cordon Tolls in Berlin[292]

4.3.2.2 Scenario 2a: Distance-Based Tolls for the Entire City of Berlin – Excluding Federal Highways

The introduction of distance-related tolls for the entire city of Berlin would increase average speeds in the network significantly, as shown by Table 49 and Figure 34. It would lead to a reduction of trips by between 3.8-9.0% for private motorized vehicles in the metropolitan area assuming the lower tariff of 10 ct/vkm; this also leads to an overall reduction of transport volumes and trip times in the city of Berlin.

Figure 34 shows the changed average speeds by region. As expected, the average speeds increase more with higher demand reactions to cost changes. It is interesting to note that speed in the inner city

[290] Source: author's diagram.

[291] Source: author's diagram.

[292] Source: author's diagram.

increases more than the average speed for the entire city. The reason for this, as already discussed in connection with the cordon-toll, is likely to be the specific structure of the road network in the center of Berlin (high-capacity corridors with high free-flow speeds).[293]

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
10 ct/vkm	-0.5	Cars	-3.81	-6.74	-9.65
30 ct/vkm	-0.5	Trucks	-0.80	-4.35	-4.06
10 ct/vkm	-1.5	Cars	-8.99	-13.42	-19.01
30 ct/vkm	-1.5	Trucks	-1.68	-4.44	-7.05

Table 49: Implications of a Distance-Based Toll of 10 ct/vkm Excluding Federal Highways in Berlin[294]

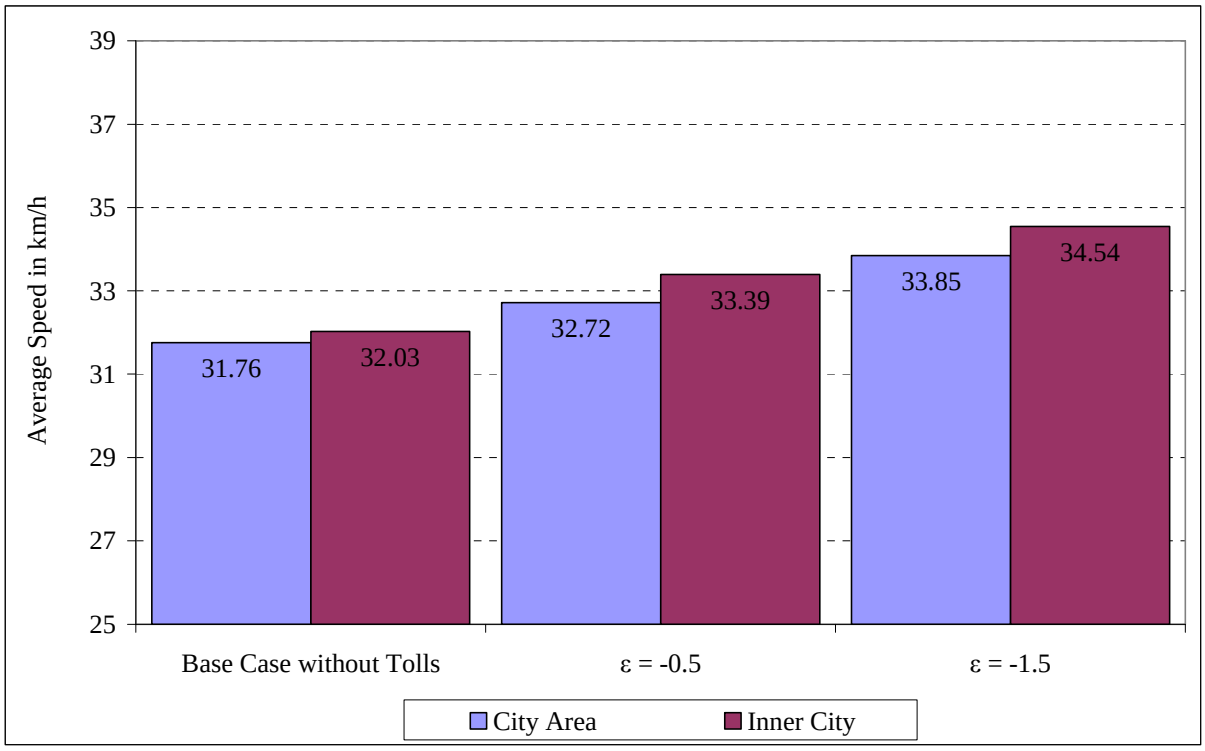

Figure 34: Changes in Average Speeds due to a Distance-Based Toll of 10 ct/vkm Excluding Federal Highways in Berlin[295]

[293] See explanation in section 4.3.2.1.

[294] Source: author's diagram.

Table 52 shows that the higher distance-related toll of 25 ct/vkm leads to a reduction of personal motorized transport trips by 8.7-20.2% in the entire metropolitan area. Travel times are reduced disproportionately compared to travel distances, therefore average speeds increase here, too. Figure 35 shows the results of average speeds, differentiated by regions. As in other cases, the increase of average speeds in the inner city is highest when demand elasticity is highest (-1.5).

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
25 ct/vkm	-0.5	Cars	-8.66	-14.86	-19.57
75 ct/vkm	-0.5	Trucks	-1.63	-11.56	-9.06
25 ct/vkm	-1.5	Cars	-20.17	-29.66	-38.27
75 ct/vkm	-1.5	Trucks	-3.48	-12.10	-15.36

Table 50: Implications of a Distance-Based Toll of 25 ct/vkm Excluding Federal Highways in Berlin[296]

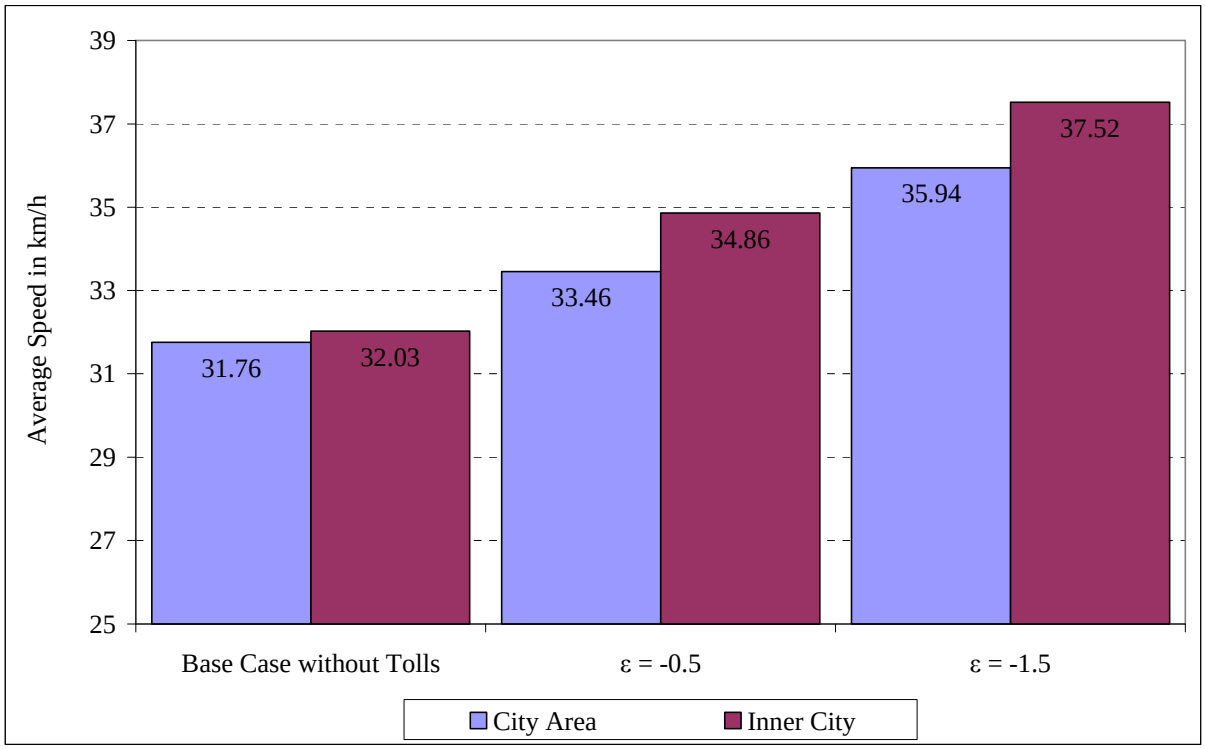

Figure 35: Changes in Average Speeds due to a Distance-Based Toll of 25 ct/vkm Excluding Federal Highways in Berlin[297]

[295] Source: author's diagram.

However, in the total model the trip lengths for motorized private traffic increase by 2.-6.5% for the lower tariff, and by 7.0-17.1% for the higher tariff. Thus, just as for the cordon-toll, a significant rerouting of transport volumes on the Federal motorways without toll can be observed. Due to these route extensions the net costs for the traffic participants are only moderately positive (linked to the higher average speeds) for the low tariff, and they are clearly negative for the higher tariff (Table 51).

1	2	3	4	5	6	7	8	9
Distance-based Tolls	**Elas-ticity**	**Change (in 1,000 EUR)**						
		User Cost Reduction before Tolls ./. after Tolls (excl. Taxes and Tolls)		**Social Surplus**		**Total Welfare Effect by Reduced Congestion**		
		Cars	**Trucks**	**Cars**	**Trucks**	**Cars**	**Trucks**	**Total**
10 ct/vkm	-0.5	+24,777	-29,457	-33,227	-1,110	-8,450	-30,566	-39,016
10 ct/vkm	-1.5	+55,964	+0,409	-61,128	-1,818	-5,523	-1,409	-6,932
25 ct/vkm	-0.5	-59,417	-48,897	-188,233	-4,487	-247,650	-53,383	-301,033
25 ct/vkm	-1.5	-19,387	+6,392	-359,675	-7,430	-379,062	-1,038	-380,100

Table 51: Welfare Effects of Changed Capacity Utilization due to a Distance-based Toll Excluding Federal Highways in Berlin (per annum)[298]

Contrary to the cordon-toll, the welfare effects now become highly significant. Due to the suppression of trips in the large-scale distance-related road pricing, consumer benefit decreases significantly. In the case of the lower toll, system-wide cost savings are more than counterbalanced by losses of consumer benefit. In the case of the higher toll, the reduction of consumer benefit due to suppressed tips is also the main cause of heavy welfare losses of the private motorized market segment.

Table 52 shows the monetarization of the environmental effects caused by distance-related road pricing solutions for Berlin. When compared to the cordon-toll, the suppression of trips within the entire Berlin area results in significantly higher environmental effects of up to € 175 mn. Particularly significant are reductions of heavy-duty traffic that account for up to 47% of these effects. However, these positive effects on the environmental quality seem to be insufficient to compensate for the negative welfare effects due to reduced capacity utilization (see Table 53).

[296] Source: author's diagram.

[297] Source: author's diagram.

[298] Source: author's diagram.

The annual revenues of the distance-related toll in Berlin are between € 892 mn and € 1.81 bn (Table 54). Nonetheless, due to the negative welfare effects, we can not advise the introduction of a distance-related road-pricing solution excluding federal highways for Berlin.

Tolling Scenario	Change of Mileage in the City Area in %		Local Environmental Effects in Million EUR p. a.								
			Low Estimate			High Estimate			Medium Estimate		
	Cars	Trucks	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
10 ct/vkm	-10.08	-4.40	+10.39	+2.87	+13.26	+41.56	+30.83	+72.39	+20.78	+7.57	+28.35
25 ct/vkm	-22.26	-11.83	+22.95	+7.72	+30.67	+91.78	+82.98	+174.76	+45.89	+20.38	+66.27

Table 52: Evaluation of the Local Environmental Effects due to Distance-Based Tolls Excluding Federal Highways in Berlin[299]

Tolling Scenario	Welfare Effects in Million EUR p. a.									TOTAL
	Noise Effects			Environmental Quality			Capacity Utilization			
	Health	Disturbance	Total	Cars	Trucks	Total	Cars	Trucks	Total	
10 ct/vkm	+2.1	+9.5	+11.6	+20.8	+7.6	+28.4	-7.0	-16.0	-23.0	+17.0
25 ct/vkm	+6.3	+11.1	+17.4	+45.9	+20.4	+66.3	-313.4	-27.2	-340.6	-256.9

Table 53: Categorized Welfare Effects of Distance-Based Tolls Excluding Federal Highways in Berlin[300]

Tolling Scenario	Welfare Effects in Million EUR p. a.				Revenues in Million EUR p. a.		
	Cars	Trucks	Common (Noise)	Total	Cars	Trucks	Total
10 ct/vkm	+13.8	-8.4	+11.6	+17.0	788.8	103.8	892.6
25 ct/vkm	-267.5	-6.8	+17.4	-256.9	1.610.3	203.4	1.813.7

Table 54: Welfare Effects and Revenues of Distance-Based Tolls Excluding Federal Highways in Berlin[301]

[299] Source: author's diagram.

[300] Source: author's diagram.

[301] Source: author's diagram.

4.3.2.3 Scenario 2b: Distance-Based Tolls for the Entire City of Berlin – Including Federal Highways

The results of the previous section indicate considerable rerouting effects caused by travel demand trying to circumvent the tolls by using the unpriced city highways in Berlin. That is why analyzing the inclusion of federal highways on the territory of Berlin in tolling systems seems worthwhile. In contrast to the Stuttgart area, these city highways are not part of important interregional routes, i.e. they are almost exclusively used by local traffic. So there are much fewer technical and organizational problems to be expected with occasional users.

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
10 ct/vkm	-0.5	Cars	-4.1	-9.8	-14.1
30 ct/vkm	-0.5	Trucks	-0,9	-9.8	-13.5
10 ct/vkm	-1.5	Cars	-9.6	-17.3	-24.3
30 ct/vkm	-1.5	Trucks	-1.9	-10.4	-17.3

Table 55: Implications of a Distance-Based Toll of 10 ct/vkm Including Federal Highways in Berlin[302]

As Table 55 shows, the effect of a toll of 10ct/vkm on the number of trips is in the same order as in the alternative scenario with untolled federal highways. But the mileage is reduced by an extra 50%-100% compared to the alternative scenario, and trip times are diminished disproportionately. This is also reflected by the resulting average speeds in Figure 36, which are slightly lower for the inner city, but much higher for the entire city area, compared to the tolling system excluding highways. This underlines the importance of avoidance traffic in the alternative scenario, as described in the previous section.

[302] Source: author's diagram.

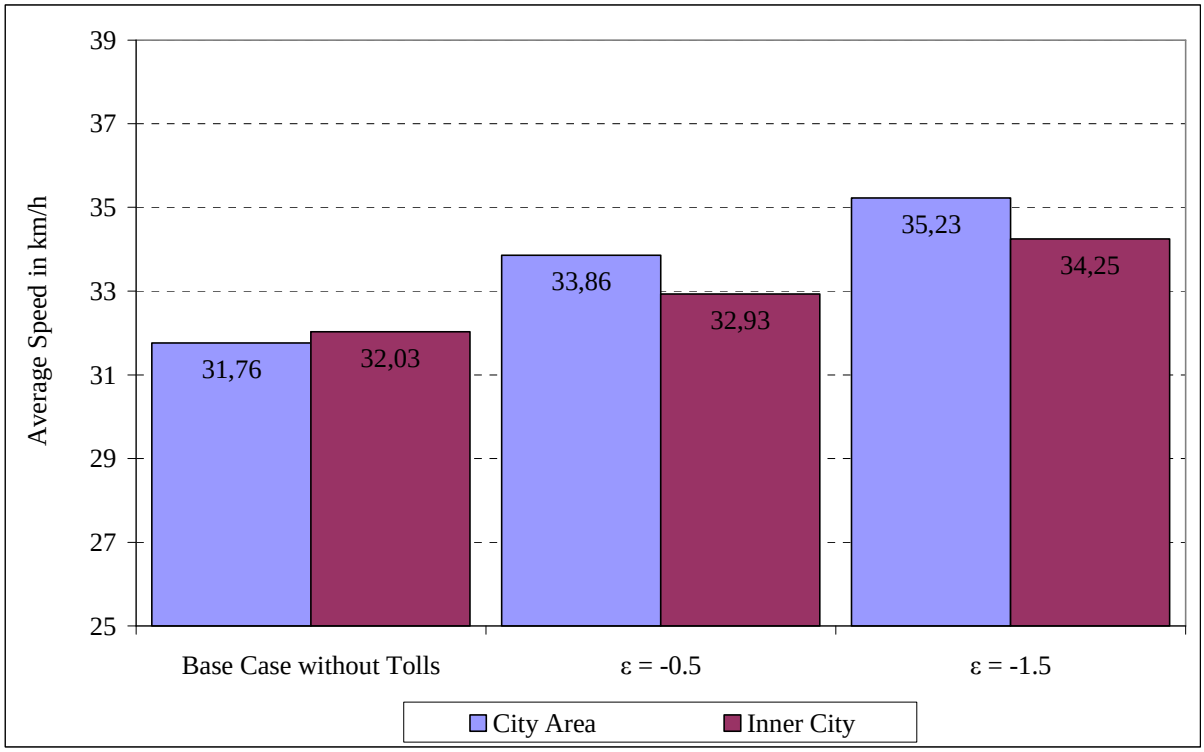

Figure 36: Changes in Average Speeds due to a Distance-Based Toll of 10 ct/vkm Including Federal Highways in Berlin[303]

The same applies to the tolling scenario assuming the higher tariff of 25 ct/vkm for cars and 75 ct/vkm for trucks, as shown by Table 56 and Figure 37.

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
25 ct/vkm	-0.5	Cars	-9.2	-20.4	-27.7
75 ct/vkm	-0.5	Trucks	-2.0	-23.7	-30.9
25 ct/vkm	-1.5	Cars	-21.2	-36.7	-47.2
75 ct/vkm	-1.5	Trucks	-4.2	-25.8	-38.3

Table 56: Implications of a Distance-Based Toll of 25 ct/vkm Including Federal Highways in Berlin[304]

[303] Source: author's diagram.

[304] Source: author's diagram.

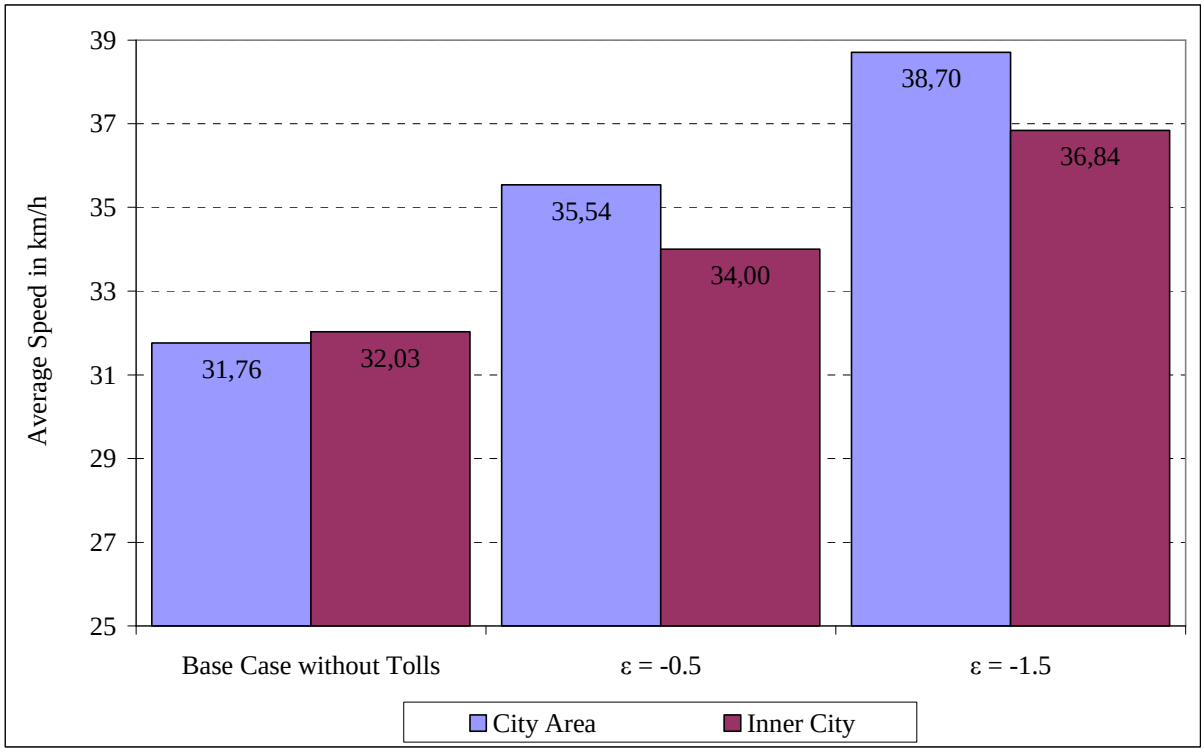

Figure 37: Changes in Average Speeds due to a Distance-Based Toll of 25 ct/vkm Including Federal Highways in Berlin[305]

As a result of higher average speeds for the whole network the user costs excluding tolls decrease in all scenarios, as shown by the columns no. 3 and 4 of Table 57. Moreover, in all scenarios with tolled federal highways the utilization of network capacities is improved, because the losses of social surplus due to cancelled trips, shown in columns no. 5 and 6 of Table 57, are more than made up for by reduced user costs.

[305] Source: author's diagram.

1	2	3	4	5	6	7	8	9
Distance-based Tolls	**Elas-ticity**	**Change (in 1,000 EUR)**						
		User Cost Reduction before Tolls ./. after Tolls (excl. Taxes and Tolls)		**Social Surplus**		**Total Welfare Effect by Reduced Congestion**		
		Cars	**Trucks**	**Cars**	**Trucks**	**Cars**	**Trucks**	**Total**
10 ct/vkm	-0.5	+79.8	+21.9	-20.3	-0.7	+59.5	+21.2	+80.7
10 ct/vkm	-1.5	+137.7	+56.5	-38.4	-1.2	+99.2	+55.3	+154.5
25 ct/vkm	-0.5	+81.4	+56.5	-113.9	-3.2	-32.5	+53.2	+20.7
25 ct/vkm	-1.5	+130.6	+130.7	-223.5	-5.5	-92.9	+125.2	+32.3

Table 57: Welfare Effects of Changed Capacity Utilization due to a Distance-based Toll Including Federal Highways in Berlin (per annum)[306]

In analogy to the alternative scenarios with untolled highways, the lower tariff yields the higher positive net effects on network capacity utilization. Larger reductions of negative environmental and noise effects for the high price scenario, depicted in Table 58 and Table 59, are not sufficient to change this picture for the totals of toll-induced net benefits. As expected, the positive environmental effects are stronger than in the scenarios with untolled highways, while the reductions of noise costs are smaller. The latter is a consequence of a characteristic of marginal noise costs, which decrease with higher traffic volumes.[307] As there are lesser rerouting effects than in the alternative scenario excluding highways, the traffic levels on the (still) heavily used highways are lower, but this implies only small positive noise effects. On the other hand, the traffic volumes in other, less heavily used parts of the city areas are a little higher, which in turn increases noise costs compared to the alternative scenario. Both effects lead to smaller reductions of noise costs.

[306] Source: author's diagram.

[307] Cf. section 2.1.2.3.

Tolling Scenario	Change of Mileage in the City Area in %		Local Environmental Effects in Million EUR p. a.								
			Low Estimate			High Estimate			Medium Estimate		
	Cars	Trucks	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
10 ct/vkm	-13.6	-10.1	+6.61	+0.29	+6.90	+81.87	+3.69	+85.56	+12.87	+0.58	+13.45
25 ct/vkm	-28.5	-24.7	+13.92	+0.73	+14.65	+172.35	+9.02	+181.37	+27.09	+1.42	+28.51

Table 58: Evaluation of the Local Environmental Effects due to Distance-Based Tolls Including Federal Highways in Berlin[308]

Tolling Scenario	Welfare Effects in Million EUR p. a.									
	Noise Effects			Environmental Quality			Capacity Utilization			TOTAL
	Health	Disturbance	Total	Cars	Trucks	Total	Cars	Trucks	Total	
10 ct/vkm	+2.4	+4.0	+6.4	+12.9	+0.6	+13.5	+79.4	+ 38.3	+117.7	+137.6
25 ct/vkm	+5.2	+9.2	+14.4	+27.1	+1.4	+28.5	-62.7	+89.2	+26.5	+69.4

Table 59: Categorized Welfare Effects of Distance-Based Tolls Including Federal Highways in Berlin[309]

Tolling Scenario	Welfare Effects in Million EUR p. a.				Revenues in Million EUR p. a.		
	Cars	Trucks	Common (Noise)	Total	Cars	Trucks	Total
10 ct/vkm	+92.3	+38.9	+6.4	+137.6	+896.1	+168.6	+1,064.7
25 ct/vkm	-35.6	+90.6	+14.4	+69.4	+1,850.9	+352.8	+2,203.7

Table 60: Welfare Effects and Revenues of Distance-Based Tolls Including Federal Highways in Berlin[310]

Even if the overall benefits of the scenarios including highway tolling are larger than without it, in none of the scenarios the total welfare effects seem to be sufficient to justify the costs of installing and operating a distance-based tolling scheme, which would require a tolling system based on satellite communication. Hence, these road-pricing solutions may become relevant in the distant future as the necessary tolling technology is unlikely to be available at acceptable costs in the medium-term.[311]

[308] Source: author's diagram.

[309] Source: author's diagram.

[310] Source: author's diagram.

[311] Cf. e.g. BECKERS ET AL. (2007).

4.3.3 Comparison of Road-Pricing Scenarios for Berlin

Table 61 shows the total welfare effects due to improved environmental quality and changed capacity utilization for all road pricing scenarios in Berlin. In two scenarios, i.e. the cordon-toll with the higher tariff, and the distance-related toll of 10 ct/vkm excluding highways, the slightly negative effects on capacity utilization are overcompensated by positive environmental effects. In the other scenarios, we observe a slight increase (or: smaller reduction) of total welfare through improved environmental quality.

Tolling Scenario	Welfare Effects in Million EUR p. a.							
	Noise	Environmental Quality			Capacity Utilization			Total
	Total	Cars	Trucks	Total	Cars	Trucks	Total	
Cordon 2 / 1 / 2	n.a.[312]	+5,2	+0,7	+5,9	-5,4	+9,6	+4,2	+10.1
Cordon 3 / 1,5 / 3	n.a. [313]	+7,2	+1,1	+8,3	-16,7	+12,6	-4,1	+4.1
10 ct/vkm excl. Highways	+11.6	+20,8	+7,6	+28,4	-7,0	-16,0	-23,0	+17.0
25 ct/vkm excl. Highways	+17.4	+45,9	+20,4	+66,3	-313,4	-27,2	-340,6	-256.9
10 ct/vkm incl. Highways	+6.4	+12.9	+0.6	+13.5	+79.4	+ 38.3	+117.7	+137.6
25 ct/vkm incl. Highways	+14.4	+27.1	+1.4	+28.5	-62.7	+89.2	+26.5	+69.4

Table 61: Welfare Effects of the Analyzed Tolling Scenarios for Berlin[314]

The total welfare effect of a tolling regime is strongly related to the scale of changing levels of social surplus due to changed network and congestion conditions. It becomes clear that neither limited inner-city tolling schemes, nor charging schemes excluding the federal highways would result in substantial increases of total welfare for Berlin. In most of these cases positive welfare effects due to diminished noise and air pollution levels are even overcompensated by losses of social surplus. Only the scenarios with a city-wide, distance-dependent toll seem to yield larger rises of total welfare. All in all, the lower range of tolls seems to induce higher total benefits for Berlin. Because the costs for the installation and operation of such a (technologically sophisticated) charging system have not been included in our calculations yet, the net welfare effects of all tolling scenarios analyzed are likely to be negative. Taking into account rising congestion levels and a cheaper tolling technology for the medium-term

[312] The analyzed cordon toll scenarios were geared to improved capacity utilization. Hence the time structure of these simulation scenarios differs from that necessary for the evaluation of noise effects. Nevertheless, similar scenarios with cordon tolls of 1.40 € – 3.50 € per day resulted in very small welfare gains of 0.6 mn. € – 2.3 mn. € p.a. due to diminished traffic noise. Cf. HIRSCHHAUSEN / NAGEL (2007).

[313] Cf. ibd.

[314] Source: author's diagram.

future, the cost-benefit-ratio for a tolling system in Berlin might improve over the next years. However, none of the charging schemes considered can be recommended for immediate implementation.

4.4 Road Pricing in Stuttgart

4.4.1 Structural Data of Stuttgart

Stuttgart is a polycentric medium-sized structure and has a relatively low density of population and jobs in the inner city, compared to the larger environment. Average commuter distances are low.[315] As a result, the network of the Stuttgart agglomeration corresponds to a mesh structure (Figure 38). This mesh structure also corresponds to the spatial distribution of demand, including multiple O-D-relations between the various sub-centers of the metropolitan area. In addition to the main center of Stuttgart, there are medium-size regional centers in Ludwigsburg, Esslingen, Sindelfingen, Böblingen, Leinfelden-Echterdingen, Filderstadt, Fellbach, Waiblingen and Leonberg.[316]

[315] Cf. SIEDENTOP (2005).

[316] Cf. AMT FÜR STADTPLANUNG UND STADTERNEUERUNG STUTTGART (2004, p. 17).

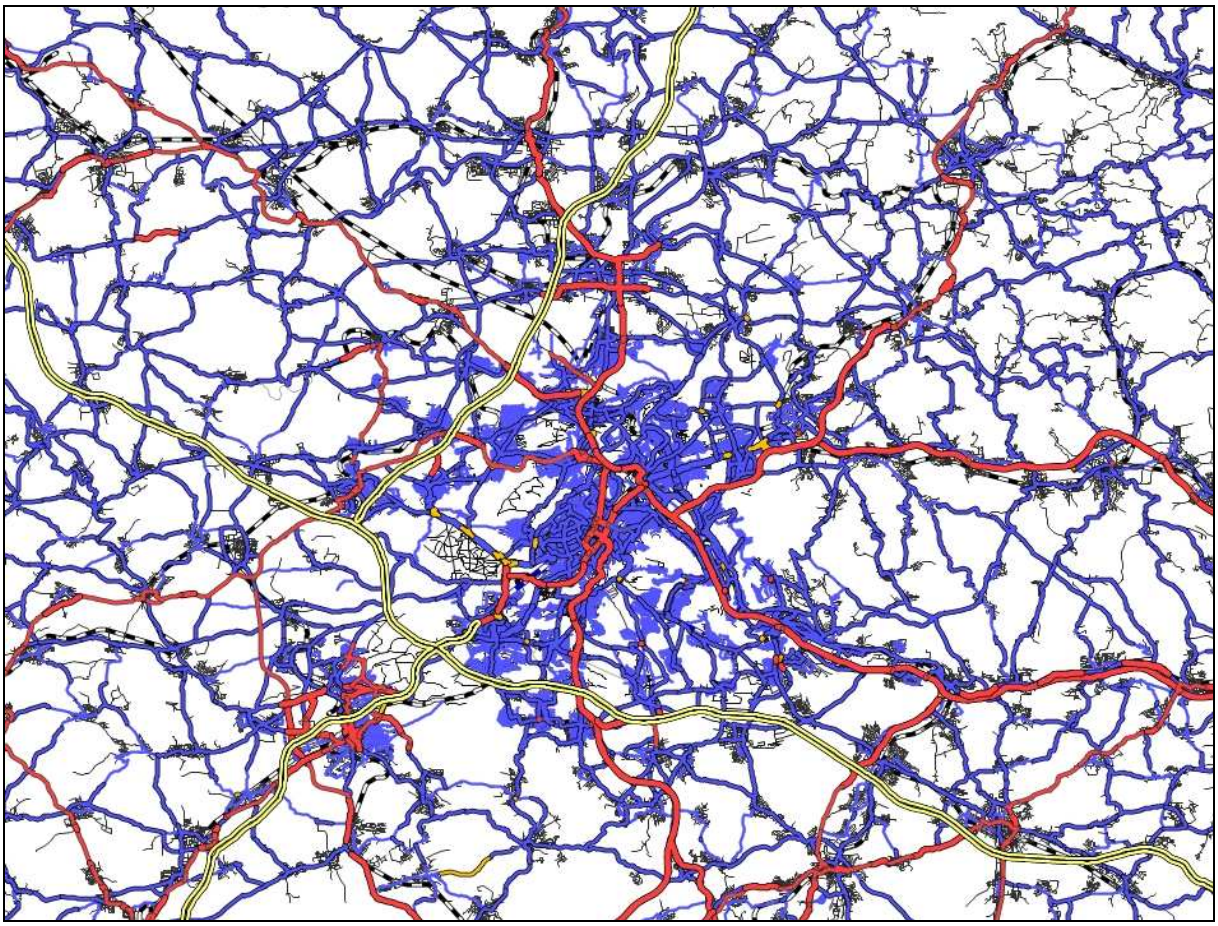

Figure 38: Mesh Structure of the Road Network in the Metropolitan Area of Stuttgart[317]

The region of Stuttgart comprises of the city of Stuttgart plus the neighboring districts of Böblingen, Esslingen, Göppingen, Ludwigsburg and Rems-Murr.[318] With an area of 3,654 km^2 and 2.62 mn. inhabitants, this is the third largest metropolitan area in Germany.[319] Population density is relatively high: 720 inhabitants/km^2.[320] An interesting feature is the more uniform distribution of the population, compared to monocentric metropolitan areas. Whereas in Berlin 80% of the population live in the city (i.e. in just 17% of the total agglomeration area), in the city of Stuttgart there are only 20 % of the inhabitants (approx. 590,000) in 6% of the total area.[321] The trend towards suburbanization continues

[317] Source: Screenshot of the Stuttgart VISUM network model.

[318] Cf. VERBAND REGION STUTTGART (2006, p. 13).

[319] Cf. AMT FÜR STADTPLANUNG UND STADTERNEUERUNG STUTTGART (2004, p. 19); the comparison relates to the number of inhabitants.

[320] Cf. AMT FÜR STADTPLANUNG UND STADTERNEUERUNG STUTTGART (2004, p. 19). In the metropolitan areas of Hamburg and Frankfurt the density is 445 resp. 557 inhabitants per km^2.

[321] Cf. AMT FÜR STADTPLANUNG UND STADTERNEUERUNG STUTTGART (2004, p. 24).

unbroken. The long-term average of the net movements from the city of Stuttgart to the periphery is about 3,500 per year.[322] This implies an increasing number of commuters between the city of Stuttgart and the periphery. From 1996 to 2000 the number of commuters increased by 21,000 to 253,000 . Motorized individual traffic across the border of the city of Stuttgart increased by 14.2% in the same period.[323]

The length of the road network of the region in 2002 was 3,300 km. This corresponds to 12% of the total road network in the federal state of Baden-Württemberg, while featuring a share of motorized vehicles of 25%. In early 2005, there were 1.83 mn. motorized vehicles registered in the city of Stuttgart, of which 1.56 mn were cars.[324] This makes up a high motorization rate of 578 vehicles per 1,000 inhabitants in the metropolitan area. The city of Stuttgart also features a high motorization (531 vehicles per 1,000 inhabitants).[325] The main reason for his may be the high per-capita income of Stuttgart.[326]

The inner city of Stuttgart has about 40,000 parking spaces, 11,000 of which are in public multi-story car parks houses, 6,000 are in public space, and 23,000 in private parking lots. There is a shortage of parking space, in particular in the densely populated areas of the inner city and the peripheral suburbs.[327]

Public transportation in the region is well developed. It includes an extensive bus and tram system, and a regional railway system with a network of 180 km and 71 stops.[328] Nonetheless, we find the high motorization rate reflected in the modal split in the city of Stuttgart: 43% of the intra-city traffic is done by private cars, 23% by public transport, 7% bicycle, and 27% walking. The share of motorized private transport in the periphery of the metropolitan area should be even higher, given the lower availability of public transportation and less congestion.

The high share of cars in the modal split, high population density, and the high level of economic integration between the subcenters of the metropolitan area lead to a high road traffic density in the region. The ever-increasing demand meets with a network which can hardly be expanded.

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[322] Ibid, p. 25.

[323] Ibid, p. 138.

[324] VERBAND REGION STUTTGART (2006, p. 89).

[325] Ibid, p. 187.

[326] In addition, preferential treatment of employees of the automobile industry (e.g. Daimler, Porsche) may be another reason for the high motorization rate of Stuttgart.

[327] Cf. AMT FÜR STADTPLANUNG UND STADTERNEUERUNG STUTTGART (2004, p. 145).

[328] Cf. VERBAND REGION STUTTGART (2006, p. 92).

Consequently the average speeds in the core network of Stuttgart are lower than in Berlin at any time of the day. Average speed in the inner city is about 20 km/h, and it is 26 km/h for the entire city of Stuttgart (compared to over 30 km/h in the inner city of Berlin). Thus the potential for a congestion-related toll in Stuttgart seems to be higher at first sight. However, broadly used speed limits in the inner city, and the mesh structure of the network in the entire metropolitan area reduce the options for an optimal use of capacities using a spatially-limited toll.

4.4.2 The Model

The Department of City Planning and Urban Renewal Stuttgart (Amt für Stadtplanung und Stadterneuerung) provided a VISUM-model with a high degree of detail (see Figure 38). It has 316,000 links, almost 10 times the level of the VISUM-model for Berlin. The model includes 11 speed-flow functions of the BPR type. The demand matrices for the metropolitan region of Stuttgart include 1,058 cells, corresponding to over a million O-D-relations per demand segment. The 7 demand segments in the original model have been aggregated into two: motorized private transport and trucks, in order to reduce VISUM calculation times.

4.4.2.1 Scenario 1: Time-Differentiated Cordon Pricing for the Center of Stuttgart

As in the case of Berlin, we calculated the effects of a time-differentiated cordon-toll pricing for the inner city of Stuttgart, the “city basin”. For the identification of the tolled access roads we relied on ENGLMANN ET AL. (1996).[329] Figure 39 shows the tolled area (in green). Table 62 shows the most important traffic effects of a time-differentiated toll with a peak-load tariff of € 2 per entry.

[329] Cf. ENGLMANN ET AL. (1996, S. 216).

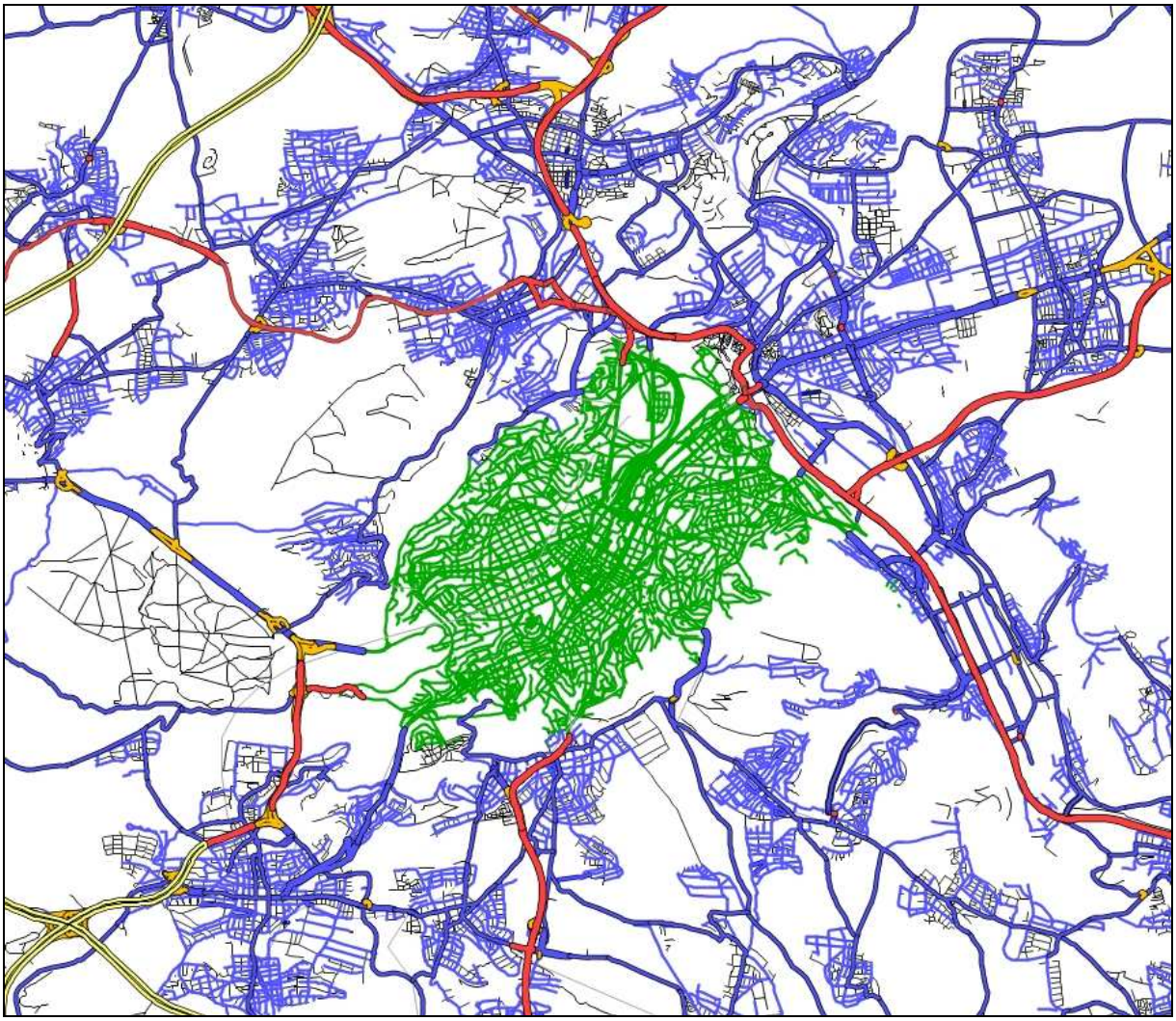

Figure 39: Cordon Tolling Area in the Inner City of Stuttgart[330]

Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Demand Segment**	**Change in %**				
			Number of Trips	**Mileage**		**Travel Times**	
			Tolling Zone	**Tolling Zone**	**City Area**	**Tolling Zone**	**City Area**
2 / 1 / 2	-0.5	Cars	-3.05	-7.90	-3.59	-6.64	-2.40
4 / 2 / 4	-0.5	Trucks	-2.35	-9.46	-0.12	-11.34	-2.15
2 / 1 / 2	-1.5	Cars	-6.23	-11.82	-6.41	-13.48	-8.57
4 / 2 / 4	-1.5	Trucks	-4.01	-11.01	-2.27	-15.73	-3.15

Table 62: Implications of Time-of-Day Differentiated Cordon Tolls with a Peak Tariff of 2.00 EUR per Entry in Stuttgart[331]

[330] Source: Screenshot of the Stuttgart VISUM network model.

The number of trips into the cordon area falls by 3.1-6.2%, quite similar to the case of Berlin. This leads to a disproportionate reduction of travel distances (7.9-11.8%) in the cordon area itself, and a reduction of 3.6-6.4% in the entire city of Stuttgart. Nonetheless, average speeds in the city and in the cordon zone only increase significantly in the case of high demand elasticity (-1.5). Figure 40 shows the changes in average speeds in the cordon area. The introduction of the cordon-toll with a peak-tariff of € 2 leads only to a slightly decreased transport intensity in the inner city of Stuttgart.

A larger reduction in trips and mileage is enforced by a higher cordon-toll of € 3 per entry (Table 63). However, in this case, too, the travel times fall only less than proportionally in the case of low demand elasticity, which is equivalent to a reduction in average speeds. Figure 41 implies that the average speed in the toll area (€ 3 per entry) can only increase in the case of high demand elasticity. Around noon, the average speed in both tariffs is slightly reduced.

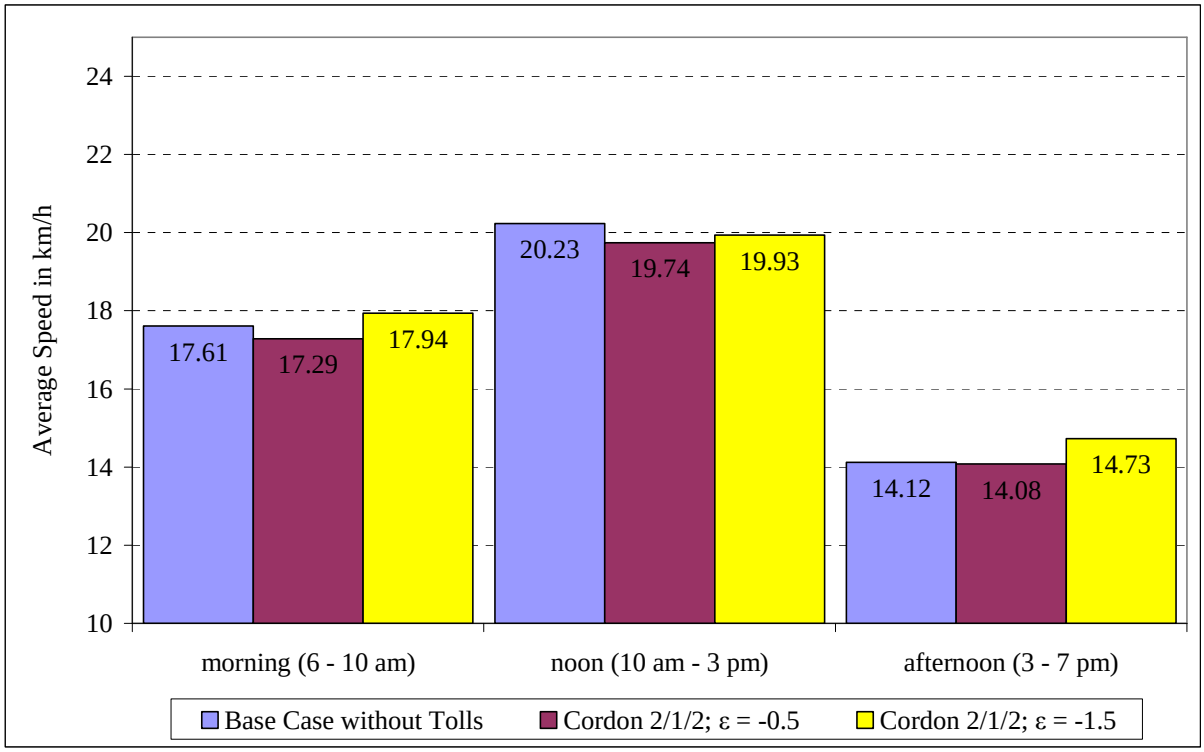

Figure 40: Changes in Average Speeds in the Tolling Area due to a Time-Differentiated Cordon Toll with Peak Tariffs of 2.00 EUR per Entry in Stuttgart[332]

[331] Source: author's diagram.

[332] Source: author's diagram.

Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Demand Segment**	**Change in %**				
			Number of Trips	**Mileage**		**Travel Times**	
			Tolling Zone	**Tolling Zone**	**City Area**	**Tolling Zone**	**City Area**
2 / 1 / 2	-0.5	Cars	-4.14	-10.14	-4.28	-9.61	-3.60
4 / 2 / 4	-0.5	Trucks	-3.13	-12.55	-2.53	-15.16	-0.28
2 / 1 / 2	-1.5	Cars	-8.08	-15.07	-7.82	-18.02	-10.90
4 / 2 / 4	-1.5	Trucks	-5.60	-15.79	-3.74	-21.55	-5.20

Table 63: Implications of Time-of-Day Differentiated Cordon Tolls with a Peak Tariff of 3.00 EUR per Entry in Stuttgart[333]

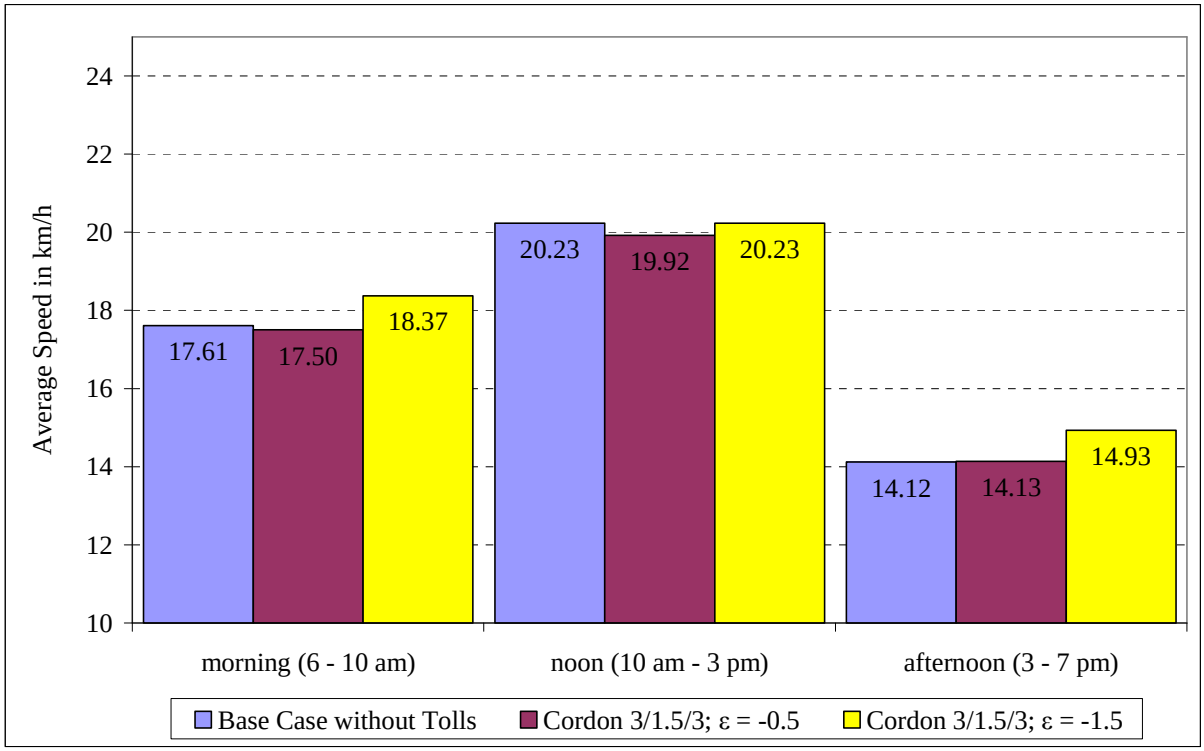

Figure 41: Changes in Average Speeds in the Tolling Area due to a Time-Differentiated Cordon Toll with Peak Tariffs of 3.00 EUR per Entry in Stuttgart[334]

When looking at the entire metropolitan area, the average speeds are reduced in both cordon-toll scenarios. In the case of lower elasticities the reduction is about 2.9-3.1%, and in the case of higher

[333] Source: author's diagram.

[334] Source: author's diagram.

elasticities it is reduced by 1.0-1.4%. This implies that the changed route choice of the traffic participants dominates the effects of reduced transport demand. This is mainly due to the mesh structure of the polycentric metropolitan area of Stuttgart.

In general, mesh networks offer more route choices with similar cost characteristics for a given O-D-pair than radial networks of monocentric areas, and individual road links are more often a potential part of routes between different O-D-relations. Both facts imply a higher interdependence between spatially distributed transport demands. A direct effect of the toll in the inner city is that traffic avoids the cordon area, leading to a deterioration of traffic conditions in the surrounding areas. Additional users on the roads situated there in turn modify the attraction of these links for the incumbent users. Therefore in a mesh road network transport users that are not even directly affected by the toll, may decide to change their route choice. This in turn modifies the attraction of individual route alternatives for other road users, and thus affects multiple O-D-relations. Thus the indirect effects of a spatially limited toll upon the reaction of traffic participants outside of the tolling region can be significant.[335] When the mesh network is very dense, more distant regions of the periphery can also be significantly affected.

On average, the model shows shorter travel distances. This is plausible because the distance costs per trip increase in proportion to the time costs per trip after the toll introduction. This effect is over-compensated by longer travel times. Contrary to Berlin, the average costs of cancelled trips in the tolled region (€ 5.60-5.94) in motorized private transport is significantly higher than the net average costs of all motorized trips, before and after the introduction of the toll (€ 3.76-3.84). This implies that trips featuring disproportionately long distances will be suppressed due to the toll. However, the direct effect of a locally limited toll is supposed to be shorter trips in the tolling area, due to the relatively high increase in costs. This unexpected result implies that the cordon-toll also affects the routing of traffic participants not directly subject to the toll, and therefore leads to a significant rerouting of entire traffic flows in the metropolitan area of Stuttgart.

[335] The strong interdependencies of relational specific demands is an additional argument in favor of a network-specific simulation, since realistic estimations of demand reactions upon the introduction of a toll can hardly be done analytically.

1	2	3	4	5	6	7	8	9
Cordon Tolls (6-10 am/ 10 am -3 pm/ 3 -7 pm)	**Elas-ticity**	**Change (in 1,000 EUR)**						
		User Cost Reduction before Tolls ./. after Tolls (excl. Taxes and Tolls)		**Social Surplus**		**Total Welfare Effect by Reduced Congestion**		
		Cars	**Trucks**	**Cars**	**Trucks**	**Cars**	**Trucks**	**Total**
2 / 1 / 2	-0.5	-101,415	-23,827	-3,946	-328	-105,462	-24,155	-129,617
2 / 1 / 2	-1.5	-72,126	-13,109	-5,903	-383	-78,028	-13,492	-91,520
3 / 1.5 / 3	-0.5	-103,882	-32,240	-6,932	-433	-110,815	-32,674	-143,489
3 / 1.5 / 3	-1.5	-72,294	-13,288	-10,498	-522	-82,792	-13,810	-96,602

Table 64: Welfare Effects of Changed Capacity Utilization due to a Time-Differentiated Cordon Toll in Stuttgart (per annum)[336]

Table 64 summarizes the welfare effects of changes in capacity utilization, resulting from a cordon-toll in Stuttgart. Since the average speeds in the network have not increased, all scenarios feature a negative effect due to increasing costs of the remaining trips (columns 3 / 4). The reductions of social surplus due to suppressed trips are relatively minor when compared to the deterioration of traffic conditions (columns 5 / 6). The welfare effects are higher with inelastic demand; differences in the tariff level have a minor impact. This underlines once again the dominance of negative route choice effects over the positive effects on the congestion level due to a reduced number of trips. This result is valid for both cordon toll varieties analyzed for Stuttgart.

We observe positive environmental effects for all cordon toll systems in the city of Stuttgart. These are listed in Table 65. As in the case of Berlin, the positive utility from improved environmental quality is insufficient to compensate for the negative effects of the cordon-toll on capacity utilization. This is also shown by Table 66 on the composition of the total welfare effects of a cordon-toll for the inner city of Stuttgart.

Table 67 shows the potential revenues of the cordon-toll for the city of Stuttgart and compares them to the welfare effects. It becomes clear that the different scenarios for the cordon-toll for Stuttgart cannot be recommended from a welfare-economic perspective. This applies even if not taking into account the high costs of the introducing and operating the tolling system.

[336] Source: author's diagram.

Tolling Scenario	Change of Mileage in the City Area in %		Local Environmental Effects in Million EUR p. a.								
			Low Estimate			High Estimate			Medium Estimate		
	Cars	Trucks	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	-5.00	-1.20	+1.10	+0.14	+1.24	+4.40	+1.56	+5.96	+2.20	+0.38	+2.58
3 / 1.5 / 3	-6.05	-3.14	+1.33	+0.38	+1.71	+5.32	+4.09	+9.41	+2.66	+1.00	+3.66

Table 65: Evaluation of the Local Environmental Effects Due to Cordon Tolls in Stuttgart[337]

Tolling Scenario	Welfare Effects in Million EUR p. a.								
	Environmental Quality			Capacity Utilization			TOTAL		
	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	+4.4	+1.6	+6.0	-91.7	-18.8	-110.5	-87.3	-17.2	-104.5
3 / 1.5 / 3	+5.3	+4.1	+9.4	-96.8	-23.2	-120.0	-91.5	-19.1	-110.6

Table 66: Categorized Welfare Effects of Cordon Tolls in Stuttgart[338]

Tolling Scenario	Welfare Effects in Million EUR p. a.			Revenues in Million EUR p. a.		
	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	-87.3	-17.2	-104.5	105.4	6.9	112.3
3 / 1.5 / 3	-91.5	-19.1	-110.6	145.2	9.5	154.7

Table 67: Welfare Effects and Revenues of Cordon Tolls in Stuttgart[339]

4.4.2.2 Scenario 2: Distance-Based Tolls for the Entire City of Stuttgart

An area-wide, distance-based toll can modify the transport conditions in the metropolitan area of Stuttgart to much better effect than a cordon-toll can. Table 68 shows this for a tariff of 10 ct/vkm for private motorized vehicles and 30 ct/vkm for trucks. The reductions in car mileage are in the same range as in Berlin, i.e. 8.2-11.7%. The mileage of trucks is reduced disproportionately, given the 30 ct/vkm. Travel times are reduced for both demand elasticities, more markedly than travel volumes are; this indicates increasing average speeds. The latter increase by 1.1-3.1% in the entire model. Figure 42 shows the increase in average speeds in the network of Stuttgart, by region. Contrary to the effect in Berlin, the increase of average travel speeds in the city center of Stuttgart is lower than outside this area.

[337] Source: author's diagram.

[338] Source: author's diagram.

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
10 ct/vkm	-0.5	Cars	-1.35	-8.17	-11.97
30 ct/vkm	-0.5	Trucks	-0.94	-14.46	-17.50
10 ct/vkm	-1.5	Cars	-2.78	-11.69	-18.87
30 ct/vkm	-1.5	Trucks	-2.09	-18.24	-24.26

Table 68: Implications of a Distance-Based Toll of 10 ct/vkm in Stuttgart[340]

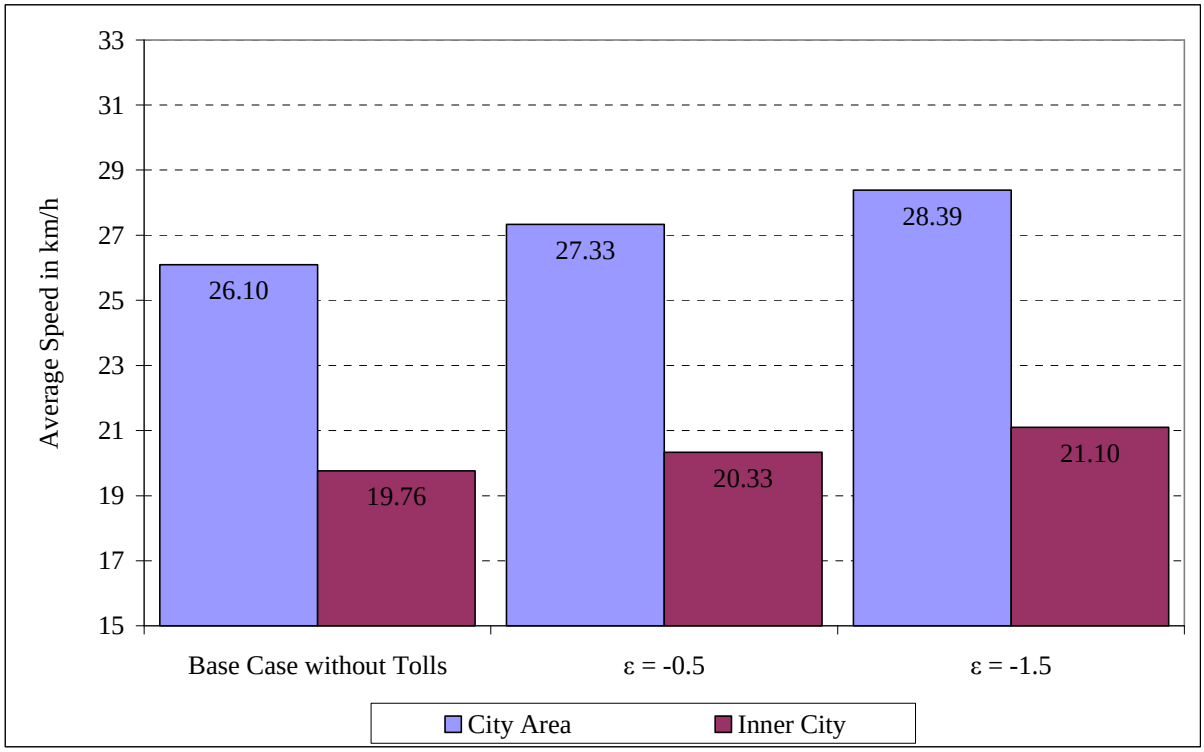

Figure 42: Changes in Average Speeds due to a Distance-Based Toll of 10 ct/vkm in Stuttgart[341]

Table 69 shows the effects of a higher tariff of 25 ct/vkm for private motorized vehicles. The reduction of travel volumes is about 18.0-27.5%, similar to the values in Berlin. Travel times are reduced disproportionately when compared to travel volume. This leads to an increase of average travel speeds by 1.6-6.7% for the entire model. Figure 43 shows that the average speed in the city of Stuttgart

[339] Source: author's diagram.

[340] Source: author's diagram.

[341] Source: author's diagram.

increases by 2.5-5.0 km/h in the case of a distance-based toll of 25 ct/vkm . In this case, too, the increase of average speed within the inner city of Stuttgart is smaller than outside.

Contrary to the case of Berlin the average trip lengths of the remaining trips decrease. Re-routing, e.g. on the federal highways (which are not tolled), seems to play a minor role. The average trip times for the entire metropolitan area are reduced, depending on the assumption of demand elasticity, by 1.2-1.6% (low elasticity) or 3.4-7.0% (high elasticity). This leads to lower net average costs for the remaining private trips on the network. Nonetheless in three of the four scenarios we observe welfare losses, due to the modified use of road capacities in the entire system (Table 70).

Tolling Scenario	Elasticity	Demand Segment	Change in %		
			Number of Trips (Metropolitan Area)	Mileage (City Area)	Travel Times (City Area)
25 ct/vkm	-0.5	Cars	-3.28	-18.02	-24.59
75 ct/vkm	-0.5	Trucks	-2.17	-31.55	-36.26
25 ct/vkm	-1.5	Cars	-7.46	-27.47	-39.16
75 ct/vkm	-1.5	Trucks	-5.45	-38.61	-47.37

Table 69: Implications of a Distance-Based Toll of 25 ct/vkm in Stuttgart[342]

[342] Source: author's diagram.

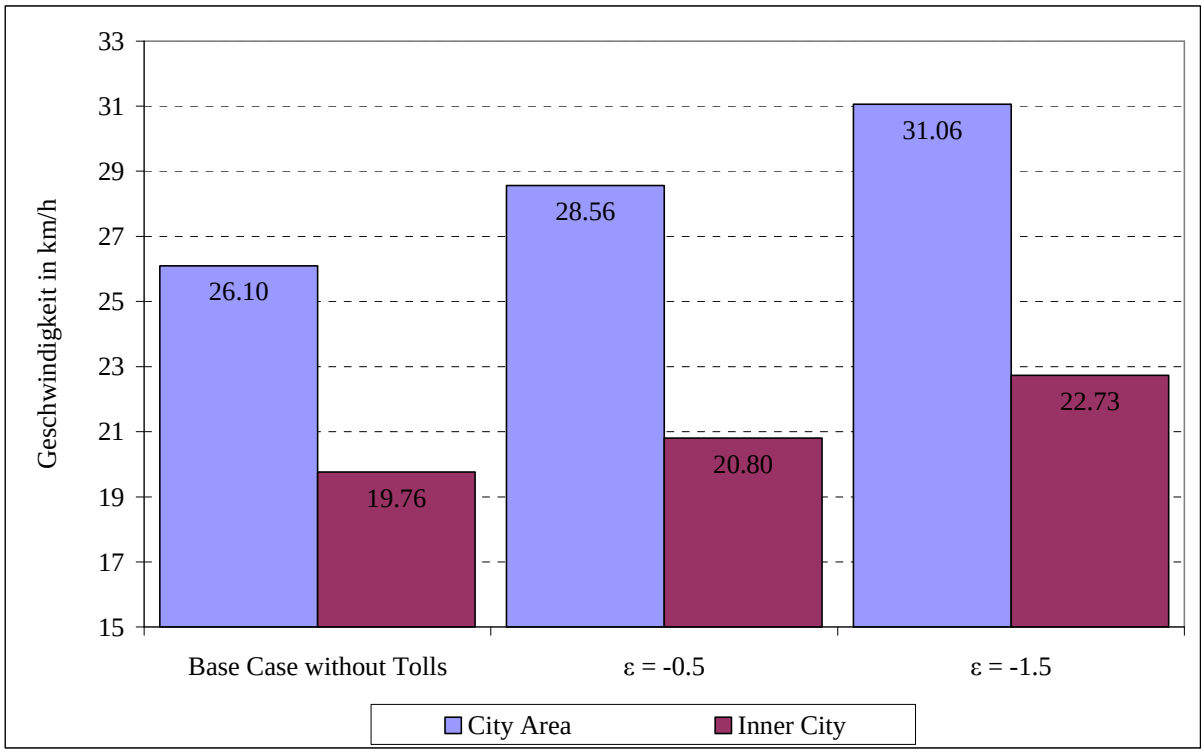

Figure 43: Changes in Average Speeds due to a Distance-Based Toll of 25 ct/vkm in Stuttgart[343]

1	2	3	4	5	6	7	8	9
Distance-based Tolls	**Elas-ticity**	**Change (in 1,000 EUR)**						
		User Cost Reduction before Tolls ./. after Tolls (excl. Taxes and Tolls)		**Social Surplus**		**Total Welfare Effect by Reduced Congestion**		
		Cars	**Trucks**	**Cars**	**Trucks**	**Cars**	**Trucks**	**Total**
10 ct/vkm	-0.5	+5,352	-7,069	-7,242	-967	-1,890	-8,035	-9,925
10 ct/vkm	-1.5	+39,056	+4,738	-10,534	-1,335	+28,520	+3,402	+31,922
25 ct/vkm	-0.5	-31,849	-25,207	-42,534	-4,991	-74,383	-30,198	-104,581
25 ct/vkm	-1.5	+24,695	+4,703	-68,187	-7,447	-43,493	-2,744	-46,237

Table 70: Welfare Effects of Changed Capacity Utilization due to a Distance-based Toll in Stuttgart (per annum)[344]

[343] Source: author's diagram.

[344] Source: author's diagram.

Hence, it seems that the positive cost development in the private demand segment is more than counterbalanced by welfare losses due to reduced social surplus in the case of the high toll, and assuming low demand elasticity. Only in one case we observe positive welfare effects, due to better capacity utilization: in the case of strong demand reaction and a moderate, i.e. low toll.

Just as in the cordon-toll scenario the net average costs of the cancelled trips (€ 5.34 - € 5.44) are significantly higher than the average costs before and after the introduction of the toll (€ 3.25- 3.44). This issue could not be totally clarified for the cordon-toll. In the case of the distance-related toll, we observe particular re-routing of commuters between subcenters of the metropolitan area that previously used a part of the tolled system of Stuttgart. It seems that a large share of trips is now suppressed due to the introduction of the toll that does not immediately lead to better traffic conditions in the periphery.

The travel volume in the city of Stuttgart was reduced so that the distance-related road pricing scenarios automatically lead to improved environmental effects, which are documented in Table 71. The disproportionate reduction of truck transport implies that this demand segment accounts for 2/3 of the reductions in negative environmental effects. Due to the specific geographical situation of Stuttgart in a basin with low air exchange the higher values for the monetarization seem to be appropriate. When we apply these values we obtain positive welfare effects of € 45.9 mn per year for the lower tariff, and € 1.1 mn per year for the higher distance-related tariff (Table 72).

Once again we have to acknowledge that this calculation does not include investment and operation costs for satellite-based distance-related road pricing systems. These costs are likely to be above the benefits in the medium term. However, distance-related road pricing solutions with moderate tariffs may be a suitable alternative for the manipulation of capacities in the road network of Stuttgart. Table 73 summarizes the welfare effects and the revenue potential of the different varieties of distance-based road pricing in Stuttgart.

Tolling Scenario	Change of Mileage in the City Area in %		Local Environmental Effects in Million EUR p. a.								
			Low Estimate			High Estimate			Medium Estimate		
	Cars	Trucks	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
10 ct/vkm	-9.93	-16.35	+2.81	+2.20	+5.01	+11.22	+23.67	+34.89	+5.61	+5.81	+11.42
25 ct/vkm	-22.75	-35.08	+6.43	+4.72	+11.15	+25.70	+50.77	+76.47	+12.85	+12.47	+25.32

Table 71: Evaluation of Local Environmental Effects due to Distance-Based Tolls in Stuttgart[345]

Tolling Scenario	Welfare Effects in Million EUR p. a.								
	Environmental Quality			Capacity Utilization			TOTAL		
	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
10 ct/vkm	+11.2	+23.7	+34.9	+13.3	-2.3	+11.0	+24.5	+21.4	+45.9
25 ct/vkm	+25.7	+50.8	+76.5	-58.9	-16.5	-75.4	-33.2	+34.3	+1.1

Table 72: Categorized Welfare Effects of Distance-Based Tolls Including Federal Highways in Stuttgart[346]

Tolling Scenario	Welfare Effects in Million EUR p. a.			Revenues in Million EUR p. a.		
	Cars	Trucks	Total	Cars	Trucks	Total
10 ct/vkm	+24.5	+21.4	+45.9	254.5	31.9	286.4
25 ct/vkm	-33.2	+34.3	+1.1	545.6	61.8	607.4

Table 73: Welfare Effects and Revenues of Distance-Based Tolls in Stuttgart[347]

4.4.3 Comparison of the Road-Pricing Scenarios for Stuttgart

Table 74 summarizes the total welfare effects caused by improved environmental quality and the modified capacity utilization for all road pricing scenarios for Stuttgart. We obtain strongly negative welfare effects for the relatively cheap cordon-toll system in the city center. On the other hand, the relatively expensive distance-related toll system can theoretically increase social welfare if the costs of toll infrastructure and operation are neglected. Taking these costs into account, none of the analyzed road pricing systems is suited for implementation in the near future.

[345] Source: author's diagram.

[346] Source: author's diagram.

[347] Source: author's diagram.

Tolling Scenario	Welfare Effects in Million EUR p. a.								
	Environmental Quality			Capacity Utilization			TOTAL		
	Cars	Trucks	Total	Cars	Trucks	Total	Cars	Trucks	Total
2 / 1 / 2	+4.4	+1.6	+6.0	-91.7	-18.8	-110.5	-87.3	-17.2	-104.5
3 / 1.5 / 3	+5.3	+4.1	+9.4	-96.8	-23.2	-120.0	-91.5	-19.1	-110.6
10 ct/vkm	+11.2	+23.7	+34.9	+13.3	-2.3	+11.0	+24.5	+21.4	+45.9
25 ct/vkm	+25.7	+50.8	+76.5	-58.9	-16.5	-75.4	-33.2	+34.3	+1.1

Table 74: Welfare Effects of the Analyzed Tolling Scenarios for Stuttgart[348]

4.5 Conclusions

Table 75 provides a comprehensive overview of the welfare effects and the revenues of all road pricing scenarios for Berlin and Stuttgart. We observed that in seven of the ten scenarios positive welfare effects are likely to occur, due to more efficient use of capacity and reduction of negative external environmental effects. All calculations neglect the cost of installing and operating the toll collection system; taking this into account would most likely lead to a net welfare loss.

- We find only slight or medium welfare effects in both agglomerations. This may be explained by the specific transport situation in the two agglomerations. The radial network of Berlin, which is better suited for a cordon-toll, has free road capacities available. The metropolitan area of Stuttgart, with its mesh network, has significant capacity constraints, which are difficult to target with a spatially-limited cordon-toll.

- Our analysis also suggests that federal highways within the city borders of Berlin should be included into tolling regimes in order to avoid deviations of trips via these highways. This would lead to higher positive welfare effects. Once again, the toll collection costs need to be considered.

- A third result is that the danger of welfare losses is lower the lower the toll tariffs are set; this is an argument in favor of low toll tariffs. On the other hand, the potential to raise revenue is of course lower, too. Policymakers are facing multiple objectives, i.e. raising revenue on the one hand, and capacity management and environmental objectives on the other hand.

[348] Source: author's diagram.

- Our main result at this point is that prior to introducing a road-pricing solution, the specific spatial simulations of different road pricing scenarios and their economic interpretation are necessary to account for the significant differences between local networks as to re-routing options and cost characteristics.

Tolling Scenario	Area	Welfare Effects in Million EUR p. a.				Revenues in Million EUR p. a.		
		Cars	Trucks	Common (Noise)	Total	Cars	Trucks	Total
2 / 1 / 2	Berlin	-0.2	+10.3	n.a.	+10.1	201.3	18.1	219.4
2 / 1 / 2	Stuttgart	-87.3	-17.2	*no data*	-99.5	105.4	6.9	112.3
3 / 1.5 / 3	Berlin	-9.5	+13.7	n.a.	+4.2	276.0	26.8	302.8
3 / 1.5 / 3	Stuttgart	-91.5	-19.1	*no data*	-110.6	145.2	9.5	154.7
10 ct/vkm (excl. highways)	Berlin	+13.8	-8.4	+11.6	+17.0	788.8	103.8	892.6
10 ct/vkm (incl. highways)	Berlin	+92.3	+38.9	+6.4	+137.6	896.1	168.6	1.064.7
10 ct/vkm	Stuttgart	+24.5	+21.4	*no data*	+45.9	254.5	31.9	286.4
25 ct/vkm (excl. highways)	Berlin	-267.5	-6.8	+17.4	-256.9	1.610.3	203.4	1.813.7
25 ct/vkm (incl. highways)	Berlin	-35.6	+90.6	+14.4	+69.4	1.850.9	352.8	2.203.7
25 ct/vkm	Stuttgart	-33.2	+34.3	*no data*	+1.1	545.6	61.8	607.4

Table 75: Welfare Effects and Revenues of the Analyzed Tolling Scenarios for Berlin and Stuttgart[349]

[349] Source: author's diagram.

5 The Implications of High Oil Prices for the Transport Sector – Conceptual Issues and Empirical Analysis for Germany

5.1 Introduction - Recent Developments

Since the end of the 1990's, the world crude oil prices have drastically risen, from around 20 USD per barrel[350] to up to 147 USD per barrel in July 2008. This development is shown for the period between January 2005 and September 2008 in Figure 44.

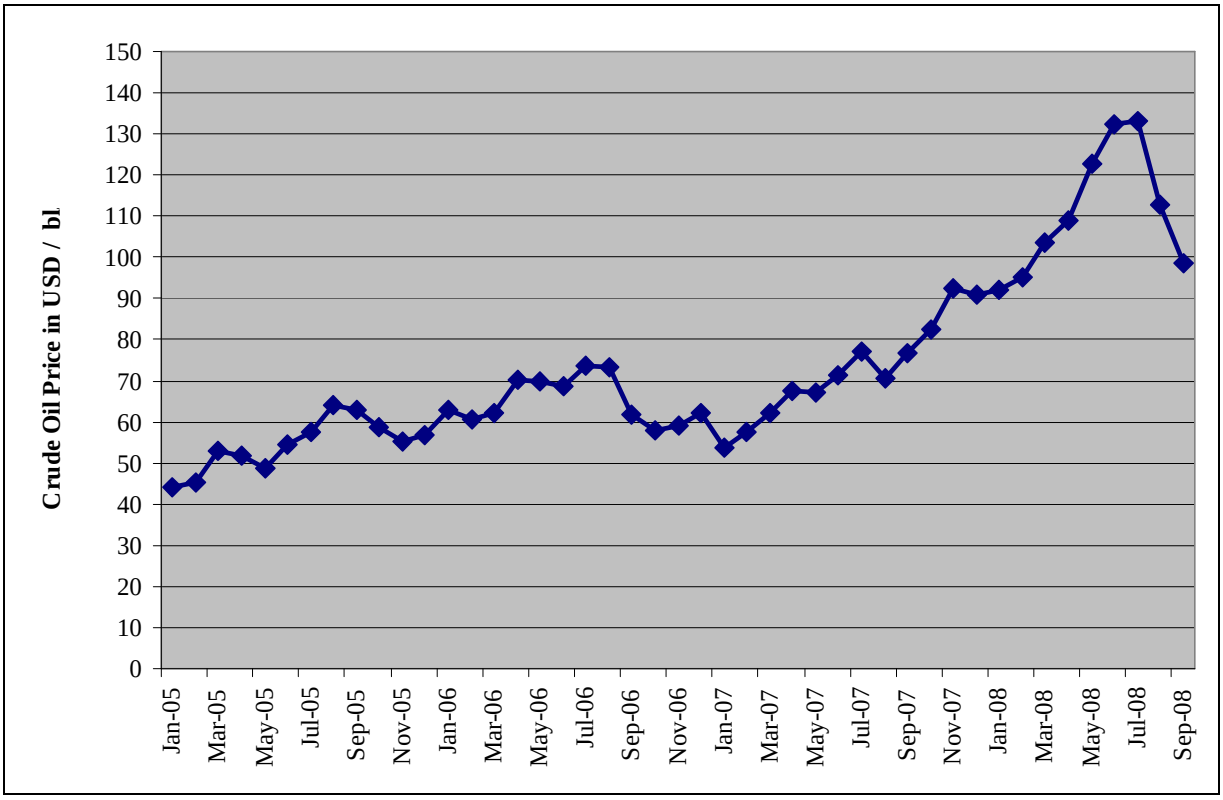

Figure 44: Recent Development of the Crude Oil Price (UK Brent)
January 2005 - September 2008[351]

Despite these rapid increases, until 2007 the inflation adjusted oil price was still lower than during the second oil crisis in 1980, as shown in Figure 45. But since then, world crude oil prices have risen further, financial analysts expecting a short-term price level of 200 USD per barrel,[352] and the current

[350] The world oil price is traditionally noted in US Dollars (USD) per barrel (=159 liter).

[351] Sources: Data from the Association of the German Petroleum Industry (MWV; http://www.mwv.de).

[352] Cf. SUBRAHMANIYAN (2008).

president of the OPEC,[353] Chakib Khelil, recently speculated about prices of up to 400 USD per barrel for worst case scenarios (e.g. a sudden stop of oil production in Iran in case of a war).[354] Even if the economies of the industrialized countries are now less oil dependent than they were in the past, the fear of an oil price induced global downturn is growing. As the transport sector is among the largest consumers of oil based products, it faces massive challenges if the oil price should rise further.

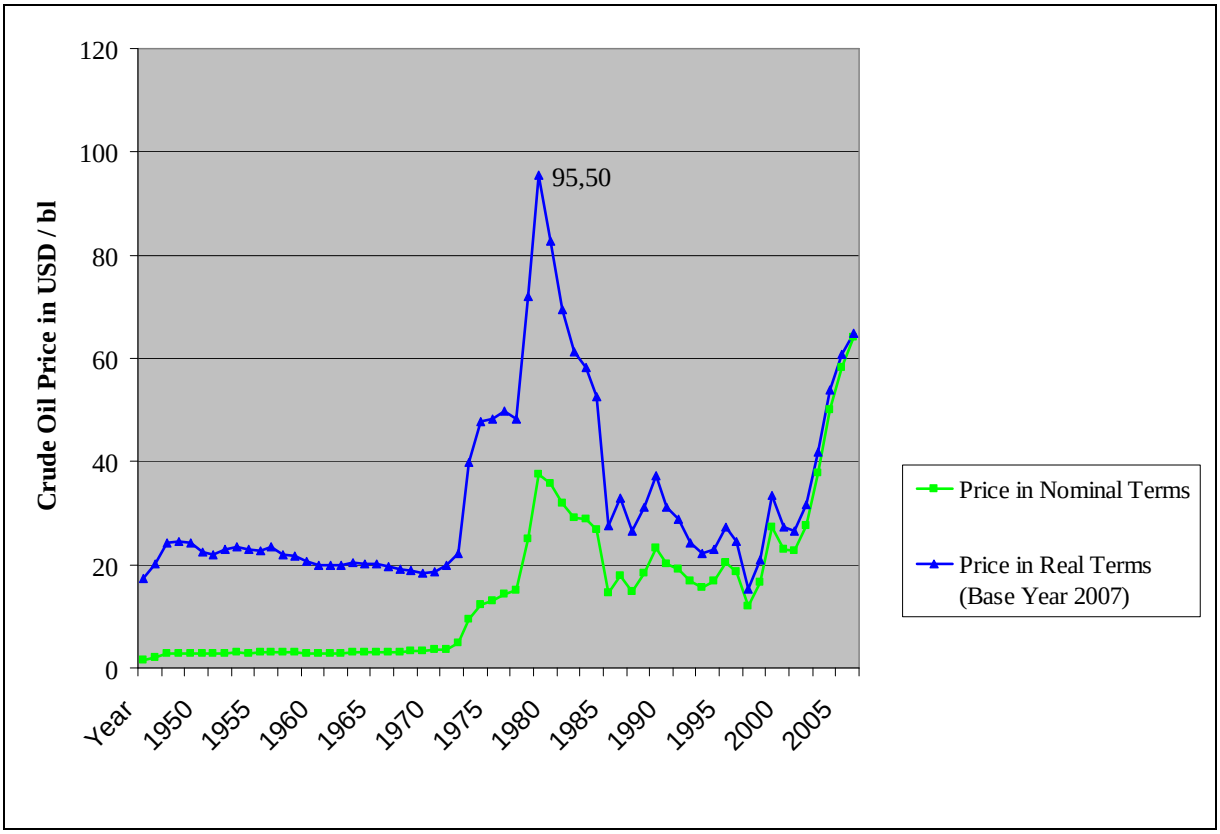

Figure 45: Long-term Development of the Crude Oil Price 1946-2007 - Inflation Adjusted[355]

In the light of these developments, we are going to analyze the most important features of the world oil market in the next section in order to understand the current price levels of oil and petroleum products. Later we are going to review empirical and model-based evidence concerning macroeconomic consequences of high oil prices for the economy, to analyze medium- and long-term options for substitution and adaptation processes of fuel supply and transport demand, and to estimate potential changes in German road transport and its CO_2 emissions for selected short-term oil price scenarios.

[353] OPEC = Organization of Petroleum Exporting Countries.

[354] Cf. DER SPIEGEL (2008).

[355] Source: http://www.inflationdata.com.

5.2 The World Crude Oil Market

5.2.1 Characteristics of Demand, Supply and Price Formation

The global oil market features some special characteristics regarding its underlying supply and demand structures. First we consider some economic fundamentals of the demand side. As the transport sector accounts for more than 50% of world oil consumption, and its share is expected to rise further,[356] we focus our analysis on the features of transport fuel demand. Then we analyze the supply side and the process of market price formation, which derives from the interaction of supply and demand. Here we focus on two decisive factors: The role of various risks on the supply side, which translate into risk premiums on market prices, and the aspect of expectations for and potential speculations at future markets. Both factors are supposed to have contributed to the recent increases and volatilities of the crude oil price.

5.2.1.1 Characteristics of the Demand Side

In most industrialized countries, the demand for fuel is stagnating (e.g. in the USA), or even slightly decreasing, as in Western Europe. These countries have high rates of car ownership near saturation levels and comparatively high pump prices, both due to high world market prices for oil products plus high petrol taxes. But a large share of today's incremental (i.e. additional) demand for liquid fuels comes from the developing world, namely China, which accounted for about 30% of incremental demand 2005-2006,[357] India, and other fast-rising Asian countries. One likely reason for the recent growth of fuel demand in these countries is the increasing living standard there, which is based on their positive economic development in recent years.

Another important reason for the increase of global demand are fuel subsidies in developing countries, especially in the Middle East and in Eastern Asia, which are designed to keep national inflation rates low. Between them, the countries that subsidize fuel account for half of the world's population, a quarter of the world's fuel use and for 100 % of current fuel demand growth.[358] When oil prices rose, for oil exporting countries these fuel subsidies were self-financing, but the national budgets of oil importing Eastern Asian Countries were heavily strained. According to THE ECONOMIST (2008d), the in Malaysia fuel subsidies amounted to 7% of the Gross Domestic Product (GDP) in 2007, in Indonesia to about 4% of GDP, in India between 2% and 3% of GDP, and in China to about 1% of GDP. Even though China recently increased the state-controlled petrol prices by 16-18%, at about

[356] Cf. EIA (2007, p. 30).

[357] Cf. EIA (2007, p. 22).

[358] Cf. HOYOS (2008).

0.85 USD per liter, the pump price remains far below the level in western countries, and new subsidies for public transport, grain farmers, taxi drivers and low-income groups have been announced,[359] which diminishes the incentives for efficient fuel use. Yet, the heavy financial burden on the national budgets will induce further reductions of fuel subsidies in developing countries. From a global perspective, this should contribute to a slower fuel demand growth in the future. However, in the short and medium term the world oil demand will remain quite inelastic to oil price changes, as fundamental adaptations of demand are costly and need time.[360]

5.2.1.2 Characteristics of the Supply Side

Due to technological and economic constraints, the supply side of the world oil market supposedly reacts very inelastically to oil price rises in the short-run, too. First of all, there are growing concerns about the total depletion of existing oil reserves and resources in the near future, the so called "peak oil thesis". The output of the largest mega-oil field explored, Ghawar in Saudi Arabia, which produces 5 million barrels per day, i.e. about 6% of the world oil supply,[361] seems to shrink, and the chances of finding similar new mega fields are rather low. In any case, the exploration and development of new oil fields to expand oil production involve very costly (and sunk) long-term investments. Only if oil prices are expected to stay high for the future, such investments will be made.

Moreover, OPEC, which accounts for about 40% of world's oil production, acts as a classic cartel.[362] Even if OPEC's impact on the oil market is weaker than it was in the 1970's, the organization is still trying to affect the oil price by regularly fixing the production quotas for its member states. Yet, in the short-run, Saudi-Arabia is the only member country capable of increasing oil production volumes significantly. Until recently, almost all other OPEC suppliers' production seems to have been close to their capacity limits, as Table 76 shows.

[359] Cf. DYER (2008).

[360] The respective options will be considered in section 5.4 (p. 162).

[361] Cf. THE ECONOMIST (2006).

[362] Of course the typical problems of quota systems in cartels apply to the OPEC, too. There are strong incentives for each cartel member to exceed their production quota while profiting from high prices due to the limited production of other cartel members.

Country	May 2008 Supply	Production Capacity	Spare Capacity
Saudi Arabia	9.20	10.65	1.45
Iran	3.87	4.02	0.15
UAE	2.66	2.85	0.19
Kuwait	2.63	2.63	0.00
Iraq	2.50	2.50	0.00
Venezuela	2.36	2.50	0.14
Nigeria	1.90	2.47	0.58
Angola	1.88	1.88	0.00
Libya	1.73	1.80	0.07
Algeria	1.38	1.40	0.02
Indonesia	0.86	0.86	0.00
Qatar	0.85	0.93	0.08
Ecuador	0.50	0.50	0.00
TOTAL	**32.30**	**34.97**	**2.67**

Table 76: Estimate of OPEC's Crude Oil Production Capacities and their Utilization (in Million Barrels per Day)[363]

Considering the demand conditions described in section 5.2.1.1, it seems more than questionable that a short-term expansion of oil production by using Saudi-Arabia's (assumed) spare capacities could cause a sustainable decrease of oil prices. Hence, we do not expect a decline of the oil price to the levels of the 1980's and 1990's, as the fundamental market conditions have changed.

If a growing, price-insensitive fuel demand meets a short-term inelastic oil (respective fuel) supply, sharply rising prices, as observed in the past, are almost inevitable. In principle, price increases are reasonable from an economic point of view, as long as price changes reflect the increased economic scarcity of a resource. But, in addition to the high levels they reached, the prices for oil and fuels have also been extremely volatile in recent years. These price volatilities may hamper economically useful adaptations to changing price levels on both sides of the markets, as they may induce wrong investment decisions. Hence in the next section we are going to explore some further factors which may contribute to the current high price volatility in the oil market.

5.2.1.3 The Role of Risks, Expectations and Speculation in Oil Markets

The key factor for a high oil price volatility is the uncertainty of market participants about the future security of oil supply. Supposedly, most oil reserves are located in politically unstable regions, such as the Middle East, Nigeria or Venezuela. This results in high risks of disrupting existing oil production and makes for difficult exploration conditions. Moreover, in oil exporting countries with autocratic

[363] Source: IEA (2008).

regimes (e.g. Venezuela or Russia) there is a permanent threat of dispossession for the technically well-equipped and -skilled Western oil companies, which increases their exploration risks and, of course, costs. All in all, due to the dominance of state-owned oil companies, information about the real supply conditions and oil reserve levels is very poor. So short-term estimates of the available Middle Eastern crude oil rely on the loaded droughts of oil tankers in the Strait of Hormuz (!) and shiploads of oil are sold directly to demand, bypassing the regular oil markets/exchanges.[364] In addition, nobody knows whether the official reserve levels of state owned oil producers (e.g. in the Middle East region or Venezuela) are overstated for strategical reasons. As in the past the national production quotas within the OPEC cartel partially depended on these reserve levels,[365] there existed considerable incentives for each OPEC member to overstate their own oil reserves in order to get a larger market share. This assumption is supported by the sudden increase of OPEC oil reserves by 80% during the 1980's.[366]

This lack of information and transparency as well as considerable political risks lead to high uncertainties about the future oil supply security. A rise of these uncertainties directly translates into higher ***risk premiums*** for market participants and a higher volatility of oil prices.

The growing role of these uncertainties is possibly intensified by short-term speculation on rising oil prices by financial investors which may result in an oil price "bubble". Some market observers, like the US economist Paul Krugman,[367] undisclosed authors of *The Economist*,[368] and the International Energy Agency (IEA) disagree. They argue that financial investors only own contracts for the future delivery of oil ("paper barrels"), which - in the absence of increased storage - will be sold at market prices to real demand as soon as the contracts are due. So there was no reduction of the physical oil supply, and hence higher market prices only reflected market participants' expectations of future prices. This seems plausible, but the question remains whether these expectations reflect ***future*** physical market conditions appropriately.

Firstly, it seems to be ***uncertain*** whether there was a ***temporary increase of world physical oil storage*** until July 2008, as there are reliable estimations for Western countries only. Especially China could have increased their short-term fuel storage, e.g. in order to avoid shortages during the 2008Olympics , and to run some power plants on diesel rather than coal for cleaner air, as suggested by the THE

[364] Cf. HERMANN (2008).

[365] Cf. SANDREA (2003, p. 4).

[366] Cf. ibd.

[367] Cf. KRUGMAN (2008).

[368] Cf. e.g. THE ECONOMIST (2008c).

ECONOMIST (2008c).[369] Such hidden temporary increases of physical demand could have contributed to the fast rise of oil prices until July 2008, but then, they should affect prices only temporarily as well.

Secondly, if commonly available information about current market conditions is poor, ***herding effects*** on financial investors may take place. A rise of crude oil prices, e.g. caused by a stronger physical demand, may be taken by the market as an indicator of better information on the part of insiders. This in turn could stimulate further investment in crude oil (directly and indirectly, via oil extraction/exploring/processing companies), and could lead to an upward spiral of the oil price. Especially investment bankers consider speculation on future markets a relevant factor in oil price formation.[370]

Thirdly, while trying to diversify their portfolios, financial investors increasingly bought ***oil investments as hedge against*** a further ***falling US Dollar*** as well as a against a ***tumbling stock market***, since in the medium-term past both had correlated with the oil price in a strongly negative way . Figure 46 illustrates this relation between the US Dollar and the crude oil price. This diversification strategy may particularly apply to large institutional investors with permanent payment obligations and a relatively high risk aversion, like US pensions funds. Their rational behavior may also induce an additional, short-term upward pressure in the oil price.

Of course the last two arguments are apply to quick, severe price declines, too. The recent fall of the oil price by about 30% between July and September 2008 can hardly be explained solely by changing market fundamentals, and seems to support the amplifying influence of financial investors on oil price movements that may have been caused by changing physical demand and supply conditions in the first place.

[369] Cf. THE ECONOMIST (2008c).

[370] Cf. e.g. THE ECONOMIST (2008c).

Figure 46: Short-term Development of the US Dollar:Euro Exchange Rate and the Crude Oil Price (WTI, in USD)[371]

Tyler Cowen, an economist from George Mason University, trenchantly summarized the result of the academic debate on the impact of speculation on the oil price as follows: ***"The bottom line is that when it comes to the key substantive questions about the oil market - why are prices so high - the correct answer is … : "expectations." If you push one step further on that, and try to evaluate or "source" those expectations, the correct answer is "we don't know.""***[372]

All in all, we see the price formation in oil markets as a mixture of physical demand or supply characteristics, respectively, and speculative (not necessarily negative) investment behavior. Both factors combine to militate for high and volatile oil prices in the medium-term future.

5.2.2 General Outlook on the Future of the Crude Oil Price

Even if the sharp rise in global demand seems to justify substantially higher market prices than during the 1990's, the world oil demand is not independent of price levels. Adaptation and substitution processes of oil demand and supply must be expected in the medium and long term, which complies with the economic function of prices as scarcity indicators. These adaptation and substitution effects

[371] Left scale: oil price (marked dark blue), right scale: exchange rate (marked light blue). Source: http://www.faz.net, based on data provided by Bloomberg.

strongly militate against the sustainability of current oil price levels. So a recent study by oil analyst Arjun N. Murti of Goldman-Sachs predicts a crude oil price of between 150 and 200 USD per barrel for the next 6-24 month, a so-called super spike. But, according to this study, this price level would induce a strong reduction of world oil demand, which in turn should cause a drop of the oil price to about 110-120 USD in 2011.[373]

Strong supply side reactions to high oil prices are suggested by a study of ECOPLAN ET AL. (2007). In their comprehensive model of the world energy market, only the reduction of (binding) capacity restrictions for the production of methanol and ethanol by 75%, compared to the business as usual (BAU) scenario, permitted the simulation of the impact of world oil prices of 80 and 100 USD. For simulation runs yielding an oil price of 140 USD even all possibilities to switch to alternative liquid fuels had to be prohibited exogenously. Hence, the authors conclude that crude oil prices above 100 USD are possible in the short term, but this price level is unlikely to persist.[374]

Recently, the cabinet of Saudi-Arabia, the only OPEC-member capable of increasing short-term oil supply significantly (the so-called “swing capacity”), called an oil price level of 135 USD “unjustifiable in terms of petroleum facts and market fundamentals”, and called for an urgency meeting of oil producing and consuming countries.[375] On the one hand, such official statements could be a reaction to political pressure from oil importing countries, i.e. the USA, to increase short-term oil supply. On the other hand, oil producing countries will be well aware of the medium-term substitution potentials for crude oil, which would be activated by the current oil prices, and hence weaken future market positions of the OPEC. Therefore, the announced efforts of Saudi-Arabia to curb the current oil price seem to be in the oil exporting countries' own best interest.

[372] Cf. http://www.economist.com/blogs/freeexchange/2008/06/a_speculative_bubble.cfm.

[373] Cf. SUBRAHMANIYAN (2008).

[374] Cf. ECOPLAN ET AL. (2007, p. 67f.).

[375] Cf. SUBRAHMANIYAN (2008).

5.2.3 Selected Long-Term Oil Price Forecasts

Table 77 shows selected forecasts for the crude oil price in real terms for the time horizon up to 2030.

Source	Title	Scenario	Price Base (Year)	2010	2015	2020	2025	2030
EWI / Prognos (2005)	Energy Report IV	Reference	2000	28	30	32	34	37
EWI / Prognos (2006)	Oil Price Variant of the Reference Forecast		2000	50		47		60
HWWI / Berenberg Bank (2005)		Reference	2004	42		49		62
EC (2006)	World Energy Technology Outlook 2050 – WETO H_2	Reference	2005	40		55		68
EC (2006)	World Energy Technology Outlook 2050 – WETO H_2	Carbon Constraint Case	2005	40		50		60
EIA (2007)	International Energy Outlook	Reference	2005	58	50	52	56	59
EIA (2007)	International Energy Outlook	Low Oil Prices	2005	49	34	34	35	36
EIA (2007)	International Energy Outlook	High Oil Prices	2005	69	80	89	94	100
EC (2007)	European Energy and Transport – Trends to 2030 (Update 2007)	Reference	2005	55	58	61	62	63
IEA (2007)	World Energy Outlook		2006		60	61	61	62
EIA (2008)	Annual Energy Outlook	Reference	2006	65		52		59
EIA (2008)	Annual Energy Outlook	Low Oil Prices	2006	63		33		35
EIA (2008)	Annual Energy Outlook	High Oil Prices	2006	69		88		96

Table 77: Selected Long-term Forecasts of the Crude Oil Price[376]

As a comparison between e.g. EWI / PROGNOS (2005) and EWI / PROGNOS (2006) shows, more recent analyzes predict higher oil prices than former studies. Clearly, this can be interpreted as a reaction to the unexpected rises of world oil prices during the last few years. Nevertheless, all forecasts presented in Table 77 predict or assume considerably lower oil prices (in real terms) for the future than their present level.

[376] Cf. the cited sources.

5.3 Implications of High and Volatile Oil Prices for the Economy – Some Aspects from Research Literature

5.3.1 Empirical Evidence for the Impact on Macroeconomic Indicators (GDP/Output/Growth)

There are several mechanisms by which rising energy prices may negatively affect the output, the economic growth of an economy and other macroeconomic indicators. However, as BROWN / YÜCEL (2001) note: "Because the precise channels through which oil price shocks affect economic activity are only partially known … research offers less guidance about how energy policy should cope with oil price shocks."[377] Nevertheless, we describe the most important of these impact-pathways, and present some estimates from macroeconomic literature regarding the possible magnitude of these effects. Taking into account the limited knowledge about causal relationships and the pace of political processes, beside the magnitude of negative macroeconomic effects, their duration and persistence seems to be of outstanding relevance. In general, the existing macroeconomic literature focuses on short- and medium-term reactions of rapidly rising oil prices (so-called price shocks), as the market system is assumed to be able to adapt to the new conditions in the long run.

The basic mechanism of rapidly rising energy costs is a supply shock: Rising oil prices signal the increased scarcity of energy as a basic input to production which cannot be substituted easily in the short-term. Consequently, the growth of output and productivity are slowed down. The decline in productivity growth lessens real wage growth and increases the unemployment rate following which inflation accelerates.[378]

In an extensive survey of empirical literature, JONES / LEIBY (1996) find that the estimated oil price elasticity of the Gross Domestic Product (GDP) ranged from -0.02 to -0.08 in the early studies, with estimates consistently clustered around -0.05,[379] i.e. a 10% rise in oil prices would diminish the GDP by 0.5%. However, these elasticities mostly refer to the 1970's and 1980's, when oil's share in global GDP – up to 5.9% in 1980 – was considerably higher than today (about 3.5%).[380] So it is reasonable to assume the magnitude of negative effects to be smaller by now. More recent studies confirm this expectation: The German COUNCIL OF ECONOMIC EXPERTS (2007) estimates that a 10% rise of the real oil price (in EUR) reduces the **growth rate** of the German GDP by about 0.1 per cent for the

[377] Cf. BROWN / YÜCEL (2001, p. 193).

[378] Cf. BROWN / YÜCEL (2001, p. 196).

[379] Cited in BROWN / YÜCEL (2001, pp. 194 f.).

[380] Cf. THE ECONOMIST (2008a).

three years following the price shock, and increases the inflation rate by about the same percentage.[381] If one assumes a pre-shock GDP growth rate of 1.8%, this 10% price rise translates into a GDP reduction of about 0.3% in absolute terms after three years. This is in line with calculations of JIMENEZ-RODRIGUEZ / SANCHEZ (2004). They find that the output loss resulting from a 100% oil price increase is around 3.5% to 5% for the USA, between about 2% and 5% for individual European countries in the Euro zone, and up to 2% for the Euro area as a whole, depending on different model specifications.[382] From these results of present research we can conclude there are considerable negative macroeconomic effects of sharp oil price rises in the short and medium term, but public fear of oil price induced economic breakdowns seems to be largely exaggerated.

One interesting long-term feature of the relationship between oil prices and economic activity became apparent during the 1980's and 1990's: Economic activity responded **asymmetrically** to oil price shocks. That is, rising oil prices seemed to retard aggregate economic activity by more than falling oil prices stimulated it.[383] Most likely, adjustment costs are responsible for this asymmetry.[384] If production capacities, heating systems, power stations and other long-lasting immobile equipment is replaced or adjusted in times of high oil prices, these investments are largely sunk. Hence they will be used longer even when subsequent oil price decreases would justify more energy-intense production methods and consumption behavior. This asymmetry may also help to explain why the power generation sector largely substituted oil as an energy source after the oil price shocks of the 1970's and 1980's, and didn't reverse to it in the low oil price era of the 1990's. If the recent oil price increases have an analogous effect on transport, i.e. currently the most heavily oil dependent sector, this could greatly contribute to existing climate change goals. In the long-term it even seems possible that these positive effects of higher oil prices outweigh the negative short- and medium-term effects on macroeconomic growth. The potential for such substitution and adaptation processes in the transport sector as well as the necessary adjustments of its policy framework will be analyzed in section 5.4. below. In the following sections we are going to summarize and discuss main insights of three studies dealing with the consequences of high oil prices on Germany and Switzerland.

[381] In addition the council notes that these values should be considered as the upper limit. Cf. COUNCIL OF ECONOMIC EXPERTS (2007, p. 85).

[382] JIMENEZ-RODRIGUEZ / SANCHEZ (2004, p. 2).

[383] BROWN / YÜCEL (2001, pp. 9 f.).

[384] BROWN / YÜCEL (2004, p. 10) also analyze alternative explanations for the asymmetry, e.g. income transfers from oil-importing nations to oil-exporting nations, a real balance effect and monetary policy.

5.3.2 Effects on Household Incomes – BERGS / GLASMACHER / THÖNE (2007)

The study by BERGS / GLASMACHER / THÖNE (2007) analyzes the effects of different high oil price scenarios on household incomes in the German federal state of North Rhine-Westphalia. They consider the expenditures for energy and fuels of 10 income groups. The relevant calculations are based on price and income elasticities. An exogenous rate for the annual economic growth of 1.5% p.a. is used. The largest price increase occurs in a scenario with prices rising linearly from 70 USD/bl. (2006) to 130 USD/bl. in 2030 (in real terms).

Despite this large price increase the study predicts comparatively small permanent effects of rising fuel costs on disposable household incomes in this scenario. Medium income groups are affected strongest, as shown in Figure 47. In the scenario the share of fuel consumption in their disposable household income rises from 3.7% in 2006 to 4.8% in 2010.

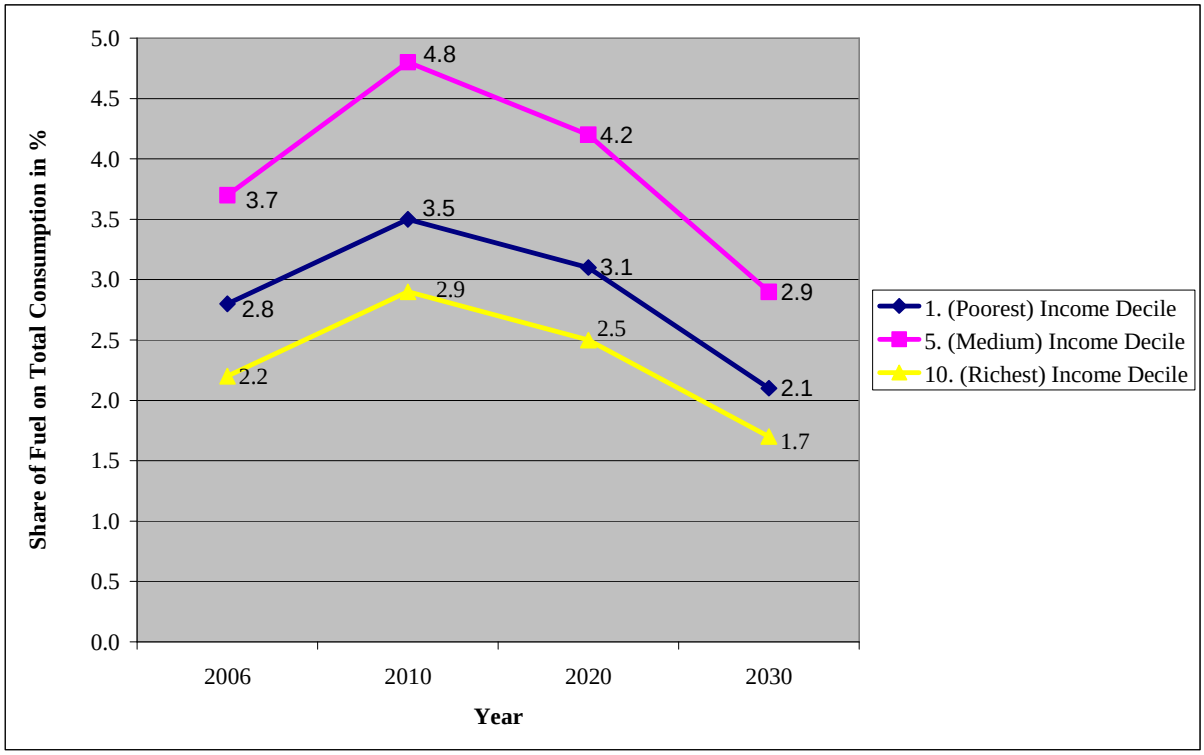

Figure 47: Effects of Scenario "Linear Increase of Oil Prices to 130 USD/bl. in 2030" on Disposable Household Incomes[385]

But, as Figure 47 also indicates, the influence of increased oil prices will be more than outweighed in the long run by rising incomes for all income groups. This is a direct result of the constant rate of

economic growth assumed in the calculations, which translates into higher disposable incomes. This assumption is questionable, because rising oil prices will decrease economic growth and increase inflation rates, as the macroeconomic literature presented in section 5.3.1 suggests. But as the oil price rises quite slowly and steadily in the scenario, oil price shocks with their harmful consequences for the economy are per se excluded from the analysis, and economic growth due to technological innovation should counterbalance inflation and negative growth effects of rising oil prices in the long run, indeed. Hence we consider the results of the study by BERGS / GLASMACHER / THÖNE (2007) to be too optimistic, but pointing in the right direction. If rising oil prices do not hamper innovation and technological change permanently, these factors may have a larger impact on the disposable incomes of households than a single input price, at least in the long run.

5.3.3 Macroeconomic and Sectoral Effects in Germany – EWI / PROGNOS (2006)

Commissioned by the German Federal Ministry of Economics and Technology, EWI / PROGNOS (2006) analyze the impacts of a scenario featuring higher future oil prices on the German economy. Parts of the study consist of comparisons with a previous study for the ministry, EWI / PROGNOS (2005), which were based on lower oil prices, the "reference case".

In EWI / PROGNOS (2006) crude oil prices are assumed to rise from 44 USD/bl in the year 2015 to 60 USD/bl. in 2030 (in real terms for the year 2000),[386] while EWI / PROGNOS (2005) was based on oil prices of 37 USD/bl. in 2030.[387] As a result of higher oil prices a slower growth rate of +1.3 % p.a. for the German GDP is expected, instead of +1.4 % p.a. in EWI/PROGNOS (2005). This result cumulated in a 50.3 % economic growth for the period between 2000 and 2030, compared to +54.0 % in the reference scenario.

For the road transport sector EWI / PROGNOS (2006) assume some additional, (presumably) exogenous parameters. So the specific fuel consumption is expected to decrease by 1/4 for heavy duty vehicles and by 1/3 for cars; the demographic decline is assumed to induce reductions of passenger transport performance, despite rising per capita incomes; freight transport will continue to grow with the further increase of the international division of labor; and there will be extensive admixture obligations and tax exemptions for biofuels. Table 78 summarizes the main results of EWI / PROGNOS (2006) for the road transport sector and compares them with the reference case of EWI / PROGNOS (2005). Unsurprisingly, higher oil prices induce slower growth of freight transport

[385] Source: BERGS / GLASMACHER / THÖNE (2007).

[386] This is equivalent to 100 USD/bl. in nominal terms, Cf. EWI / PROGNOS (2006, p. 13).

[387] Cf. Table 77: Selected Long-term Forecasts of the Crude Oil Price and EWI / PROGNOS (2005).

performance in the road transport sector, a stronger decline of passenger transport performance, and higher shares of biofuels and alternative propulsion technologies.

Parameter	**Reference Scenario, EWI/PROGNOS (2005)**	**High Oil Price Scenario, EWI/ PROGNOS (2006)**
Passenger Transport Performance	-9%	-12%
Passenger Transport Mileage	-1%	-7%
Freight Transport Performance	+58%	+53%
Freight Transport Mileage	+42%	+39%
Petrol Consumption (Mineral Oil based, in Peta Joule)	-63%	-74%
Diesel Consumption (Mineral Oil based, in Peta Joule)	+13%	-11%
Market Share of Biofuels in 2030	9%	25%
Market Share of Diesel Cars in 2030	57%	52%
Market Share of Petrol Cars in 2030	37%	38%
Market Share of Alternative Propulsion Technologies in 2030	6%	10%

Table 78: Central Results of EWI / PROGNOS (2005) and EWI / PROGNOS (2006) for the Road Transport Sector (2002-2030)

Table 79 compares the development of freight and passenger transport performance for transport modes other than road for both scenarios. The less oil-dependent modes rail and inland waterways gain in absolute terms and market shares, while the strong growth of air transport is only slightly diminished by higher oil prices.

Parameter	Reference Scenario, EWI/PROGNOS (2005)	High Oil Price Scenario, EWI/ PROGNOS (2006)
Passenger Transport Performance Short-Distance Rail	+15%	+33%
Passenger Transport Performance Long-Distance Rail	+23%	+33%
Passenger Transport Performance Aviation	+65%	+60%
Freight Transport Performance Rail	+77%	+76%
Freight Transport Performance Inland Waterways	+38%	+49%
Freight Transport Performance Aviation	+179%	+172%

Table 79: Central Results of EWI / PROGNOS (2005) and EWI/PROGNOS (2006) for other Transport Modes (2002-2030)

As Figure 48 shows, according to EWI / PROGNOS (2006) the overall passenger transport performance in the high oil price scenario is only slightly lower than in the reference case.

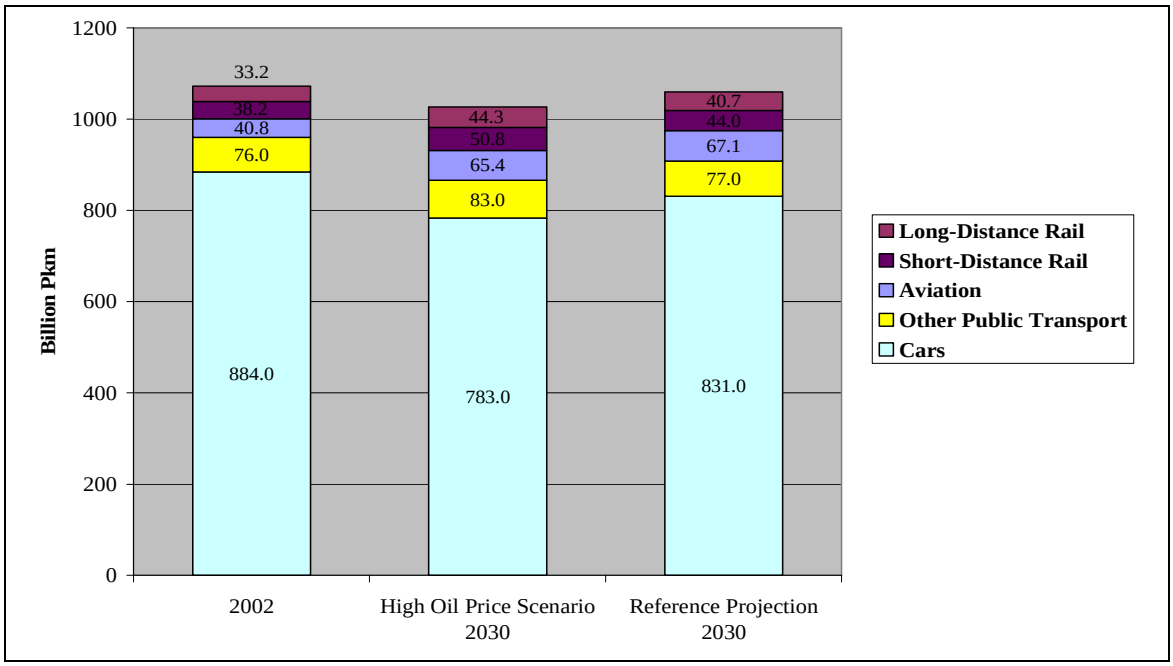

Figure 48: Transport Performance and Modal Split according to Scenarios of EWI / PROGNOS (2006)[388]

[388] Cf. EWI / PROGNOS (2006, p. 72).

Figure 49 indicates the estimated changes of Germany's sectoral CO_2 emissions for both the reference case of EWI / PROGNOS (2005) and the high oil price scenario of EWI / PROGNOS (2006). Compared with the base year 2002, for both scenarios slightly lower CO_2 emissions are predicted, but on a similar scale. According to EWI / PROGNOS (2006), the reduced CO_2 emissions from the transport sector are more than outweighed by higher emissions from power generation, if compared to the reference projection. This seems rather questionable, as in the European Emissions Trading System (ETS) the absolute CO_2 emission levels from energy production and other industry sectors should be – at least at the European level – controllable, which should entail lower overall CO_2 emissions in the case of high oil prices. A possible explanation could be that EWI / PROGNOS (2006) implicitly assumes that the German power generation and industry sectors will be net-buyers of CO_2 certificates within the EU ETS, and thus will be permitted to emit more CO_2 than their European counterparts, which act as net-sellers then.

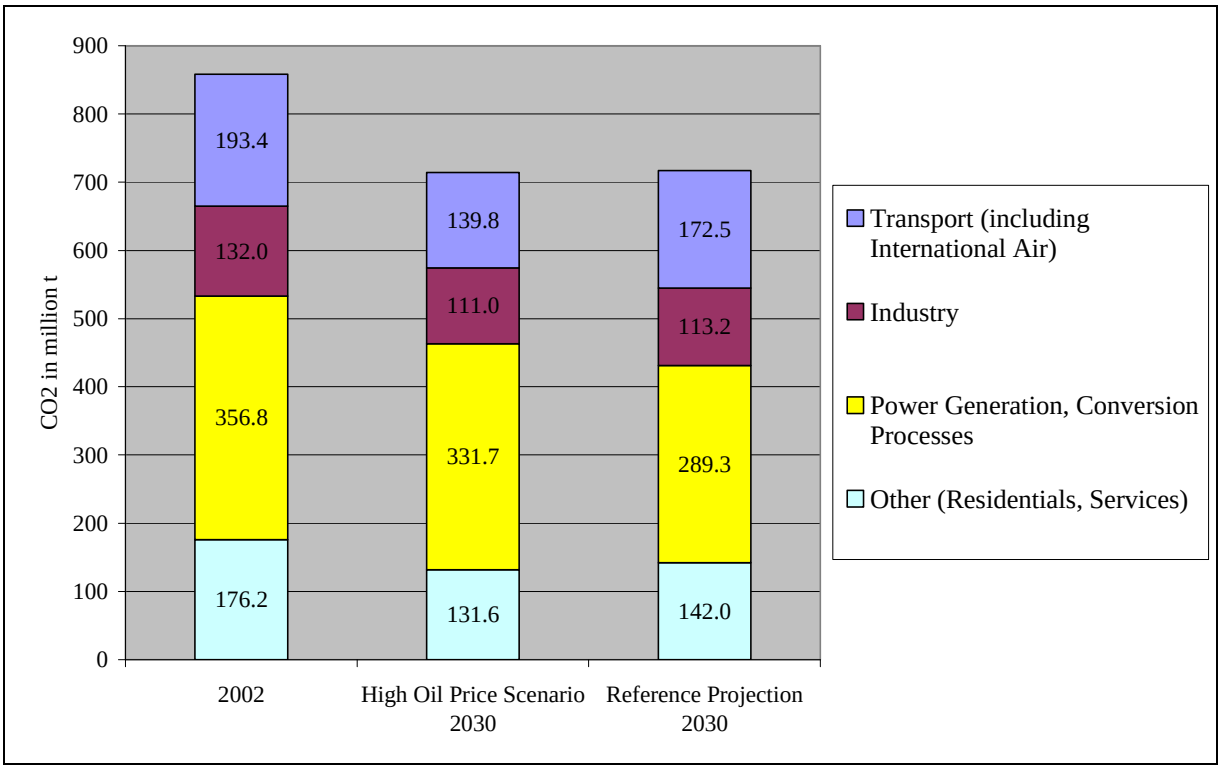

Figure 49: Prediction of Germany's Sectoral CO_2 Emissions in the Scenarios of EWI / PROGNOS (2006)[389]

A further, more general critique of both studies EWI / PROGNOS (2005) and EWI / PROGNOS (2006) is that, despite revealed basic assumptions and a lot of numerical results, the methodology used

[389] Cf. EWI / PROGNOS (2006, p. 132).

for the estimations is not always clear and replicable. That makes a final appraisal of their results difficult, even if they are broadly in line with our expectations.

5.3.4 Macroeconomic and Sectoral Effects in Switzerland - ECOPLAN ET AL. (2007)

Commissioned by the Swiss Federal Office of Energy, the study of ECOPLAN ET AL. (2007) analyzes long-term effects of high oil price scenarios on GDP, sectoral output and other economic indicators in Switzerland between 2005 and 2035. They use an approach based on the dynamic computable equilibrium model MultiSWISSEnergy, which differentiates between six regions (Switzerland, EU, USA, other developed countries, OPEC; other developing countries) and 12 economic sub-sectors (five energy related, seven non-energy related sectors).

Besides a reference scenario, ECOPLAN ET AL. (2007) calculate the impacts of three scenarios assuming exogenously set oil prices and two different peak oil scenarios which are based on an exogenously set oil supply, peaking in 2010 and 2020 respectively. Moreover, two different pathways for technological development were assumed: “forced renewable” and “conventional energy sources”. Since most of the results are similar for both pathways, we concentrate on the more conservative technological pathway “conventional energy sources”. Figure 50 shows the resulting oil prices for the different scenarios between 2000 and 2035.

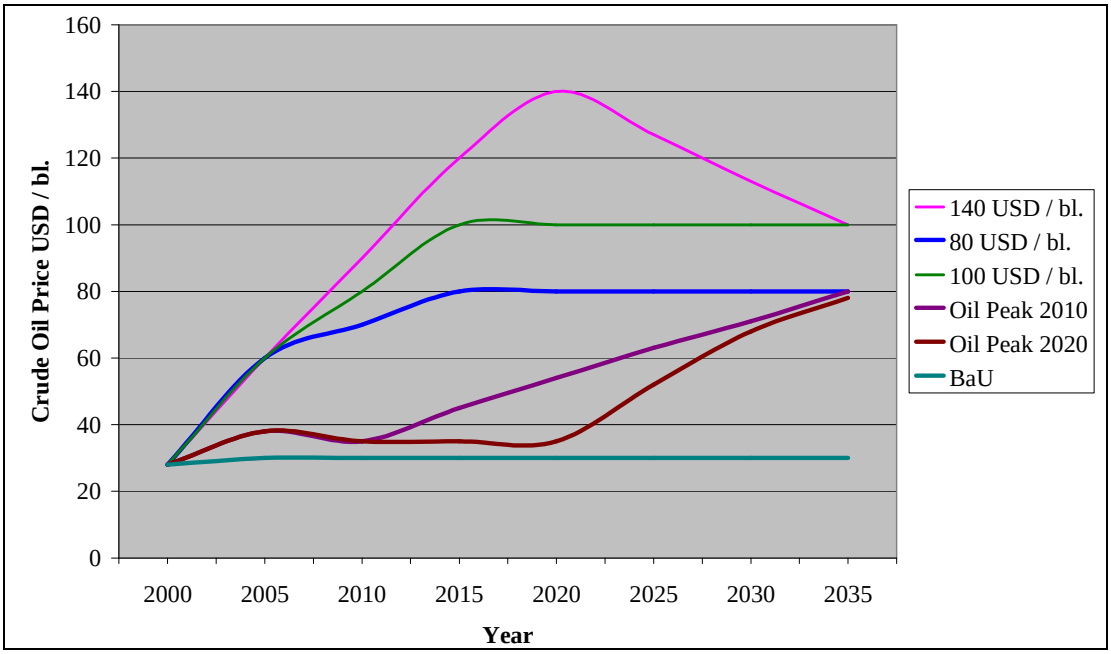

Figure 50: Crude Oil Price Scenarios of ECOPLAN ET AL. (2007)[390]

[390] ECOPLAN ET AL. (2007, p. 16).

As already mentioned, the model-based computation of the impact of these high crude oil prices are only possible on very pessimistic technological assumptions. In order to simulate oil prices of 80 and 100 USD respectively, binding capacity restrictions for the production of methanol/ethanol from alternative fossil sources (e.g. coal) of -75%, compared to the business as usual (BAU) scenario, had to be implemented

For simulation runs yielding an oil price of 140 USD even all possibilities to switch to alternative liquid fuels had to be prohibited exogenously. ECOPLAN ET AL. (2007) conclude that crude oil prices above 100 USD are possible in the short term, but this price level is unlikely to persist. At this price level various alternatives to oil should be competitive. In this context the authors explicitly mention the production of ethanol or methanol from alternative fossil sources, power generation from non-fossil sources as well as comparatively cheap improvements of the efficiency of energy use.[391]

Similar to EWI / PROGNOS (2006), ECOPLAN ET AL. (2007) predicts a loss in economic growth of up to 5.2% in Switzerland for high oil price scenarios by 2035, compared to the low oil price BaU Scenario. Nevertheless, according to their model calculations, the immediate economic consequences of higher oil prices would not be devastating, as the Swiss GDP is still expected to rise by about 60 % by 2035. In analogy to the computations of BERGS / GLASMACHER / THÖNE (2007) and EWI / PROGNOS (2006), this is caused by – essentially model-exogenous – innovation processes and technological changes. While the consequences for the whole economy of Switzerland seem to be limited, the impacts of higher oil prices result in considerable sectoral adaptations, as Figure 51 demonstrates for selected scenarios.

[391] Cf. ECOPLAN ET AL. (2007, pp. 67 f.).

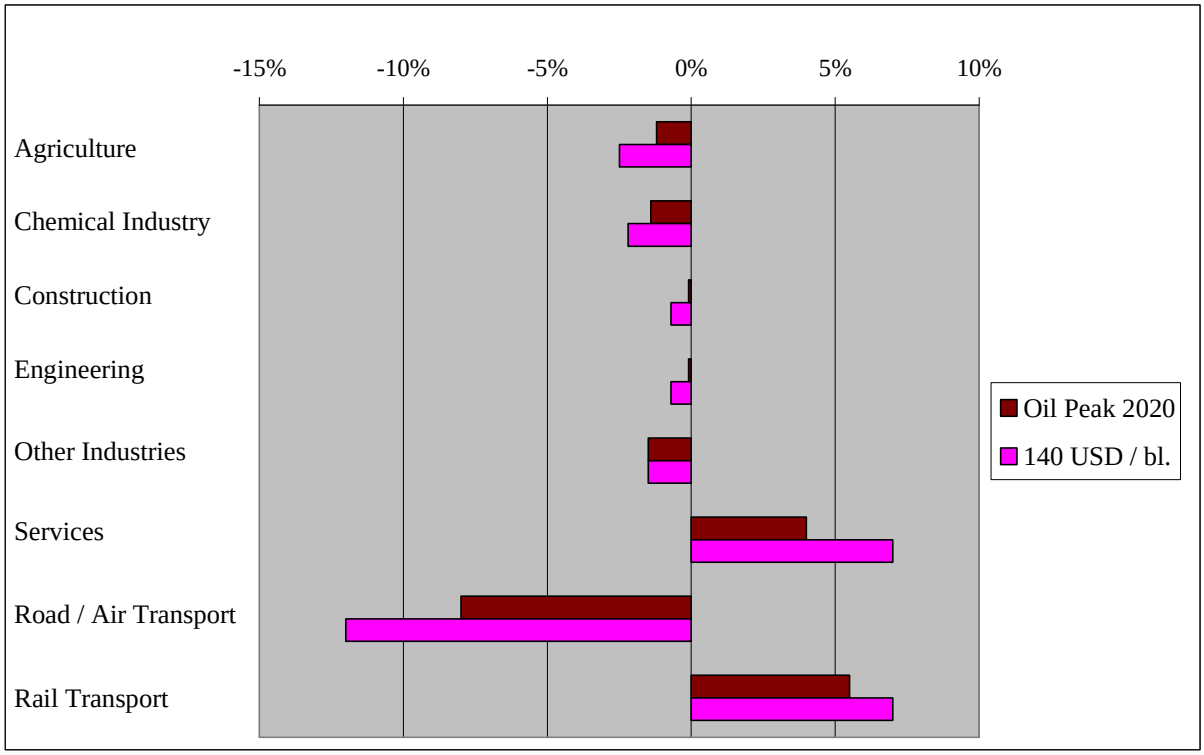

Figure 51: Change of Sectoral Output Compared to BaU Scenario in Switzerland in 2035, according to Selected Oil Price Scenarios of ECOPLAN ET AL. (2007)[392]

Unsurprisingly, the higher the reliance of a sector on energy in general and on oil in particular, the more significant is the negative impact of high oil prices on sectoral output. The less energy intense service sector seems to profit (up to + 6% output, compared to the BaU Scenario) from substitution processes from other, more energy intense industry sectors. The rail transport sector increases its output by up to 9% at the expense of the more oil dependent road and air transport sectors (up to -12 % output, compared to the BaU Scenario). Of course, in all scenarios featuring higher oil prices the overall transport volume is predicted to shrink.

One of the most alarmingly results of ECOPLAN ET AL. (2007) is that in all high oil price scenarios based on conventional energy sources, despite the assumption of high oil prices an **increase** of global CO_2 emissions by 50% - 80% is expected for the time horizon from 2000 to 2035. These emission levels may be slightly lower than in the BaU scenario, but the political goal to reduce global CO_2 emissions significantly would be missed by far. Even in the more ambitious "forced renewable"-scenarios only small absolute decreases of global CO_2 emissions will have been reached by 2035. On more optimistic assumptions about cost developments and capacity limits for all renewable energy

[392] Cf. ECOPLAN ET AL. (2006, p. 106).

sources, this alternative technological development path assumes an exogenous global CO_2 capacity limit, differentiating between developed and developing countries, and results in roughly constant CO_2 emissions at the level reached in 2010.[393]

So, one main conclusion of ECOPLAN ET AL. (2007) is that high oil prices may support the political efforts to reduce global CO_2 emissions. But beside their direct, reducing effect on demand, high oil prices may also induce increased CO_2 emissions by stimulating substitution processes from oil to alternative fossil based fuels (e.g. coal). Hence, ECOPLAN ET AL. (2007) underline the importance of developing a clear regulatory framework for climate protection policy. We will return to this in section 5.4.2.3 below. Anyway, high oil prices should not be considered surrogate for active climate protection policies.

5.4 Adaptation and Substitution Options for the Transport Sector

Road transport is currently one of the most heavily oil dependent economic sectors. In this section we explore the potential for adaptation and substitution processes in transport markets which may be induced by higher oil prices. First, in section 5.4.1, we analyze short-, medium-, and long-term demand side options to reduce the consumption of oil based fuels. Next, in section 5.4.2, possible reactions of the fuel supply side will be considered. As we will show, the reactions of both fuel market sides to high crude oil prices will contribute to limit the rise of crude oil prices. This would be in line with basic economic theory, as a high price of a resource signals high scarcity, which in turn should induce increased efforts to reduce its consumption by behavioral and technological changes.

5.4.1 Demand Side Responses to High Oil Prices – Changed User Behavior

Developed road freight and passenger transport systems are essential for the existence of modern societies. They ensure the mobility of factors, goods and people across spatially differentiated markets, and increase the level of competition between these markets. While road freight transport is a necessary precondition for trade, road passenger transport provides individual mobility, which is highly appreciated as a consumption good. In addition, both road freight and passenger transport amplify positive agglomeration and specialization economies, [394] as they help to decrease economically relevant distances between market participants.

[393] Cf. ECOPLAN ET AL. (2007, pp. 85 f.).

[394] Positive agglomeration economies are the main reason for the spatial concentration and specialization of economic activities. They are characterized by market external effects between neighboring firms, e.g. labor market pooling, the sharing of intermediate inputs and local public goods as well as knowledge interactions between these firms. Cf. e.g. GRAHAM (2005).

This high appreciation of road transport is reflected by a high willingness to pay for fuel that continues growing with rising income levels, resulting in low negative price elasticities and positive income elasticities for fuel.[395] Despite considerably higher end user prices for petrol and diesel than for other oil based products, more than 50% of all consumed oil based products in Germany were used for transport purposes, as Figure 52 shows.

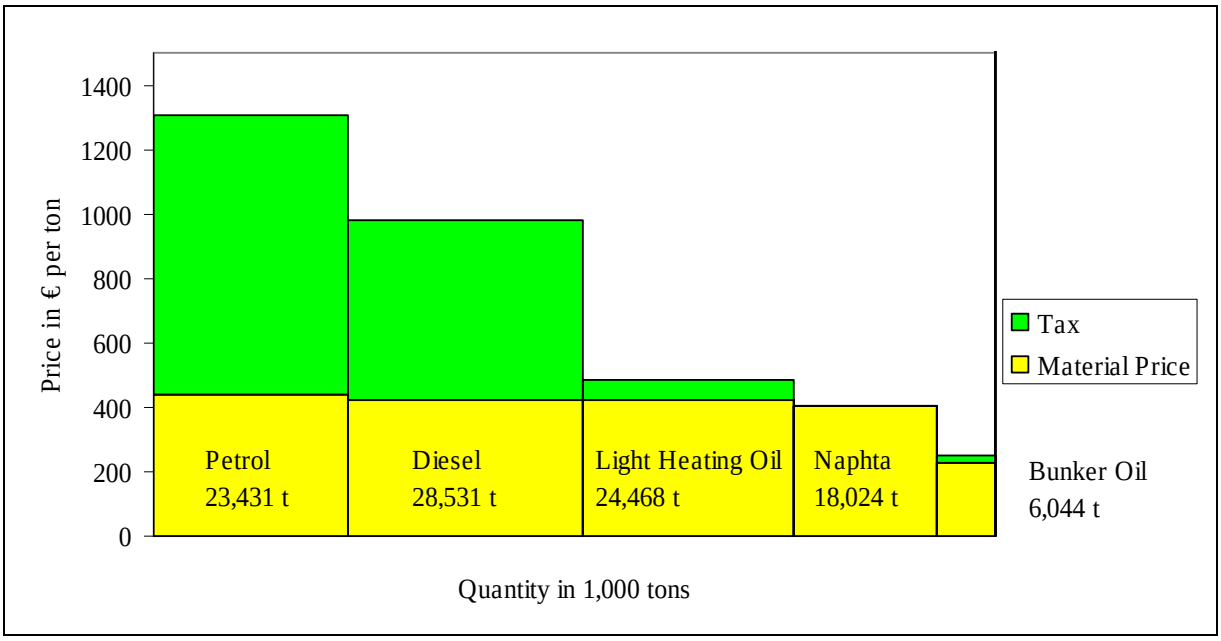

Figure 52: Annual Demand and End User Prices of Oil Based Products in Germany 2005, Crude Oil Price of 55 USD/bl.[396]

In the short-term, there are only limited options for the road transport sector to adapt to rising fuel prices and find suitable substitutes. This is reflected by very low short-term fuel price elasticities. From the 31 studies compared within the EU project TRACE the mean (median) of the calculated short-term elasticities of car mileage with respect to fuel price is -0.15 (-0.13).[397] The extensive meta-analysis by GRAHAM / GLAISTER (2002), which included 372 different studies, also calculates a short-term fuel price elasticity of car mileage of -0.15.[398] The data base on fuel price elasticities for road freight transport is comparatively weak, but generally even lower elasticity values (in absolute terms) than in the passenger transport demand segment are assumed. This presumption seems reasonable, since - on average - freight transport costs account for only 3.3 % of end user product

[395] Cf. e.g. GRAHAM / GLAISTER (2002).

[396] Source: Own calculations, based on data from the Website of the Association of German Petroleum Industry (MWV).

[397] The main results of TRACE are summarized by the article of DE JONG / GUNN (2001).

[398] Cf. GRAHAM / GLAISTER (2002, p. 94).

prices in Germany,[399] which implies an almost negligible direct impact of rising fuel prices on final product prices and demand.

Nevertheless, within a medium- and long-term horizon there are effective adaptation measures to higher oil prices for the transport sector, which is reflected e.g. by higher long run fuel price elasticities for car mileage of around -0.31.[400] Figure 53 shows the distribution of short-term and long-term fuel price elasticities in the studies surveyed by DE JONG / GUNN (2001).

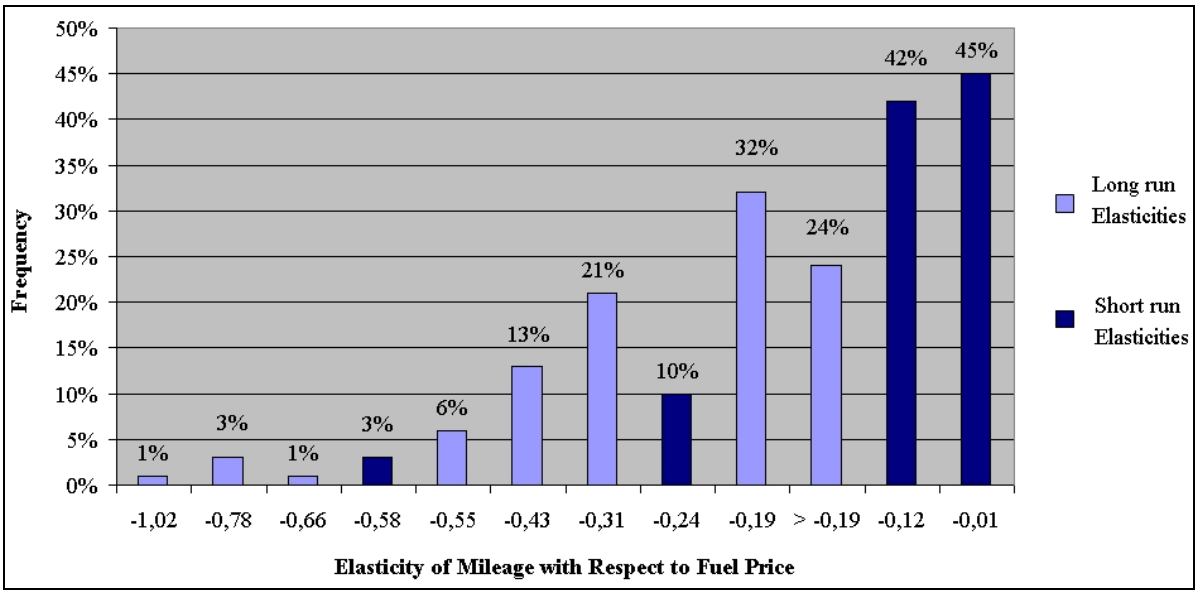

Figure 53: Distribution of Values for 31 Short-term and 72 Long-term Elasticities of Mileage with Respect to Fuel Price, according to the Survey by DE JONG / GUNN (2002)[401]

The reaction of for car trip demand to rising fuel prices will vary depending on different trip purposes. Generally it is plausible that the demand for non-work trips will be more elastic than the demand for work and business trips, where a high share of trips may be considered indispensable by the users in the short-term. But, as Figure 54 demonstrates, these trip purposes account for only 21 % (work) plus 12 % (business) of the passenger transport performance in Germany.

Short-term demand options in order to reduce fuel consumption include the cancellation of trips (applies to leisure trips), the use of alternative modes (e.g. public transport or bicycle), higher

[399] This value was derived from the German input-output matrix for the year 2005. Cf. STATISTISCHES BUNDESAMT (2008).

[400] Cf. GRAHAM / GLAISTER (2002, p. 95).

[401] Cited by GRAHAM / GLAISTER (2002, pp. 25 f.).

occupation/utilization rates (e.g. car pooling for work trips, bundling of shopping trips) and shorter trip distances due to changes of trip targets (e.g. for shopping and leisure trips).

Medium-term options to adapt to higher fuel prices are the replacement of the existing fleet by more fuel-efficient conventional vehicles or by available hybrid electric vehicles (HEV) such as the Toyota Prius model, and a switch to the fuel-tax-privileged LPG [402]- and CNG [403]-propulsion technologies.[404]

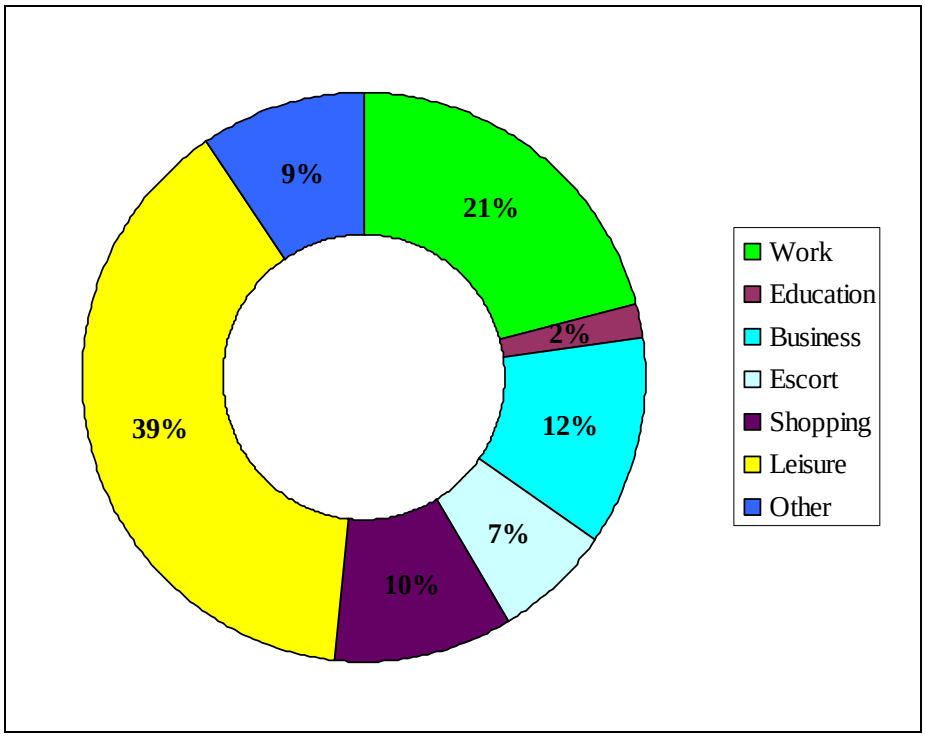

Figure 54: Transport Performance of Different Trip Purposes in Germany's Individual Road Transport (in Pkm)[405]

As LPG and CNG driven vehicles emit less local pollutants (e.g. NO_X and PM10) than conventional petrol cars, a lower fuel tax for these vehicles is reasonable from an economic point of view. In addition, a more extensive use of these technologies helps to decrease the dependence on oil based

[402] LPG = Liquid Petroleum Gas.

[403] CNG = Compressed Natural Gas.

[404] Especially in the case of LPG, retrofitting existing petrol cars to a bivalent petrol / LPG drive is an option for car users. Currently, in Germany LPG costs about 80 ct. per liter less than petrol, mainly due to the lower fuel tax on LPG. The costs for retrofitting a conventional petrol car to bivalent LPG/petrol drive amount to 2,000 EUR – 2,500 EUR. Taking into account the increased average fuel consumption and an assumed average petrol consumption of 8 liter / 100 km (LPG: 10 liter / 100 km), the retrofit pays off after a mileage of 40,000 to 50,000 km. The larger the specific fuel consumption of a petrol car and its annual mileage, the more worthwhile such a retrofit to a bivalent drive may be from an individual perspective.

[405] Source: INFAS / DIW (2004, p. 96).

fuels. Petroleum gas, the base material for LPG, is a side product of the conventional refinery process, and natural gas reserves are more abundant than those of crude oil.[406] Nevertheless, LPG and CNG vehicles emit similar amounts of CO_2 as their conventional counterparts. This rather challenges the scale of the German tax differentiation between these fuels.[407] Of course, a consistent European tax framework for all CO_2 emissions from fossil sources (heating oil, coal, gasoline, diesel etc.) which are not subject to the EU Emission Trading System (ETS) would be desirable in the medium- and long-term.

As a long-term demand adaptation strategy to higher fuel price levels a quicker market penetration of alternative propulsion technologies can be expected. So General Motors are going to start the serial production of the first mass-market plugin-hybrid car, the GM-Chevrolet "Volt", as early as 2010/2011. The end user price for the "Volt" is expected to be 30,000 – 40,000 USD.[408] With reasonable driving features,[409] a range of 650 km for the combined use of its electric motor and the combustion engine generator,[410] and a charging time for the batteries of 3h (at 220V), it is a promising vehicle. Moreover, the charging costs for the batteries (8kWh) are very low, and the fuel consumption in the combustion engine mode (about 4.7 liter / 100 km) is moderate, too. [411] Nevertheless, the "Volt" and other plugin-hybrids will still have to demonstrate their suitability for everyday use on a large scale, e.g. as regards the technical durability of the hybrid drive and batteries.

All in all, there are a number of mid- and long-term adaptation and substitution strategies for road transport demand, if the price level of oil based fuels should stay high or even rise further. Compared with a business-as-usual scenario, high oil price levels are likely to stimulate a decrease of transport performance, a shift to more fuel efficient vehicles, and higher occupancy rates / load factors in the industrialized western countries. These demand responses to high fuel prices will simultaneously contribute to the reduction of European transport sector's currently strong oil dependency and to achieving political goals to limit the emission of greenhouse gases (GHG). But, as shown by ECOPLAN ET AL. (2007), high crude oil prices may also provoke responses of the fuel supply side, as alternative, oil-independent technologies for fuel production are available or in advanced

[406] Cf. BGR (2006).

[407] The same applies to tthe current fuel tax differentiation between diesel and petrol. As diesel cars emit more local pollutants than petrol cars (e.g.PM10), relatively higher fuel taxes on diesel would be sensible.

[408] Cf. http://gm-volt.com.

[409] The "Volt" will feature about 160 km/h top speed, and an acceleration to 100 km/h in 9s. Cf. http://gm-volt.com.

[410] The range will be 65 km if the "Volt" is solely driven by its electric motor. Cf. http://gm-volt.com.

[411] Cf. http://gm-volt.com.

development stages. Possible supply side reactions and their consequences will be explored in the next section.

5.4.2 Supply Side Responses to High Oil Prices – Alternative Fuels

Despite recent encouraging developments regarding electric cars, it can be assumed that liquid fuels will continue to play an important role in the transport sector in the medium-term future. Road freight transport, air transport and the shipping industry will continue to use these fuels for the foreseeable future, as technological alternatives to conventional combustion engines are not in sight for these sectors. In addition, especially in the developing world a connection to the electricity grid is often unavailable area-wide, and its construction would likely be more costly than building an - at least rudimentary - infrastructure for the supply with liquid fuels (e.g. petrol stations etc.).

While the current refinery technology is adjusted to crude oil as base material, proven, alternative production technologies for liquid fuels are already available. We will consider here both the potential of fuel based on alternative fossil sources, like Coal-to-Liquids (CtL) and Gas-to-Liquids (GtL), as well as fuel based on regenerative sources.

5.4.2.1 Alternative Fuels from Fossil Sources: Coal- and Gas-to-Liquids (CtL/GtL)

For the production of coal based liquid fuels (CtL) usually the Fischer-Tropsch process is applied.[412] It is a proven technology, invented in Germany in the 1920s, and applied on a large scale during World War II, in order to ensure a fuel supply of the German Wehrmacht independently from oil imports. The technology was further developed in coal-rich South Africa during the Apartheid regime, when an embargo cut off South Africa from cheap crude oil. Today still about 30% of the fuel consumed in South Africa is coal based, and the producing firm, Sasol, offers all kinds of liquid fuels: diesel, petrol and kerosene. Due to the abundant availability of cheap coal, the production of fuels based on this source in South Africa costs only about 25 USD per barrel. In 2005/2006 experts estimated that producing CtL elsewhere could cost between 40 and 60 USD per barrel, depending on the local availability, quality and price of coal.[413] Even if today's world market price for coal is higher by about a third compared to 2005, [414] at the current price level of crude oil the production costs of CtL should be competitive. Because coal and oil are imperfect substitutes, their prices tend to move in the same direction. But, as Figure 55 shows, the price for coal is much less volatile than that of crude oil.

[412] Beside the Fischer-Tropsch process there are also other proven technologies based on coal, which could be used for the production of liquid fuels, e.g. underground coal gasification (UCG).

[413] Cf. THE ECONOMIST (2006), NIEHÖRSTER (2005).

[414] Cf. data provided by www.kohlenstatistik.de.

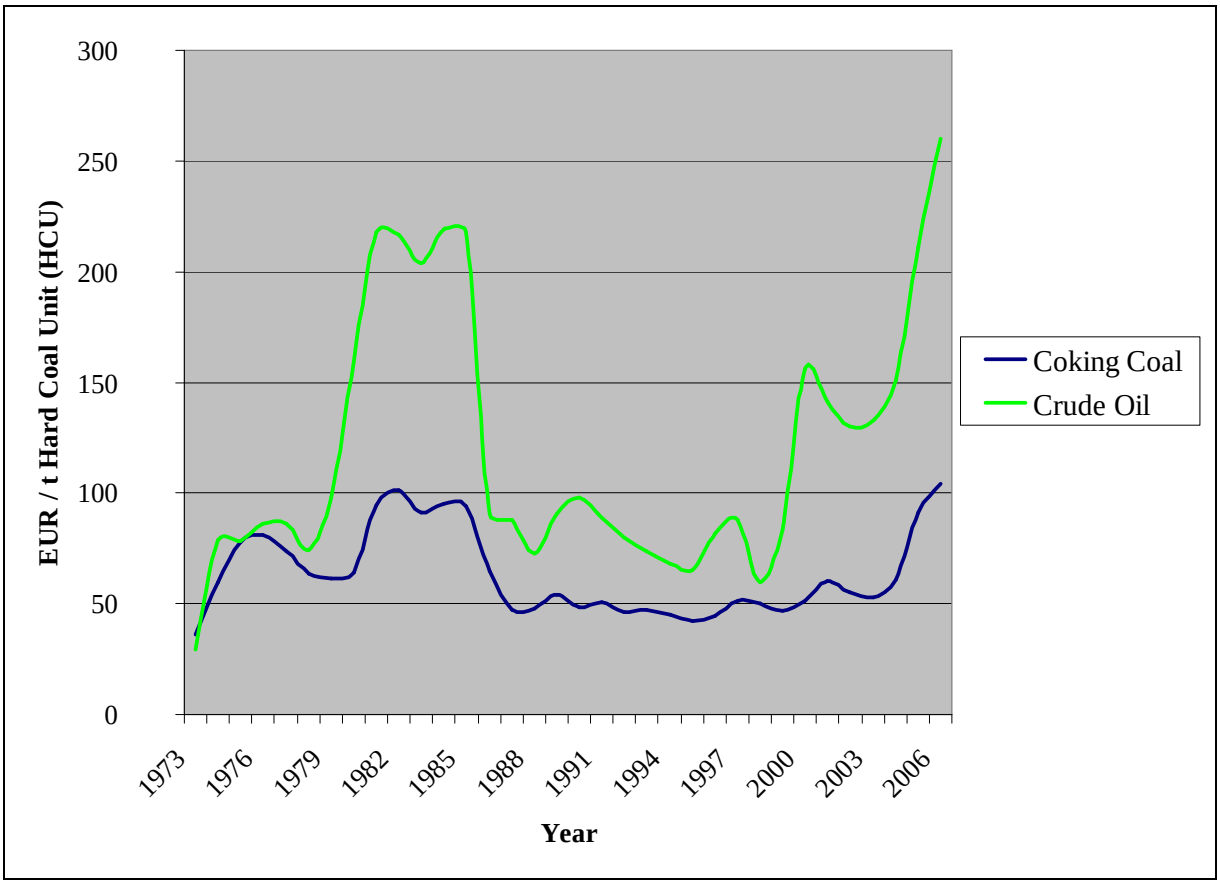

Figure 55: Historical Prices for Coking Coal and Crude Oil 1973-2006[415]

This reflects the fact, that, due to the spatially ubiquitous distribution of global coal reserves, the geopolitical risks of coal supply are lower than of crude oil supply. Moreover, the current reserve / production ratio is about 140 years, compared to an estimated 40 years of range for oil,[416] and the costs per energy unit (hard coal unit, HCU) are considerably lower, as Figure 55 also demonstrates.

Currently, diverse CtL-refineries are being built in coal-rich China (Ningxia, Shaanxi), often in cooperation of Western companies like Sasol and Shell with local firms. Most of these plants shall be ready for operation by the year 2012, finally they will have a combined capacity of about 18 million tons of liquid fuels and chemical products per year.[417] This is equivalent to about 8.5 % of China's current consumption of oil based products.[418]

[415] Source: Data provided by http://www.kohlenstatistik.de.

[416] The reserve / production ratio is a static, relative measure for the future availability of depletable resources. It relates the known reserves of a resource with its current annual production. Cf. for the data used BGR (2006), plus own calculations.

[417] Cf. INTERNATIONAL ENERGY (2007).

[418] According to the Official Chinese News Agency Xinhua, the demand for oil based products in China was 52.73 million t in the first quarter of 2008.

Yet, coal is not the only fossil alternative to crude oil for fuel production. Natural gas can be used as input for similar technological processes. Compared to coal, the natural gas supply is more limited regarding its spatial distribution and world reserve levels, but it is more widely available than crude oil, and the current reserve / production ratio is about 70 years.[419] Currently there are several GtL refineries in advanced building phases, e.g. in Nigeria and Qatar.[420] Shell is currently building a large GtL refinery in Qatar, scheduled to be finished in 2010. It will have a production capacity of 140,000 barrels of liquid output daily (mainly diesel), which is equivalent to about 20-25 % of Germany's daily diesel consumption. In addition, the LPG and ethane equivalent of 120,000 barrels of oil will be produced daily.[421]

The construction of large-scale CtL and GtL refineries requires high sunk investments. A German expert speaks of at least 1.5 billion EUR per CtL plant,[422] the estimated costs for Chinese CtL-refineries with an annual output of 3-6 million t are about 5-6 billion USD per plant.[423] In addition, the construction of these plants needs long planning phases of more than 6 years,[424] and involves dealing with considerable uncertainties regarding future input prices (e.g. for coal/gas and process energy) and oil price levels (substitute). Hence, on one the hand the recent renaissance of the CtL technology in China and the large scale introduction of GtL production clearly indicate the expectation that the price for crude oil will not fall back to the levels of the 1980's and 1990's. On the other hand, the option to produce non-oil based transport fuels and related products at prices of about 60 USD per barrel should limit oil price increases in the medium- and long-term. Taking the possible risk of input price increases for CtL and GtL production into account, we expect a long-term price level for crude oil of 80-100 USD per barrel or below.

From an environmental perspective, some authors such as ECOPLAN ET AL. (2007) take a very critical view of the high energy consumption involved in the CtL production process. Indeed, the production of CtL causes roughly twice the well-to-wheel GHG emissions if compared to the conventional fuel production from crude oil.[425] But, as we will show in section 5.4.2.3, regulatory measures within the existing European climate policy framework are well suited to deal with this potential problem. Given an adequate policy framework, we see both CtL and GtL as useful

[419] Cf. BGR (2006).

[420] Cf. THE ECONOMIST (2006).

[421] Cf. Website of Shell Qatar.

[422] Cf. NIEHÖRSTER (2005).

[423] Cf. INTERNATIONAL ENERGY (2007).

[424] Cf. NIEHÖRSTER (2005).

[425] Cf. IES (2006, p. 44).

technological supplements to conventional refinery processes based on crude oil. They may contribute to a lessened oil dependence of the transport sector in the future.

5.4.2.2 Fuels from Renewable Sources: Biomass-to-Liquids (BtL)

Another technological trend which has attracted considerable attention in the last few years is the fuel production from regenerative sources, i.e. biomass. In contrast to fuels from fossil sources, BtL or biofuels are made from a renewable and – in principle – non-exhaustible feedstock. Moreover, as biomass extracts CO_2 from the atmosphere during the photosynthesis process, the consumption of biofuels potentially involves lesser (direct and indirect) CO_2 emissions than that of fuels based on fossil sources.

The so-called first generation biofuels are ethanol (as substitute or additive for/to petrol), which is conventionally produced by the alcoholic fermentation of sugar or starch,[426] and bio-diesel, which is produced by transesterification from plant oils.[427] Table 80 shows estimates of THE ROYAL SOCIETY (2008) for the production costs of conventional biofuels made from different feedstock. If exempted from fuel-taxes, their production costs already seem to be competitive to retail prices of oil based fuels, and further decreasing costs due to technological advances can be expected.

[426] For the ethanol production, starch feedstock has to be converted into sugar via saccharification.

[427] Especially older diesel engines can run on pure plant oil, too. But the transesterification reduces the viscosity of the oil, improves its consistency and miscibility with diesel, as well as improving other properties, such as its viscosity when cold. Cf. THE ROYAL SOCIETY (2008, p. 24).

Fuel	Price 2006 (in US ct./l)	Price 2030 (in US ct./l)
Petroleum products pre-tax price	35-60	
Petroleum products retail price	150-200 in Europe, About 80 in USA	
Ethanol from sugar cane	25-50	25-35
Ethanol from corn	60-80	35-55
Ethanol from beet	60-80	40-60
Ethanol from wheat	70-95	45-65
Ethanol from ligno-cellulose (wood, straw)	80-110	25-65
Bio-Diesel from animal fats	40-55	40-50
Bio-Diesel from vegetable oils	70-100	40-75
Fischer-Tropsch-synthesis for BtL	90-110	70-85

Table 80: Estimated Costs of Biofuels 2006 and 2030[428]

Despite their asset of using – seemingly – CO_2 neutral feedstock, considerable environmental problems are associated with biofuel production of the first generation: First, treating biofuel feedstock plants with synthetic fertilizers may increase nitrous oxide (N_2O) emissions,[429] which is a greenhouse gas 310 times stronger than CO_2.[430] Second, the clearing of forests or marshlands to claim agricultural areas for conventional biofuel feedstock may eliminate important natural CO_2 sinks. Both factors may result in an overall negative greenhouse gas balance for the production of biofuels of the first generation. Moreover, monocultures of plants used in biofuel production may have severe negative impacts on local ecosystems, e.g. by the eutrophication or acidification of soil and water and losses in biodiversity.[431]

Another important criticism of conventional biofuels is that their production often directly competes with food production. The rising demand for feedstock as well as large subsidies for biofuels in

[428] Cf. THE ROYAL SOCIETY (2008, p. 49).

[429] Cf. CRUTZEN ET AL. (2007).

[430] Cf. IPCC (2007).

[431] Cf. e.g. IES (2006, p. 39).

developed countries are supposed to have contributed to steeply rising world market prices for basic food in the recent past. Such rising food prices may be bearable in developed countries, as their population usually spend only a small share of their income on food. But in the developing world, where many people cannot afford more than basic food, they may have disastrous consequences. This is ethically questionable. In order to lessen potential resource conflicts with agricultural food production, the focus of research on biofuels recently shifted to the exploration of new feedstocks and the development of production methods for these raw materials. The feedstocks for the so-called second generation of biofuels often are undemanding plants which grow on soils not suited for other agricultural use.

One promising feedstock plant for the future production of biofuels is Jatropha, an inedible plant with nuts containing about 30% of oil suitable for the production of bio-diesel. Jatropha is said to be resistant to drought and pests and requires very little water or fertilizer. It can be cultivated in tropical and sub-tropical regions even on infertile soils, which could not be used for agricultural purposes otherwise. Recently, Bayer CropScience, Daimler and Archer Daniels Midland Company (a bio-diesel refiner) announced a cooperation to explore the commercial potential of Jatropha based diesel.[432]

For future bio-ethanol production promising new feedstocks are grass varieties like Switchgrass. Switchgrass is a perennial grass native to North American prairies, which grows extremely quickly on soil not suitable for food crops. According to a five-year study conducted by researchers at the University of Nebraska-Lincoln, the cellulose of switch grass contains up to 540 % more energy than was needed to grow, harvest and process it into bio-ethanol.[433] Nevertheless, the technology for producing ethanol from (ligno-)cellulose instead of sugar or starch is still under development, and it may take years before it will be available on a large scale.

In contrast to this, the adaptation of the Fischer-Tropsch process to a large-scale production of second-generation biofuels is already more advanced. In Freiberg the Choren AG converts waste wood, e.g. leftovers from forestry and timber-mills, and fast-growing timber, e.g. cottonwood, into diesel ("SunDiesel") using this process. This plant already produces on a commercial scale 15,000 tons of diesel p.a. There are concrete plans for a full-scale plant refinery with an annual capacity of 200,000 tons in Schwedt, and further plants of this unit size are being planned.[434]

[432] Cf. BAYER CROPSCIENCE AG (2008).

[433] Cf. SCHMER ET AL. (2007).

[434] Cf. RUDLOFF (2007).

In addition, there are considerable research efforts to exploit biotechnology for the biofuel production, e.g. tailor-made microorganisms, enzymes or catalysts for new production processes intended to enable higher effectiveness and hence lower costs for biofuels. For instance Amyris Biotechnologies, a spin-off of the University at Berkeley, California, developed a fermentation process based on microorganisms specially designed to increase the productivity of ethanol production from sugar cane by a **factor of 20**. In cooperation with the second-largest Brazilian ethanol distributor, they are currently building a demonstration plant in Brazil which should be ready in 2010, while commercial production is scheduled to start one or two years later. [435] Figure 56 shows some of the production methods and feedstocks currently under development and evaluation.

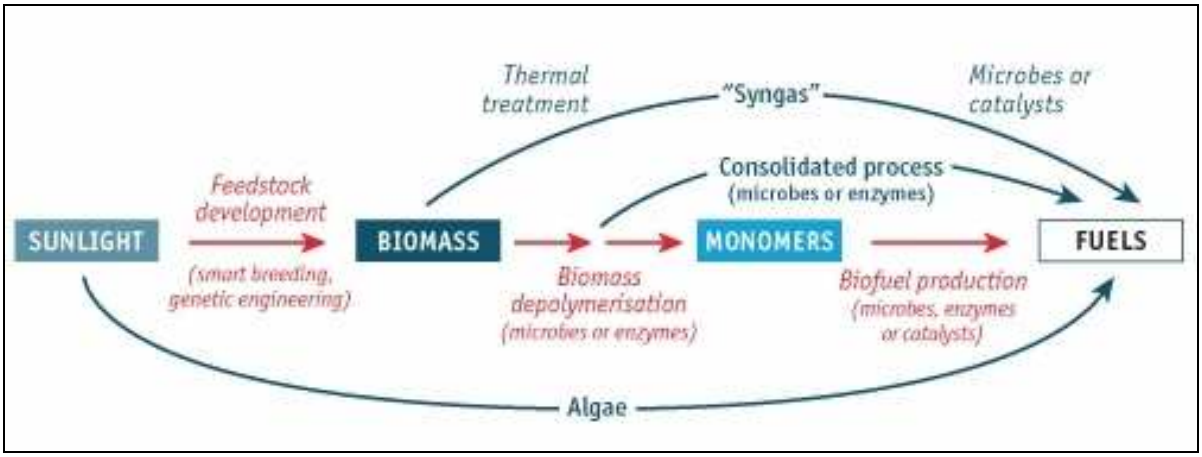

Figure 56: Potential Pathways for the Production of Biofuels[436]

In terms of large-scale production capacities the development of second generation biofuels is still in an earlier stage than CtL and GtL production. Nevertheless, the great variety of potential approaches and possible feedstocks give rise to the expectation that biofuels may significantly contribute to the fuel supply of the medium-term future.

[435] Cf. THE ECONOMIST (2008b).

[436] Source: THE ECONOMIST (2008b).

5.4.2.3 Long-term Outlook and Regulatory Needs for Alternative Fuels

Recently, the U.S. Energy Information Administration (EIA) updated its long-term projections for worldwide fuel production until 2030. For their high-price scenario, which assumes crude oil prices of 88 USD in 2020, and 96 USD in 2030,[437] EIA (2008) estimates a world market share for alternative fuels of up to 19% in 2030.[438] Their projection for the worldwide fuel production is shown in Figure 57.

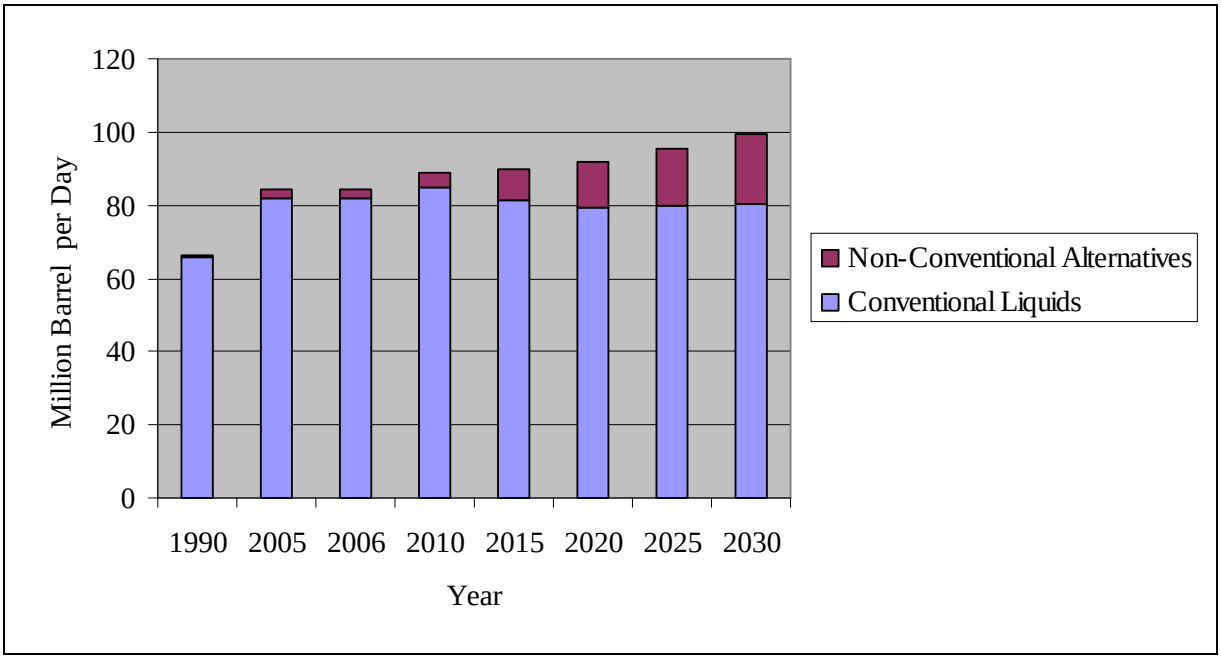

Figure 57: Projections of Worldwide Liquid Fuel Production – EIA (2008) High Oil Price Scenario[439]

Compared to the reference scenario of EIA (2008), which assumes crude oil prices of 52 USD in 2020 and 59 USD in 2030, the market share of alternative fuels in the high-price scenario is roughly doubled. Moreover, the total fuel consumption in 2030 is expected to be about 12 % lower than in the reference case, and OPEC's share of global fuel production is supposed to decrease from an estimated 44 % in the reference case to 36 % in the high-price scenario. Both characteristics of the high-price scenario would contribute to the political goals of limiting CO_2 emissions and diminishing supply side risks / dependencies. But, as indicated by the almost constant absolute consumption of conventional liquid fuels in Figure 57, and the expected high share of fossil alternative fuels in Figure 58, the

[437] In real terms for 2006, Cf. EIA (2008, p. 158).

[438] Cf. EIA (2008, p. 203 f.).

[439] Source: EIA (2008).

expected supply side substitution processes need some regulatory framework to comply with climate protection goals.

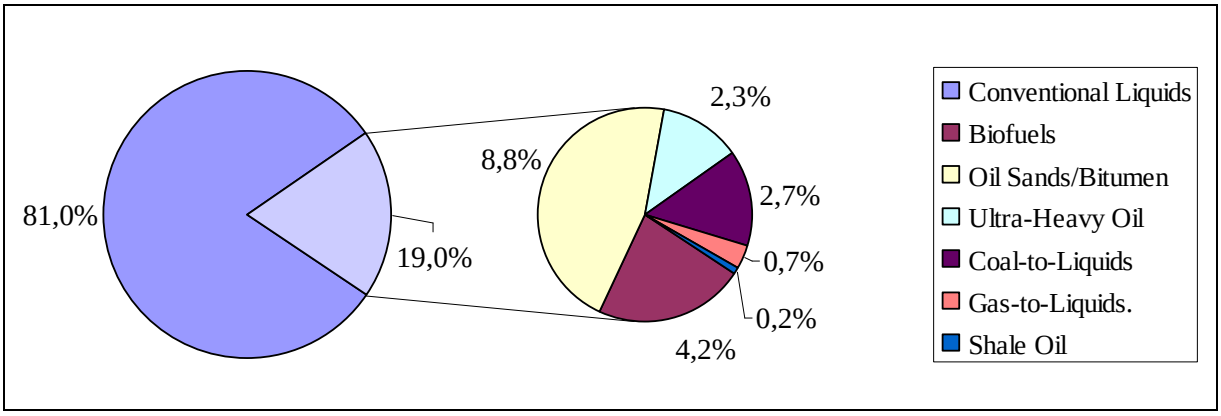

Figure 58: Estimated Production Share of Alternative Fuels in 2030 – EIA (2008) High Oil Price Scenario[440]

For the European transport sector, the simplest way to take into account the specific CO_2 emissions of alternative fuels is the application of existing regulatory measures. The use of process energy for CtL, GtL and BtL in Europe would already be subject to the European Emissions Trading Scheme (ETS), which makes further measures on the production side unnecessary. As long as the process energy for imported CtL-or GtL-fuels is not subject to an emissions trading scheme or similar measures in their originating countries (e.g. the USA, China, South Africa), an additional tax on these imports seems to be economically reasonable, even if it is not clear whether such import taxes would be in line with the binding agreements of the World Trade Organization (WTO).

In addition, alternative fuels from fossil sources (GtL from natural gas and CtL) could easily be taxed at the same level as oil-based fuels, because they generate the same amount of direct CO_2 emissions. In general, the tax level should take into account the specific CO_2 emissions per liter of fuel, which differ for diesel and petrol. As already pointed out, the development of a consistent tax framework for all European CO_2 emissions from fossil sources (heating oil, coal, gasoline, diesel etc.) which are not subject to the ETS is desirable. For BtL-fuels some adaptations seem to be necessary, as taxing according to the net CO_2 impact would justify fuel tax reductions and exemptions.

[440] Source: EIA (2008, pp. 203 f.).

5.5 Implications of High Oil Prices for the Road Transport Sector in Germany – Own Calculations

The Goal of this section is to explore some of the implications of different oil price scenarios for the transport sector, concentrating on the road transport sector, because it is the most important mode. In particular, we analyze the impacts of extreme short-term increases in oil prices of up to 250 USD per barrel and shifts of the EUR-USD-exchange rate to 1:1. As described in sections 5.2.1 and 5.4, we consider price levels of more than 100 USD per barrel crude oil to be unsustainable for the medium- and long-term future. Furthermore, current economic fundamentals (lower interest rates in the US, diminishing importance of the USD as international reserve currency, huge public budget deficit) indicate a further devaluation of the USD against the EUR rather than the revaluation analyzed.[441] Hence, the basic assumptions for the scenarios should not be regarded as our predictions, but as stylized if-then-analyzes for the worst case.

For calculating of the effects of higher oil prices and changing exchange rates we chose a bottom-up-approach. First, from assumptions on crude oil prices (in USD per barrel), we derived corresponding levels of pump prices (in EUR) for diesel and petrol (super) in Germany, taking into account USD:EUR exchange rates, fixed conversion ratios at refineries,[442] constant distribution costs and existing national taxes. With historical data on average fuel and crude oil prices, published by the Association of German Petroleum Industry (MWV), the results could be easily controlled. The parameters and key assumptions used for the calculation of petrol pump prices for the base year 2007 are shown in Table 81.

[441] Cf. e.g. MÜLLER (2008).

[442] This implies a relatively constant output mix (diesel plus petrol) of refineries. While the output mixes of European and US refineries differ considerably (with a much higher share of diesel in Europe), short-term adaptations of the refinery process are not possible without high refitting costs. Hence, it is reasonable to assume a constant output mix for the near future. Cf. THE ECONOMIST (2008c).

Parameter	**Base Scenario 2007**	**Remarks/Sources**
Crude oil price in USD per barrel	67	Average for 2007, according to MWV[443]
Exchange rate USD:EUR	1.37	Average for 2007, according to www.oanda.com
Economic conversion ratio crude oil/petrol	0.7562	Eight-year-average ratio of import prices crude oil/petrol (years 2000-2007), according to MWV
Import costs of petrol (EUR per liter)	*0.41*	*Intermediate Result, cross-checked with MWV data*
Distribution costs and profits (EUR per liter)	+ 0.086	according to MWV data
Fuel and eco taxes (EUR per liter)	+ 0.655	EnergieStG
19% VAT (EUR per liter)	+ 0.22	
Pump Price (EUR per liter)	**= 1.37**	**Result**

Table 81: Model Calculation of Petrol Prices (in EUR per liter) from Oil Prices (in USD per barrel)[444]

In a second step we calculated the changes in German car and truck mileage as well as adaptations of technical fuel efficiency and fuel consumption resulting from fuel price increases. For these computations we applied short-term price elasticities from the literature review by GRAHAM/GLAISTER (2002). They estimated a fuel price elasticity of demand of -0.25 for fuel consumption and -0.15 for the mileage of cars,[445] i.e. if the fuel price rises by 10%, fuel consumption drops by 2.5% and car mileage by 1.5%. Finally, we used the fuel consumption statistics for the German vehicle fleet from DIW (2008) and the fixed conversion factors of diesel (2,650g CO_2 per liter) and petrol (2,360g CO_2 per liter) to translate the reductions of fuel demand into decreases of CO_2 emissions from the road transport sector.

Our calculations are based on some simplifications of real world transport and fuel markets. Firstly, we do not define an explicit Business-as-Usual (BaU) scenario to compare our oil price scenarios with, but use the historical data of the year 2007 for these purposes instead. For the near future (up to two

[443] Cf. Website of Association of German Petroleum Industry (MWV).

[444] Cf. the cited sources and own calculations.

[445] Cf. GRAHAM/GLAISTER (2002, p. 95). For trucks no comparable elasticity data was available, hence we used values of -0.15 for the reduction of fuel consumption, and -0.05 for decreases of mileage.

years) considered here, this seems to be reasonable, as fundamental changes of economic framework conditions (taxes, relative market prices of fuel sorts etc.) are unlikely and therefore less important. The chosen short time horizon of oil price changes also justifies the application of short-term fuel elasticities, which are considerably lower than their long-term equivalents.[446] Furthermore, we did not take into account the option of refitting petrol cars to LPG or natural gas propulsion technology, which might somewhat overstate the possible reductions of CO_2. In addition, we did not include the mandatory admixture and voluntary fuelling with biofuels in our calculations, which in turn understates the decrease of CO_2 emissions. Unfortunately, we were not able to estimate the negative impacts of the analyzed scenarios on economic welfare and household incomes. Nevertheless, we consider our calculation method as a transparent approach that is sufficiently precise to derive first conclusions about possible effects of rising oil prices on the German road transport sector, and our calculations can easily be replicated using alternative assumptions about future oil prices, exchange rates, time horizons, demand elasticities and other parameters.

Table 82 summarizes the historical data for the base year 2007, the current situation (in spring 2008), and the basic assumptions for the three future scenarios we analyzed. For the conversion of future nominal EUR values to the real values of 2008 we used an annual discount rate of 2%.

Scenario	**Oil Price in USD/bl.**	**Exchange Rate USD:EUR**	**Time Horizon**	**DIESEL Pump Price in EUR_{2008} /l**	**SUPER Pump Price in EUR_{2008} /l**
Base Case	67	1.37	2007	1.14	1.37
Spring 2008	120	1.58	2008	1.41	1.63
Scenario 1	200	1.58	2009	**1.87**	**2.09**
Scenario 2	250	1.58	2010	**2.13**	**2.35**
Scenario 3	200	1.00	2010	**2.52**	**2.75**

Table 82: Key Parameters and Fuel Prices for Analyzed Scenarios[447]

While the first two of the high price scenarios proceed on the assumption of a constant exchange rate USD:EUR, scenario 3 implies a stronger US currency, and should be considered as the worst (and quite unlikely) case. Comparing the two historical calculations for 2007 and spring 2008, it becomes

[446] Cf. GRAHAM/GLAISTER (2002, p. 95).

[447] Source: own calculations.

clear that the negative correlation between the USD and the crude oil price helped to reduce the impact of recently rising oil prices on the pump prices in the Euro zone. In addition, as both Table 82 and Figure 59 show, the existing taxes on fuels result in increases of pump prices for fuel that are **less than proportional** to the underlying oil price increases. Certainly, this cushioning effect of fuel taxes raised per liter would becomes weaker if oil prices should rise further, as indicated by Figure 59.

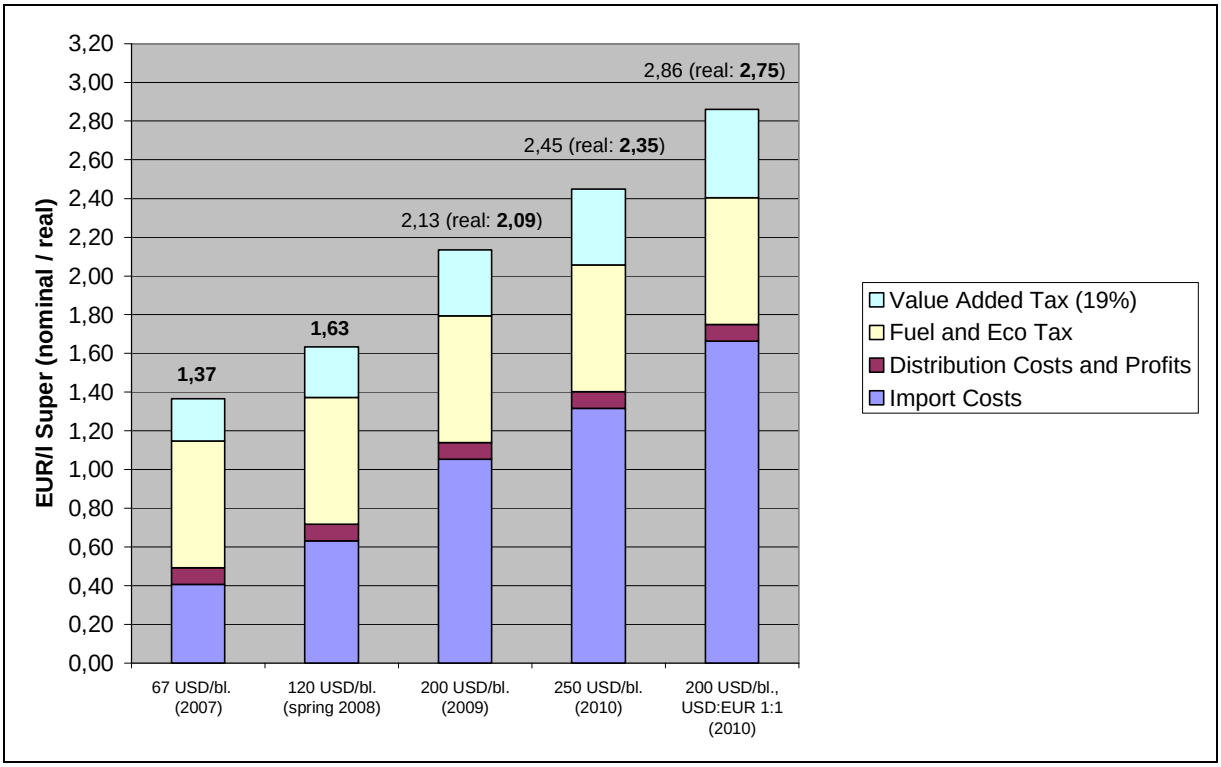

Figure 59: Composition of Petrol Prices for Different Oil Price Scenarios[448]

Despite the cushioning effects of the weak US dollar and the existing fuel taxes, oil prices of 200 USD or even more result in heavy fuel price increases, as the calculations presented in Table 83 indicate.

[448] Source: own calculations. The figures for profits refer only to the distribution stage.

Parameter (Change to Base Case 2007)	**Spring 2008**	**200 USD/bl. (2009)**	**250 USD/bl. (2010)**	**200 USD/bl., USD:EUR = 1:1 (2010)**
End Price SUPER	**+ 19.6 %**	**+ 50.2 %**	**+ 65.6 %**	**+ 93.5%**
End Price DIESEL	**+ 23.2 %**	**+ 63.4 %**	**+ 86.4 %**	**+ 120.8 %**
Mileage Petrol Cars	- 2.9 %	- 7.5 %	- 9,8 %	- 14,0 %
Mileage Diesel Cars	- 3.5 %	- 9.5 %	- 13.0 %	- 18.1 %
Mileage Trucks	- 1.2 %	- 3,2 %	- 4.3 %	- 6.0 %
Fuel Consumption Petrol Cars	- 4.9 %	- 12.6 %	- 16.4 %	- 23.4 %
Fuel Consumption Diesel Cars	- 5.8 %	- 15.9 %	- 21.6 %	- 30.2 %
Fuel Consumption Trucks	- 3.5 %	- 9.5 %	- 13.0 %	- 18.1 %
CO_2 Emissions	**- 4.8 %**	**- 12.6 %**	**- 16.8 %**	**- 23.7 %**
CO_2 Emissions (in million t)	**- 7.2**	**- 19.1**	**-25.5**	**-36.0**

Table 83: Scenario Results - Changes in Mileage, Fuel Consumption and CO_2 Emissions[449]

Nevertheless, even these considerable fuel price increases will not lead to a breakdown of the road transport sector in Germany. On the other side, further oil price increases may contribute to the achievement of existing climate protection goals. But these – insecure and likely temporary – oil price rises are not a suitable substitute for an active climate policy for the transport sector.

5.6 Conclusions

Our analysis of the basic demand and supply conditions of the world oil market shows that considerably higher oil price levels than during the 1980's and 1990's are likely for the medium-term future. Nevertheless, we regard the price levels reached in July 2008 as unsustainably high. Adaptation and substitution processes of oil demand and fuel supply will occur in the medium- and long-term, which complies with the economic function of prices as scarcity indicators. These adaptation and substitution effects strongly militate against the persistence of the current oil price levels. Taking into account the medium-term potential of alternative fuels and the demand side options to reduce fuel consumption, we expect a long-term price level for crude oil of 80-100 USD (in real terms) per barrel or below. This is in line with the estimates of most experts, e.g. ECOPLAN ET AL. (2008).

[449] Source: own calculations, based on GRAHAM/GLAISTER (2002) and DIW (2008).

Moreover, our analysis shows that the impact of higher oil prices on the economy, on household incomes and the transport sector should not be overestimated. There are considerable negative macroeconomic effects of sharp oil price rises in the short- and medium-term, but the share of oil-based products on GDP in developed countries is much lower now than it was in the 1970's and 1980's, and public fear of oil price induced economic breakdowns seems to be largely exaggerated. If rising oil prices do not hamper innovation and technological change permanently, these factors will have a larger long-term impact on economic growth and household incomes than a single input price.

Current high price levels boosted research efforts to substitute crude oil and oil based products, as the tremendous progress of alternative propulsion technologies (e.g. plugin-hybrids) and the ongoing development of new production methods for non-oil based fuels demonstrates. Even if the market penetration of these new technologies will still need time, the diversity of approaches and research directions is encouraging, and large amounts of money are being invested by established firms there. These supply side responses will contribute to a reduced oil dependence of the transport sector in the medium-term future. As for transport demand, there are effective adaptation measures to higher oil prices even for the short-term, e.g. higher occupancy rates, or changed destination and mode choices. In the medium- and long-term, an increased fuel efficiency of new vehicles diminishes impacts of high fuel prices further; the same applies to expected increases of household incomes.

As shown by the calculations in section 5.5, even considerable fuel price increases will not lead to a breakdown of the road transport sector in Germany. High oil prices may support the political efforts to reduce global CO_2 emissions. But beside their direct, reducing effect on demand, high oil prices also may induce increased CO_2 emissions by stimulating substitution processes from oil to alternative fossil based fuels (e.g. coal). These substitution processes need some regulatory framework to comply with climate protection goals. In any case, high oil prices are not a suitable substitute for an active climate policy for the transport sector. Hence, the further development of the appropriate framework conditions and sector specific instruments should be promoted.

6 Conclusions

From our studies analyzing potential welfare effects of different urban road pricing schemes (chapters 2, 3 and 4) and the potential impacts of different oil price scenarios on road transport (chapter 5) we are able to derive some general conclusions.

As shown in chapter 2, the characteristics of external cost categories influence the efficient spatial and temporal structure of toll tariffs as well as their optimal level and differentiation. Furthermore, not all external costs are equally suited to be internalized through road pricing schemes. From theoretical considerations and a review of existing literature we conclude that spatially disaggregated network models with an associated elastic trip demand are needed to model urban road transport adequately, as local traffic conditions and external effects like noise and congestion may vary substantially. Both noise and congestion effects have a pronounced temporal structure. Hence, considering time-differentiated tolls is useful. In addition, we consider the inclusion of at least two demand segments, i.e. cars and trucks, in such analyses as necessary. Both demand segments interact with each other on existing road capacities and differ in their values of time and distance, and user behavior.

Chapter 3 applies the insights of chapter 2 to a case study analyzing the effects of environmentally oriented road charging schemes exclusively for trucks in Berlin. As trucks cause much stronger environmental and noise effects per vehicle kilometer than passenger cars, a toll solely levied on this demand segment could be seen as a first approximation to an internalization strategy for noise and local environmental effects. Nevertheless, the interaction between truck demand and passenger car demand on the network requires the inclusion of both demand segments in the model.

With a welfare effect of +9.0 million € p.a. and +10.7 million € p.a., respectively, reduced air pollution levels dominate the overall benefits of the analyzed time-differentiated pricing schemes for trucks. Despite a pricing structure explicitly dedicated to the reduction of noise effects, the benefits from decreased health risks and annoyance levels due to traffic noise are comparatively small, between 4.4 and 4.8 million € p.a. Taking into account the ambivalent congestion effects, the analyzed road charging system for trucks may achieve total benefits between 14.7 and 17.2 million € per year. In comparison to the installation and operational costs of a toll collection system the potential welfare gains to be achieved by the toll seem to be rather small. If we consider additionally the fact that air pollution burdens are likely to decrease further due to the stepwise renewal of urban truck and car fleets within the next few years, an implementation of the explored environmentally oriented truck charging system cannot be recommended.

In chapter 4 we estimated the effects of tolling schemes for cars and trucks in the structurally differing agglomerations Berlin and Stuttgart. On the one hand, this was a cordon-toll, differentiated according

to the time of day, for the respective inner city, the Stuttgart "city basin", and the "great dog's head" in Berlin. Other scenarios feature mileage-dependent tolls for the entire city area.

We observed that in seven of the ten scenarios analyzed positive welfare effects due to a more efficient use of capacity and a reduction of negative external environmental effects are likely to occur. However, these potential benefits are apparently too small to justify the installation and operating costs for a toll collection system. The slight or medium welfare effects may be explained by the specific transport situation in the two agglomerations. The radial network of Berlin, which is better suited for a comparatively cheap cordon-tolling system, has free road capacities available. The metropolitan area of Stuttgart, with its mesh network, has significant capacity constraints, which are difficult to target with a spatially-limited cordon-toll. On the other hand, the benefits of distance-dependent tolls are higher in both metropolitan areas, at least if city-highways (in Berlin) are included in the charging scheme. The danger of welfare losses is lower the lower the toll tariffs are fixed; this is an argument in favor of low toll tariffs. However, due to the high costs of the sophisticated technology required for mileage-dependent tolling solutions, none of the considered charging schemes can be recommended for immediate implementation. Furthermore, our results indicate that spatial simulations of different road pricing scenarios and their economic interpretation are required to allow for the significant differences of local networks with respect to rerouting options, and cost characteristics. Anyway, the interdependence between the spatial structure of agglomerations and the potential impact of differing road pricing solutions should be researched further.

As fuel costs also represent an important share of the decision-relevant costs for the individual transport user, we consider the analysis of the impact of high crude oil prices on the transport sector provided in chapter 5 a useful complement to our simulation studies. Taking into account the medium-term adaptation and substitution processes of oil demand and fuel supply, we expect a long-term price level for crude oil of 80-100 USD (in real terms) per barrel or below. As demonstrated in chapter 5, high price levels boost research efforts to substitute crude oil and oil based products, e.g. by alternative propulsion technologies and new production methods for non-oil based fuels. These supply side responses will contribute to a reduced oil dependence of the transport sector in the medium-term future. Regarding transport demand, our analyses show that there are a number of effective adaptation measures to higher oil prices even for the short-term, e.g. higher occupancy rates, or changed destination and mode choices. In the medium- and long-term, an increased fuel efficiency of new vehicles diminishes impacts of high fuel prices further; the same applies to expected increases of household incomes. As the calculations in chapter 5 indicate, even in the short-run considerable fuel price increases will not lead to a breakdown of the road transport sector in Germany.

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Annex A: Estimation of a Network-wide Supply Function and Approximation of User Equilibrium

Computation by a network-wide, power-based function for supply and performance is a complementary method of determining the equilibrium after the introduction of a toll, if the cobweb procedure does not converge. The network-wide demand function is already determined by assumptions about the function type and the cost elasticity, as well as the cost-quantity combination of the original equilibrium. But also for the supply function after the introduction of a toll, price-quantity combinations are available after a few iteration steps, which allow a regression estimate.[450] If both functions are known, the mathematical determination of the equilibrium point after introduction of a toll is made possible by equating the new supply with the demand function.

This procedure was tested on simulation scenarios, for which the cobweb procedure described above could also be used. This meant that – as opposed to the non-converging scenarios – comparison data was available, which could provide information about the closeness to reality of the values calculated by means of the regression procedure. The procedure is explained below using the scenario of a distance-related toll of 10 ct per vkm for the Stuttgart city centre and a generalized cost elasticity of -0.5 as an example.

In order to estimate the network supply function, car and truck trips were pooled as vehicle journeys. Thereby truck trips were weighted double, compared to car journeys; this corresponds to the assignment procedure in the internal VISUM routines. The weighted average costs per journey were calculated by dividing the sum of the total costs for time, distance and tolls, for both demand segments, by the total number of vehicle journeys.

In the original equilibrium of the model without a toll, 3,809,233 journeys (q) at a weighted cost (c) of 602 ct were made in the Stuttgart metropolitan area. The results in the following inverse demand function for the entire network, if one uses an assumed cost elasticity of -0.5:

$$c = 8{,}737{,}199{,}277{,}892{,}860 * q^{-2}$$

With the data points after 3 or 6 iteration points, respectively, the following alternative network-wide, power-based supply functions were estimated with the regression calculation.[451]

[450] Thereby, it is not necessary for the iterations to converge.

[451] To make this clearer, the number of decimal points were reduced for the functions shown here. The calculations were made with 10 decimal points in order to minimize rounding errors.

$q = 0.000012 * c^{1.1725}$ (3 data points, $R^2 = 0.995$)

$q = 0.0000065 * c^{1.2132}$ (6 data points, $R^2 = 0.959$)

The quality of the estimate of the regression equation, expressed by the coefficient of determination R^2, is also convincing for the case with six data points; this justifies the specification of this type of function. As can be recognized by the exponents of the equation, the network-wide supply in the Stuttgart model is relatively inelastic, i.e. an increase in the number of vehicles causes an over proportional growth in average costs c. This is typical for heavily used road networks and is the cause of the lacking convergence in the cobweb procedure, in the case of a presumed elastic demand in Stuttgart.

The estimated user equilibrium for the traffic network after introduction of a toll is at the intersection of the supply and demand functions. It was calculated by equating supply and demand. In the equation, the following cost-quantity combinations arise for the alternative supply functions (the differences to the model without a toll are shown in brackets):

3,756,370 journeys (-1.39 %) at 619.21 ct average costs (+2.83 %) for the regression equation with 3 data points or

3,756,468 journeys (-1.39 %) at 619.17 ct average costs (+2.83 %) for the regression equation with 6 data points.

The differences in the results for the alternative supply functions are minimal. This makes it clear that even with very few data points, a useful estimate of the network-wide supply function is possible; this saves valuable VISUM computing time. Further test calculations of other scenarios with a different number of data points confirm the results achieved here.[452]

In order to make a detailed evaluation of effects of the toll scenario on traffic, a VISUM assignment had to be carried out with the aid of the data calculated for the equilibrium point after toll. To do this, the demand matrices of two iteration steps were combined in a linear manner, in such a way that their sum corresponded to the calculated number of journeys in the supposed equilibrium. In the case on hand, the demand matrices for cars and trucks from the first two iteration steps were mixed in the relation 14:86 and reassigned to the network. When evaluating the simulation run, the actual average costs per journey of 620.57 ct were determined; this is a deviation of merely +0.23 % compared to the calculated values for the user equilibrium. This, as well, supports the procedure's practicability and

[452] The regression was based on 5 data points in each case in the four scenarios that were calculated with the procedure.

closeness to the results of the cobweb procedure. In addition, the simulation run was evaluated with respect to the effects on traffic that were modeled. In Table 84 and Table 85, the differences for selected traffic key figures are shown, in comparison to the cobweb procedure.

Area	Iterative Step	Quantity Trips	Average Costs per Trip	Average Speed
Stuttgart City Area	No. 5	-1.33 %	+1.50 %	+4.55%
	No. 6 (Final Step)	-1.30 %	+1.62 %	+3.95 %
	Estimated Supply Function	***-1,39 %***	***+1.34 %***	***+4.74 %***
Stuttgart City Center	No. 5	-3.12%	XXX	+2.78%
	No. 6 (Final Step)	-2.98%	XXX	+1.39%
	Estimated Supply Function	***-3.17%***	***XXX***	***+2.91%***

Table 84: Comparison of the Results of the Iterative Cobweb Procedure vs. Estimated Supply Function in Stuttgart (Toll 10 ct/vkm, Elasticity -0.5)[453]

With the cobweb procedure, in the event of convergence, the differences for the control parameters: number of journey average costs per journey mileage, journey duration and average speed always become smaller during the course of the iteration. For this reason the real values for these parameters will usually be between those of two consecutive iterative steps. As shown in Table 84 and Table 85, this does not apply to values modeled by the supply function; forecast values for reductions in travel demand tend to be too high. However, deviations between the key figures calculated iteratively and the regression-based values calculated for the region being considered are very small. Therefore, it can be assumed that the procedure developed here for determining a user equilibrium by calculation represents a useful complement to the Cobweb procedure.

[453] Source: Own representation.

Area	Iterative Step	Quantity Trips	Average Costs per Trip	Average Speed
Stuttgart City Area	No. 5	-3.20%	+7.31%	+9.09 %
	No. 6 (Final Step)	-3.18 %	+7.39%	+8.04 %
	Estimated Supply Function	***-3.38 %***	***+7.01 %***	***+9.45 %***
Stuttgart City Center	No. 5	-7.76 %	XXX	+4.60 %
	No. 6 (Final Step)	-7.61 %	XXX	+2.04 %
	Estimated Supply Function	***-7.83 %***	***XXX***	***+5.26 %***

Table 85: Comparison of the Results of the Iterative Cobweb Procedure vs. Estimated Supply Function in Stuttgart (Toll 25 ct/vkm, Elasticity -0.5)[454]

The precision of the prognosis of the regression procedure seems to be sufficient, especially for strategic planning. Above all, this method allows statements to be made about the effects of a toll on traffic, which are close to results of the cobweb procedure, even if the latter does not converge.

[454] Source: Own representation.