Evaluating Policies to Achieve Emission Goals in Urban Road Transport

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1. Introduction

Many large cities have developed a climate change program that usually determines very ambitious goals concerning the reduction of carbon and other greenhouse gas emissions within the next decades. But in most of them transport is supposed to contribute only to a small extent to achieving those goals and many measures dealing with emissions from transportation are not yet implemented. And even if there is something done, instruments chosen are usually relatively weak. Given the large bulk of studies on that topic one wonders why cities are not adopting better instruments.

This is our point of departure. We examine whether transport oriented policies that are actually available can contribute to achieving carbon emission goals on the urban level. To be more specific: we ask whether speed limits, cordon tolls and highway tolls can be used to achieve those goals also in urban transport[1]. And, second, we evaluate the relative performance of these instruments to identify the most efficient of these policies. Our choice of instruments includes different types of policies: regulation, road pricing and as control an external market driven price increase that might imply that policy action is not required.

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[1] We do not consider other policies that are also feasible for cities such as parking policy, expanding or subsidizing public transport, changes in road capacity or routes available, or a stepwise switch to electric vehicles. Concerning parking there is some research, for instance, Calthrop andProost (2006). In particular there is a discussion whether parking fees can be a substitute for congestion tolls. This depends on the relative differentiation of both instruments concerning time, location, peaks (e.g. Calthrop et al. 2000). The effects of subsidizing public transport on CO_2 emissions has been studied by Parry and Small (2009), for Brussels by Mayeres and Proost (2005) and together with other transport subsidies by and Hirte (2012) and Hirte and Tscharaktschiew (2013a). Anas and Timilsina (2009) study the effects of changes in road capacity in Beijing on CO_2 emissions. Concerning electric vehicles there is a study on the effects of subsidizing electric vehicles in cities by Hirte and Tscharaktschiew (2013c). In addition there is research on the effects of emission and fuel taxes. In some countries, e.g. the U.S. those taxes are to some extent control variables of local governments. Tscharaktschiew and Hirte (2010) provide a simulation study on the impacts of congestion tolls and emission taxes including their interaction for metropolitan areas. Concerning fuel taxes there is, for instance, a study for Mexico by Parry and Timilsina (2010).

For each scenario we calculate the benefits and costs by applying a computable spatial general equilibrium approach. This provides us with a kind of extended costs-benefit analysis where all repercussion effects are taken into account. We focus on CO_2 emissions but, of course, the policies considered simultaneously work against other emissions, too.

Of course, there are uncountable studies on effects of those policies. While most of the literature focuses on countries, we explicitly focus on the city level. Concerning this, the number of studies is much smaller. Further, most studies examine a single policy[2] whereas we compare a variety of policies and are therefore able to evaluate the relative performance of these policies.

There is a huge literature on greenhouse gas emissions of transport and on evaluating measures to internalize corresponding externalities[3]. In addition to theoretical and scientific literature a bulk of studies, the most influential written for the EU commission, suggest and discuss various policies to lower transport induced emissions. This literature is part of the more comprehensive literature on externalities in transport. Very influential works are those of Verhoef (1996), Parry and Small (2005) and the UNITE (see Link et al., 2002) and IMPACT (see Maibach et al., 2008) studies for the EU commission. Anas and Lindsey (2011) and Lindsey (2010) provide an overview on the literature of road user charges and Parry et al. (2007) an overview of different policies applicable to lower externalities of road traffic. A recent survey on the literature on environmental policies in transportation is provided by Proost and van Dender (2013) and many topics are discussed in the Handbook of Transport and Environment (Hensher and Button 2003). Despite that, there is much less applied work concerning transport in cities (see a recent overview by Anas and Lipsey, 2011). Moreover, those policies are also a hot topic in national and supranational policies (e.g. EU, 2011). This includes regulation such as CAFE in the U.S. or the EU emission standards for car fleets.

There are some examples on the city level of very specific policies to reduce externalities in transport such as the ERP scheme in Singapore enacted in 1998 and its predecessor Area License Scheme (e.g. Santos et al., 2004), the London Congestion Pricing Plan (LCC) introduced in 2003, the Congestion Pricing Program in Stockholm implemented in 2006, respectively 2007, and the Milan Ecopass. These schemes produced positive side effects on the city's GHG emissions. CO_2 emissions went down in 2008 by 22 per cent under the LCC (Transport for London, 2006), by 14 per cent in Stockholm (Eliasson, 2009) and by 15 per cent in Milan (Rotaris et al., 2010). These co-benefits are usually not the focus of that policy and are hardly discussed. This shows that policies primarily not implemented to fight

[2] E.g. studies on highway congestion charges only consider this policy (e.g. Daniel and Bekka, 2000). However, there are some studies where a smaller number of policies are considered (e.g. Tscharaktschiew and Hirte, 2012) or a number of policies in a partial equilibrium approach, e.g. the TRENEN model (Mayeres and Proost, 2005).

[3] There are many studies proposing estimates of externalities of road transport, e.g., Quinet (2004) or van Essen et al. (2008). Link et al. (2002), Infras/IWW (2004), Infras (2007) or Hirte (2008 and 2009) focus on transport externalities in Germany.Delucchi and McCubbin (2009) provide estimates for the U.S.

emissions but to lower congestion and noise might also reduce emissions. Whether they are efficient instruments is not unambiguously clear[4].

Our findings show clearly that transport policies have a high potential to reduce emissions. It is therefore not convincing that most cities do either not suggest including transport in their mitigation policies or do not enact strict measures. If mitigation is costly then an efficient policy should invest in that policy that provides the highest marginal benefit of the investment. This is supposed to include policies aiming at transportation.

We proceed as follows. First, we determine a carbon emission goal for our model city. Then we present the basics of the simulation model: Its structure, some theory and the calibration. Subsequently we present the results of the simulation and, eventually, provide some conclusions.

2. Emission Goal

We derive our carbon emission goal for our model city by referring to the policy of the City of Hamburg the second largest city in Germany. Its policy is linked to the national aims, is well documented and gives an idea of climate change oriented policies of many German cities.

The City of Hamburg announced to reduce CO_2 emissions from 1990 to 2020 by 40 per cent (Hamburg, 2011)[5]. According to some figures published by the city emissions went down from 20.7 mill t/a in 1990 to 17.6 mill t/a in 2007 and to estimated 16.5 mill t/a in 2012 (Hamburg, 2011, Rabenstein, 2011). However, a reduction of 40 per cent implies that in 2020 emission should be at most 12.4 mill t/a. This is a reduction of 23.6 per cent in comparison to 2012. We take this figure seriously and assume in the following that emissions in transport shall be reduced by about 24 per cent in the medium term[6].

We then ask whether a city can carry out policies that are effective to achieve this goal and what are the social net costs of these policies. However, we do not wish to focus on Hamburg but provide a more general answer. For this reason we develop and use a general model of a city and calibrate this to typical figures of the largest German cities. So we construct some kind of prototype of a German city. Nonetheless, our results also carry over to other cities.

4 Concerning congestion, Tscharaktschiew and Hirte (2010) have shown that congestion tolls contribute considerably to emission goals and might be more efficient than other instruments because they simultaneously internalize congestion and climate change externalities.

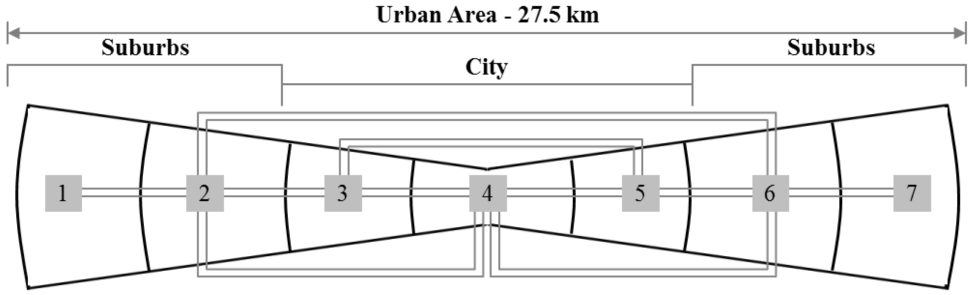
5 Until 2050 the reduction shall achieve 80 per cent of the 1990 level and 75 per cent of the 2012 level. Similar goals can be found for other cities. E.g. London wants to achieve a reduction of 60 per cent in 2025 in comparison to the 1990 level (e.g. Transport for London, 2012).

6 The findings will not change significantly if the emission goal is slightly changed. For instance, the EU aims at a reduction of thirty per cent of carbon emissions between 2008 and 2030. Using such a goal will not affect the quality of the findings.

3. Model

Our model is based on the RELU-TRAN model of Anas and coauthors (Anas and Xu, 1999, Anas and Liu, 2007) and on further developments provided by Tscharaktschiew and Hirte (2010, 2012) and Hirte andTscharaktschiew (2013a). The transport network and the calibration are taken from Nitzsche and Tscharaktschiew (2013).

Figure 1: The spatial structure of the prototype



The model is a spatial city model. The city is composed of seven districts (see Figure 1) of different size. The inner three zones represent the 'City' while the other represents the suburbs. Zone 4 is the city center.

Districts are linked by a network of main roads. It is possible to drive from zone to zone through the whole city. In that case transport crosses the city center. In addition there are some faster roads linking different districts. For instance it is possible to drive from zone 2 or zone 6 directly to the city center (zone 4) without using local streets in zone 3 or 5. Further there are large roads (city highways, ring roads) linking suburbs 2 and 6 and those linking suburbs 3 and 5.

Households in the city decide on residence location and on the work location in a discrete choice approach (see Anas and Liu, 2007). This random utility approach makes the spatial structure more realistic in comparison to a standard monocentric city model. Households further choose shopping locations, the amount of consumption, their supply of labor in terms of workdays and the size of their flats. Further, there is a discrete choice of transport modes and routes. Households work and shopping location choice implies that firms implicitly decide on the location of their facility, too. Final goods are produced by firms that use intermediates, land and labor as inputs. Intermediates are also produced in different zones by using labor and land as inputs. Intermediates have to be delivered to the final good producer. This generates freight traffic.[7] Further, there is a local and a federal government levying income and sales taxes and consuming public goods. Monetary transport costs are paid to an external transport sector providing services, fuel and cars. A share of local land

7 A full description of the model is provided by Nitzsche and Tscharaktschiew (2013).

rents is redistributed to city inhabitants while the larger share is income of absentee landlords.

To avoid effects that occur due to money that vanishes in some kind of black hole or falls down like manna from heaven, i.e. the outside world, the model is closed by a current account that is balanced. This ensures that the simulations include all repercussion effects and considers the whole welfare change. By this we mean the following: different policy schemes imply differences in tax payments to the national government, in deliveries to and from other German states, in demand for intermediates,in public consumption or variations of income transfers to absentee landlords and payments to the transport sector. This changes net money flows out of the city and implies social gains or losses outside of the city. Because we do not model this outside world in a fully specified way our welfare calculations would not represent the whole impact of the policy. As a consequence welfare differences among the policies might stem from money that makes the city poorer or richer simply because it vanishes from the city economy or falls down from nowhere into the city economy. This would severely bias the comparison of the different policies. For this reason, money flows leaving the city have to be equal to the money flows entering the city. Therefore the current account should be balanced. Besides, this is also fulfilled in the real world where this balance is an outcome of economic accounting.

4. Calibration and the Base City

The model is calibrated so that it reproduces some general features of large German cities as well as standard parameters known from the literature. Table 1 and Table 2 display some of the figures used in the model and a comparison to data for Germany and large German cities.

Table 1 presents the figures taken from Germany as a whole. For instance, the gross wage in the model is on average 20.36 € per hour while it is 20.33 € in Germany. Model split, the ratio of shopping trips to commuting trips, the share of commuting and housing costs on income or average daily travel time and travel distance fully reflect German data.

Table 2 shows further figures including those known for large German cities. For instance, the job to residents ratio reproduced in the model is 0.91 in the center and 1.27 in the most distant suburbs. This is about the level found for Hamburg (HH) and Stuttgart (S).

Table 1: Calibration vs. real data (1)

Average	Modell	Data		Source
Gross wage (€/h)	20.36	20.33	2010	[1]
Workdays (days/a)	217	213-222	2010	[2]
Net income (€/a)	34184	34476	2009	[1]
Income share of travel costs of housing costs	 0.11 0.22	 0.11 0.23	 2009 2010	 [1] [3]
Ratio shopping trips/commuting trips	1.51	1.50	2008	[4]
Daily travel time [min]	87	79-88	2008	[4]
Daily travel distance [km]	37	39	2008	[4]
Modal split car/transit/foot	 0.52/0.30/0.18	 0.52/0.30/0.18	 2008	[4]

[1] Federal Statistical Office (2011) [2] IAB (2011)[3] Federal Statistical Office (2012)
[4] Federal Ministry of Transport, Building and Urban Affairs (2010)

Table 2: Calibration vs. real data (2)

Average figures	Model	Data		Source
Share of freight traffic	0.09	0.08	2010	[a]
Car speed [kmh]	33	30	2002	[b]
Fuel consumption [l/100km]	7.9	8.0	2008	[c]
GDP per capita [1000 €]	44.6	44.4 (N) 47.5 (HH)	2009	[d]
Daily work hours Daily non work hours[h]	7.53 10.47	7.51 10.49	2002	[e]
Ratio of jobs/residents Center Border suburb	 0.91 1.27	 0.79/0.89 1.33/1.56	 (HH, S) (HH, S)	 [f]

[a] Federal Ministry of Transport, Building and Urban Affairs (2012)
[b] Federal Ministry of Transport, Building and Urban Affairs (2004)
[c] Federal Statistical Office (2010) [d] Statistical Offices of the Länder (2010)
[e] Federal Statistical Office (2004) [f] Siedentop (2007)

5. Policy Measures to Achieve the Emission Goal

Next we present the results of our simulations. According to our strategy we have varied all instruments to find that level of a policy that allows achieving the emission goal. If it is not possible to do so, we choose the policy that reduces emissions as far as possible and that we consider to be feasible.

Policy 1: Regulation – speed limits.
Many cities in Germany and also in other countries have enacted speed limits in residential areas of the cities. For this reason our first policy is to introduce a general speed limit of 30 kmh on all roads within the city. As it turns out it is exactly this level that lowers CO_2 emissions by 24 per cent.

Policy 2: Cordon toll.
London and Stockholm have introduced a cordon toll for the inner city. Obviously this instrument is feasible and works. Therefore we choose this instrument as our Policy 2. We distinguish three different cordon tolls on travelling into the City:

- **Policy 2a) a cordon toll on all road transport,**
- **Policy 2b) a cordon toll on passenger travel,**
- **Policy 2c) a cordon toll on freight traffic.**

Policy 3: Highway toll.
Our third policy is a highway toll. We choose this instrument because it is feasible. Cities can and some even do impose charges on main roads such as tunnels or bridges. In Germany and some other countries there is also a toll on highways. In Germany the toll is only levied on lorries in other countries also on cars. Though these tolls are often not charged within urban areas we consider a highway charge as feasible. We distinguish

- **Policy 3a) a highway toll on passenger travel,**
- **Policy 3b) a highway toll on freight traffic.**

Scenario 4: Do nothing - increase in fuel prices.
Finally, there is a discussion that the market driven raise of fuel prices might be a good enough substitute for policies. Then, policies should do nothing. To get an idea of this reasoning, we consider a huge exogenous increase of fuel prices as Scenario 4.

To be able to compare different policies without imposing an arbitrary bias we held public expenditure constant and redistribute any change in tax revenue via lump sum taxes[8]. This kind of tax recycling is in particular large when toll revenue accrues (Policy 2 &Policy 3). Concerning transportation it is even more important how to specify tax recycling. The reason is that transport demand and so the tax base are inelastic. Therefore, high tax rates are needed to achieve an internalization of externalities. This generates high tax revenue and a large tax recycling effect (see Mayeres and Proost, 2001).

The best way to recycle taxes is to reduce the most distorting tax in the system (e.g. Parry and Bento, 2001). Often income tax recycling is considered (e.g. Parry and Bento, 2001, or

[8] We adopt a balanced budget approach and assume that government expenditure other than taxes or transfers are fixed. This approach is state of the art. An important reason for adopting this procedure is that we want to avoid specifying how government expenditure enter welfare, i.e. whether government expenditure are wasteful or welfare enhancing.

Parry and Small, 2005). However, in the German case there is neither a local income tax nor a local VAT. We want to make things as simple as possible and assume that revenue is equally redistributed to all inhabitants of the city via transfers[9]. This implies that our calculations underestimate the benefits of Policies 2 and Policies 3.

Further, we consider heterogeneous households. Since the marginal utility of income differ across households in the random utility approach according to the stochastic preference parameter (e.g. Anas, 2013), the way revenue is redistributed is important. Nonetheless, we choose lump sum recycling because we are not primarily concerned with redistribution and we cannot lower property tax or city's fees that are absent in the model. Unfortunately, the sign of this redistribution effect cannot be assessed in advance. In general we expect that lump sum recycling generates redistribution in favor of the poorer households and, thus, provides another benefit of tax instruments[10].

6. Results

In the following we present and discuss the results of our policy simulations. We first present changes in externalities, then those on the household level before we present the welfare changes.

Our simulation is a comparative static exercise and we do not consider any dynamics. Nonetheless, we can give a range for the time horizon implicitly assumed in the model. By assuming that structures, i.e. buildings, roads and infrastructure of public transit are constant in the simulations, we do not consider long term investment decisions. As a consequence people respond only in a medium term way – they can adjust quantities but also travel mode and routes, and they also can relocate their residence and work location. Therefore we dare to say that the time horizon in the simulation is between ten and twenty years and fits the time horizon of the emission goal defined above.

We begin with the results on externalities, then we move to findings concerning households, transport and land use and, eventually, turn to the cost-benefit evaluation that is based on equivalent variations.

6.1 External Costs

We present the changes in different transport related externalities in Table 3. Each column represents a scenario.

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9 Besides, most distortionary taxes are federal taxes in Germany. The cities' power to tax is restricted to supplements on property and trade taxes, as well as on some very small taxes.

10 Hirte and Tscharaktschiew (2013a) provide a derivation of optimal policy in a random utility city model where the redistribution is explicitly derived. This shows that redistribution matters not only with respect to net tax payments but also concerning transport and the land market.

Table 3: Impact on externalities

Aim **CO_2** **-24 %**	**(1)** **Speed limit** **30 kmh**	**(2a)** **City toll** **5.60€**	**(2b)** **City toll (cars)** **5.60€**	**(2c)** **City toll (freight)** **5.60€**	**(3a)** **Highw. toll (cars)** **10.30€**	**(3b)** **Highw. toll (freight)** **9.60€**	**(4)** **Fuel price** **+221%**
Accident	-63.0	-48.9	-45.6	-0.4	-21.2	1.3	-36.0
CO_2	**-24.3**	**-25.0**	**-24.0**	**-0.3**	**-4.9**	**-0.2**	**-24.3**
Air pollution	-19.2	-9.8	-8.9	-0.4	-4.6	-0.4	-9.7
Noise	3.5	-14.9	-8.3	-0.5	1.4	2.6	-7.7
Travel time	20.3	-1.0	0.8	-0.1	6.3	-0.1	-0.8

Changes in per cent in comparison to the benchmark. Columns (3a) and (3b) are based on the maximum reduction achievable with the respective instrument.

Policy 1: speed limit of 30 kmh.

In column two of Table 3 we show the findings for a city wide speed limit of 30 kmh. Because a speed limit of 30 kmh is already standard in living quarters in many German cities, we assume that this is the strongest speed limit that can be implemented. We tried to differentiate the speed limit for different zones and routes. However, it turns out that only a general speed limit of 30 kmh that includes city highways is sufficiently high to achieve the carbon emission goal. The row named "CO_2" reveals that carbon emissions drop by 24 per cent as response to this general speed limit (see column (1) of Table 3). There are positive co-benefits because a lower speed also reduces accidents and other air pollution to a large degree and more than under all other scenarios. In contrast, slower speed raises noise because more traffic shifts to local streets. People avoid the highways because distances to be traveled are longer while speed limits imply that velocity is not higher compared to that on other roads. As a consequence car traffic in the living quarters increases.

Policy 2: cordon toll (City toll).

Imposing a cordon toll of 5.60 € for each trip into the City, i.e. the inner three zones, reduces emissions by about 25 per cent (see columns (2a) and (2b) of Table 3). A cordon toll of 5.60 € to be paid for a trip into the city might not be unfeasible. A two-way public transit ticket costs about the same in some large German cities. According to our findings, this toll can be used to achieve the emission goal. However, a cordon toll levied only on freight traffic does not have any significant effect (see column (2c) of Table 3). Therefore the toll can either be levied on cars and freight ("City toll"), or only on cars ("City toll (cars)"). The effects of both are very similar. The reason for the small effect of a freight toll is that freight traffic is only about nine per cent of all road traffic and freight traffic is less elastic than passenger travel. Under the City toll accidents and air pollution fall considerably, even not so much than with the speed limit. However, this measure also reduces noise and does hardly affect travel time. Surprisingly, there is a small increase in travel time because in our case traffic crossing the border between the city and suburbs declines while traffic within the city and within the suburbs increases. The effect on carbon emission is comparable to the effect in London.

Policy 3: highway toll.
A highway toll on private cars and on freight traffic is not suitable to achieve the emission goal (see column (3a) and (3b) in Table 3). A charge of 10.30 € per two-way trip for passenger cars and of 9.60 € per two-way freight trip has the strongest impact on emissions. At that high level of the charge carbon emissions can be reduced by only 5 per cent with policy (3a) while a charge on freight does not affect carbon emissions at all. Because a charge on the highway changes route choice, congestion in the city increases. These results show that charging freight traffic on beltways provides no positive effect on emissions. They might even cause adverse effects on accidents and noise because freight traffic switches to inner city roads.

Scenario 4: Do nothing – increase in fuel prices.
As soon as worldwide economic growth is increasing again after the recent crisis, fuel prices are expected to increase. Because a rise in fuel prices is supposed to reduce traffic and, thus, emissions the issue arises whether an additional instrument is required. We found that a raise in the fuel price of 221 per cent is required to reduce emission by about 24 per cent (see column (4) in Table 3). If the price increase is smaller policy action should be discussed. Effects on accidents, air pollution and noise are also positive even not as large as under policies 2a and 2b. Nonetheless it becomes clear that an increase in fuel prices will lower the need for other instruments.

6.2 Household Decisions and Transport

The measures affect individual decisions through different channels. We can show this by looking at the individual decision in a formal way.

In a discrete monocentric city model households maximize utility subject to the monetary budget constraint and a time constraint. If consumption, leisure and housing provide utility, these are the three control variables for the non-location decision.

Assume that preferences can be represented by a quasi-concave, twice differentiable utility function $u(x, q, l, a)$, where x is consumption, q is housing, l is leisure and a represents local externalities such as noise and air pollution. It is assumed that the latter are exogenous in the household decision even though they depend on travel decisions of all households. To simplify presentation of the small formal model we reduce consumption to local consumption and do not consider VAT taxes. Hence, we do not consider shopping trips to other zones even though they are included in the simulation model.

The monetary budget constraint ensures that expenditure for goods px, with p as consumer price that includes local shopping trip costs, plus those for housing rq, where r is the location dependent price of a square meter of land, equals monetary income. Monetary income is daily net wage income, where w is the hourly wage net of income taxes and h are daily work hours, minus commuting costs that depend on location decisions. Hence: $px + rq = (wh - cd)D + T$, where c is commuting costs per vehicle kilometer traveled (VKT), d is commuting distance, D is the number of workdays or commuting trips, and T are transfers from the government.

The time budget constraint states that yearly working time plus commuting time plus leisure plus time required for local shopping trips equal the yearly time endowment E, thus, $(h + td)D + l + td_x x = E$, where t is travel time per VKT and d_x is the shopping distance.

Consolidating both equations yields the following Lagrangian

$$\mathfrak{J} = u(x,q,l,a) - \lambda\{px + rq - (wh - cd)D - T\} - \mu\{(h + td)D + l + td_x x - E\}, \quad (1)$$

whereλ represents the marginal utility of income and $\mu$the marginal utility of time. Maximizing with respect to $x, q, l$and the number of workdays Dyields the first order conditions for the non-location decision variables.[11]

$$\left.\begin{aligned} &\mathfrak{J}_x: \frac{\partial u}{\partial x} - \lambda p - \mu t d_x = 0 \\ &\mathfrak{J}_q: \frac{\partial u}{\partial q} - \lambda r = 0 \\ &\mathfrak{J}_l: \frac{\partial u}{\partial l} - \mu = 0 \end{aligned}\right\} \quad \begin{aligned} &\rightarrow MRS_{qx} = \frac{p + \vartheta d_x}{r} \\ &\rightarrow MRS_{lx} = \frac{p + \vartheta d_x}{\vartheta} \end{aligned} \quad (2)$$

$$\mathfrak{J}_D: \lambda(wh - cd) - \mu(h + td) = 0 \rightarrow \vartheta \equiv \frac{\mu}{\lambda} = \frac{wh - cd}{h + td}$$

The marginal rate of substitution between housing and consumption, MRS_{qx}, as well as the MRS between leisure and consumption, MRS_{lx}, equals the inverse relative price of both goods. The value of time (VOT), ϑ, represents the opportunity costs of time and is equal to daily labor income minus commuting costs per unit of daily time required for working. The latter is the sum of daily work hours and commuting time. The VOT amounts to about 50 per cent of the daily gross wage.

11 We assume that households can vary their number of workdays but that the number of daily hours is fixed. One can think of different ways to vary the number of workdays per year. In the medium term this includes that people can choose to work only a share of the year. If households decide to work, they choose a contract that specifies the number of hours per day. This specification generates a link between labor supply and commuting. Hirte and Tscharaktschiew (2013b) discuss the influence of different ways to model labor supply on transport related issues.

In addition there is the location choice. We follow Anas and Liu (2007) and use the random utility function for each household living in zone i and working in zone j

$$U_{ij} = u_{ij}\left(x_{ij}, q_{ij}, l_{ij}, a_{ij}\right) + \varepsilon_{ij}, \quad \forall ij, \tag{3}$$

which is the sum of the deterministic utility u_{ij}over consumption, housing consumption and leisure, plus an i.i.d. distributed preference parameterε_{ij}. The random utility approach allows reproducing all types of location patterns and produces therefore much more realistic outcomes than a standard discrete monocentric city approach, where each type of household makes the identical decision.[12] If we apply an extreme value distribution random utility maximization yields the probability of a household to choose the location choice set ij given by[13]

$$\Psi_{ij} = \frac{\exp(\Lambda V_{ij})}{\sum_m \sum_n \exp(\Lambda V_{mn})}, \quad \forall ij, \tag{4}$$

whereΛ is the distribution parameter and $V_{ij}$is indirect utility of household type ij that is defined as

$$\begin{aligned} V_{ij} = \{ & \max u_{ij}\left(x_{ij}, q_{ij}, l_{ij}, a_{ij}\right) \\ & s.t.: p_i x_{ij} + r_i q_{ij} = \left(w_j h - c_{ij} d_{ij}\right) D_{ij} + T \\ & s.t.: \left(h + t_{ij} d_{ij}\right) D_{ij} + l_{ij} + t_i d_i x_{ij} = E \\ & s.t.: D_{ij} \geq 0 \}, \quad \forall ij. \end{aligned} \tag{5}$$

These equations show clearly that location decisions depend on all variables and the location preference parameter. Households choose that zone that provides the highest random utility. The stochastic approach allows considering a huge variety of households – in our case 1.5 million households are taken into account.

The policies considered impose different effects. First, they affect global externalities such as carbon emissions. This does not change individual decisions but affects social welfare because it is only a component of aggregate welfare. Second, they affect local externalities such as noise, external accident costs and air pollution. Because these change individual utility and act as some kind of negative amenity, these policies impact location decisions and change the location choice probability (see equation (4)). Third, they affect congestion and, thus, change travel times. As a consequence, the VOT and relative prices change, too (see the variable t in equation (1) and the VOT, ϑ, in the first order conditions (2)). Moreo-

12 A discussion of both approaches is provided by Anas (2013).
13 See, for instance, McFadden (1974), Ben-Akiva and Lerman (1985), Anas and Liu (2007).

ver, changes in tax revenue also imply changes in distortions caused by other taxes. This is extensively discussed in environmental economics[14]. These effects occur due to tax recycling, tax interaction, i.e. changes in revenue and, thus, distortions from other distortionary taxes, and due to tax shifting, i.e. new distortions generated by the policy instrument. These distortions arise because taxes change the relative prices of goods and, so, change substitution effects in favor of the relatively cheaper good (they are included in$p$, w or c in (2)). Third, there might be income effects via redistribution of toll revenue and from changes in revenue of other taxes (see Tin (2) and (5)). And, fourth, there might be repercussion effects from general equilibrium changes in wages due to changes in local labor supply, in rents due to changes in land demand and in good prices due to changes in demand and supply of local goods. These repercussions impact on all other effects[15].

It is hardly possible to derive a unique sign and intuition of the effects of the scenarios on individual decisions. For instance, the speed limit policy (column 1 in Table 4) lowers speed and, thus, raises travel time considerably. As a consequence the VOT declines making leisure relatively more attractive than consumption. Therefore, one expects that leisure increases while labor supply declines as do consumption and housing. However, as column (1) in Table 4 shows leisure declines in the simulation. This comes from repercussion effects on labor demand. Firms face lower demand and higher costs of transport for intermediates. Hence, intermediate demand falls and, in the end, labor demand declines too. This causes an average decrease in income that lowers leisure demand.

Further changes concern land use and transport. Policies also affect location decisions of households (see (4) in combination with (5)) including decisions on shopping destinations as well as route choice and modal choice. Some information on location changes are given in the lower part of Table 4. Raising travel costs for households unequivocally raises population density in the center while lowering it in the suburbs. For instance, population density in the City increases by 0.5 per cent as response to the speed limit. In contrast firms move outwards to benefit from the larger intermediate supply in suburbs and reduce transport costs, thus, decreasing the job density in the City.

Imposing a toll also lowers the VOT. However, toll revenue is redistributed imposing an additional income effect. As a consequence leisure demand, consumption and housing increase while labor supply declines (columns 2a and 2b in Table 4). Imposing a toll on freight transport (FT) produces amuch smaller income effect (columns 2c and 3b in Table 4). Hence, the substitution effects might determine the overall sing of leisure and consump-

[14] E.g. see Bovenberg and de Mooji (1994), Parry (1995), Bovenberg (1999) or Parry and Small (2005).

[15] It is generally possible to derive the effects of different policies on welfare analytically. Parry and Small (2005) do so for fuel taxes and Calthrop et al. (2007) for congestion tolls, both deriving the different components described above. They, however, do not use a spatial approach and are, thus, not closely linked to this study. Hirte and Tscharaktschiew (2013c) provide such a derivation for subsidies on electric vehicles in a second best random utility approach and Anas (2013) show the general approach to derive such effects in a first best random utility approach. However, in all cases the signs are not unequivocal and have to be determined by running simulations.

tion. Finally, a raise in the fuel price (column 4 in Table 4) lowers the VOT directly but does not create an additional income effect. On the other side, the higher fuel price raises demand of the transport sector that includes fuel producers for urban goods, increases exports and the demand for labor in comparison with the initial reduction in labor supply. This raises wages and, eventually, the substitution effects are more than offset by the expansion of labor demand by firms.

Table 4: Changes in household and spatial structure

Aim **CO_2** **-24%**		**(1)** **Speed limit** **30 kmh**	**(2a)** **City toll** **5.60€**	**(2b)** **City toll (cars)** **5.60€**	**(2c)** **City toll (freight)** **5.60€**	**(3a)** **Highw. toll (cars)** **10.30€**	**(3b)** **Highw. toll (freight)** **9.60€**	**(4)** **Fuel price** **+221%**
Household								
Consumption		-2.1	0.2	0.4	-2.4	-0.8	-0.1	-1.8
Housing		-0.8	0.3	0.1	1.4	0.2	0.1	-0.9
Leisure		-1.1	0.3	0.2	1.1	-0.3	--	-0.2
Workdays		-2.7	-0.6	-0.4	-1.2	-0.9	--	0.5
Density								
Households	City	0.5	0.9	0.4	-0.1	0.2	-0.2	0.7
	Suburbs	-0.4	-0.6	-0.3	--	-0.1	0.2	-0.4
Jobs	City	-0.3	-0.9	-0.1	--	-0.1	--	0.3
	Suburbs	0.2	0.6	0.1	--	--	--	-0.2

Changes in per cent in comparison to the benchmark. Columns (3a) and (3b) are based on the maximum reduction achievable with the respective instrument.

Table 5 displays changes in transport variables. All policies except for freight tolls (FT) lower average distances traveled for shopping and commuting and in most cases also average distances of freight traffic (see panel Trips in Table 5). The reason is that all scenarios have some distance related component. However, the speed limit as well as the price increase are stronger tied to the kilometer driven and, so, have a stronger distance relation. This implies that average distances are stronger reduced than under the toll regimes.

Our approach also provides information on changes in the number of trips and distances due to changes in location, which would not be the case in a pure transport model. We can learn from Table 5 that the number of commuting and shopping trips decline in the case of a speed limit or higher fuel price. This is due to the strong decline in labor supply and consumption (see above, Table 4). So, traffic declines considerably due to the reduction of distance and the number of trips under both scenarios (1a and 4, Table 5). Because lower traffic reduces congestion there is a reboundeffect dampening the effect of the cordon tolls on traffic. Under a cordon toll on passenger travel the countervailing income effect raises labor supply and the number of commuting trips as well as the number of shopping trips.

Hence, in the cases of policies 2a and 2b (lower part of Table 5) the changes in the number of trips and the average distance are of opposite sign. In contrast, a highway toll on passenger (Policy 3a in Table 5) causes a shift from highway use to the use of local streets and, so, causes additional time costs. Therefore a rebound effect only occurs under the congestion toll policies (e.g. Hymel et al., 2010).

Table 5: Changes in transport variables

Aim CO_2 **-24%**		**(1) Speed limit 30 kmh**	**(2a) City toll 5.6€**	**(2b) City toll (PT) 5.6€**	**(2c) City toll (FT) 5.6€**	**(3a) Highw toll (PT) 10.3€**	**(3b) Highw toll (FT) 9.6€**	**(4) Fuel price +221%**
Spatial Structure of Trips (change in per cent)								
Shopping	Intrazone	2.8	0.4	0.3	--	1.3	--	2.4
	Neighbor zone	2.4	5.0	4.7	-0.1	1.0	-0.1	0.9
	Extreme cross	-6.8	-0.2	2.1	0.1	-4.4	0.9	-4.2
	Across toll border		-4.9	-5.2	0.1			
Commuting	Intrazone	1.9	0.4	0.2	--	1.0	--	2.5
	Neighbor zone	1.8	3.5	3.2	-0.1	0.9	-0.1	1.4
	Extreme cross	-3.5	0.4	2.1	--	-3.3	0.7	-4.9
	Across toll border		-3.5	-3.7	--			
Freight	Intrazone	1.0	0.4	-0.9	15.5	--	0.2	1.1
	Neighbor zone	0.7	0.3	-0.3	4.4	-0.1	0.2	0.6
	Extreme cross	-2.0	-0.4	0.4	15.7	--	-0.8	-1.7
	Across toll border		-0.4	0.4	-1.1			

Trips (changes in per cent)								
Shopping	Av. dist. No of trips	-6.6 -2.1	-2.7 0.2	-2.0 0.4	-- -0.1	-2.6 -0.8	0.2 -0.1	-3.4 -1.8
Commuting	Av. dist. No. of trips	-7.4 -2.7	-2.5 0.6	-1.8 0.4	-- -0.1	-2.8 -0.9	0.2 --	-3.6 -0.5
Freight	Av. dist. No. of trips	-6.4 -2.9	-1.4 -0.4	-3.3 0.8	-- -0.9	0.3 -0.6	-1.2 -0.2	-2.1 --
Speed (changes in per cent)								
Cars		-17.9	21.2	22.7	--	-7.2	0.6	24.8
Freight		-11.1	32.1	31.4	0.7	2.7	-3.7	25.6

Changes in per cent in comparison to the benchmark. Columns (3a) and (3b) are based on the maximum reduction achievable with the respective instrument.

The upper part of Table 5 provides even more information on travel distances. It distinguishes changes in trips within the home zone of firms and households (intrazone traffic), to neighboring zones and across the whole urban area (extreme cross). It also shows changes in travel trips across the toll border between zone 2 and 3, respectively, zone 5 and 6. The distance related scenarios 1 and 4 generate the strongest change in traffic pattern. The number of trips in the home zone or the neighbor zone increases while traveling across the whole urban area declines. Slightly weaker is the effect of a highway toll on passenger travel (3a). In that case route choice is shifted to local routes. That makes extreme cross-traveling less attractive.

Very interesting is the case of the cordon toll (2a and 2b). In these cases travel destinations are closer to the home zone of the households. Because the toll is only charged when crossing the border between suburbs and the city, households avoid crossing this border and travel among other zones. The figures in columns 2a and 2b of Table 5 reflect this: shopping and commuting traffic crossing this border declines. The effect on freight traffic is hardly to see. This is really surprising – it reflects the fact that firms are less elastic concerning intermediate inputs.

6.3 Welfare and cost-benefit results

As shown there are many changes in the variables: quantities, locations, spatial structure of the city, trips, distances, routes, travel modes, land use pattern and externalities. To evaluate policies it is useful to provide a single measure for the impact of all these changes on social costs and benefits. It would be possible to carry out a standard cost-benefit analysis. However, our simulation approach provides us with much more and better information. For this reason we can go beyond a cost-benefit analysis and consider all kind of interactions. This implies that using the consumer surplus is not appropriate because this measure is path dependent. In our case where so many variables change and where we do not have a dynamic model all variables change simultaneously. This is the reason why we need a general measure that is robust against the time sequence of events. The standard measure that is best suited to compare different policies is the Hicksian equivalent variation, henceforth, EV. The EV gives the income value of the welfare change in the model. To calculate it we need a welfare function.

If we use a utilitarian welfare function, the random utility approach we apply says that urban welfare is the expected sum of indirect utilities of all city inhabitants (see Anas, 2013). The equivalent variation is then that amount of income that has to be given to or taken away from all households so that their expected indirect utility is the same before and after the policy shock.

In particular we consider social welfare and define it as the sum of urban welfare plus welfare of absentee landlords, W_A, minus the social costs of carbon emissions, Em, that is not included in household utility in our approach. Because there is no direct spatial link between carbon emissions in the city and the climate change costs that might occur elsewhere we evaluate carbon emissions with a social cost factor that is within the range of estimates in the literature. This yields the following welfare function

$$W = E\left[\max_{(ij)}(V_{ij} + e_{ij})\right] + W_A - Em$$

The equivalent variation (EV) is then the aggregate of the equivalent variation of the urban households, the income required at old prices to make the absentee landlords as well off as under new prices and income, and the difference in carbon emissions evaluated with the social value of carbon emissions[16].

[16] Because calculating the equivalent variation implies that households might choose another location choice set and it is not possible to follow a specific household from the benchmark to its decision in the counterfactual equilibrium, there is no closed form solution to the equivalent variation (EV) (see Bröcker, 2012). Instead, we approximate the EV in the way Anas and Rhee (2006) suggest. Bröcker (2013) has discussed the bias and resumes that it is small for large policy changes and for ‘fairly heterogeneous households’. Further, there is no indication that relative EVs are strongly biased. In our case the bias is even smaller because we can calculate the EV of absentee landlords and changes in social costs of emissions in the correct way. For these reasons we are very confident that our measure provides results close to the true EV and are certain that this does not have an effect on qualitative findings.

Table 6: Welfare effects (cost-benefit) and externalities in millions of Euro

Aim CO_2 -24%	**(1) Speed limit 30 kmh**	**(2a) City toll 5.60€**	**(2b) City toll (cars) 5.60€**	**(2c) City toll (freight) 5.60€**	**(3a) Highw. toll (cars) 10.30€**	**(3b) Highw. toll (freight) 9.60€**	**(4) Fuel price +221%**
Aggregate EV	**-1213**	**589**	**670**	**-29**	**-434**	**-30**	**-790**
EV as percentage of GDP	-1.8%	0.8%	1.0%	-0.0004%	-0.6	-0.0004%	-1.1%
EV city inhabitants	**-1583**	**73**	**139**	**3**	**-569**	**-6**	**-1162**
EV absentee landlords	-270	-14	42	-36	-72	-9	-30
Externalities (net benefits from reduction of external costs in transport)							
Aggregate	640	530	489	5	206	-15	402
Accident costs	575	447	417	3	193	-12	329
CO_2 emission costs	57	58	56	1	11	--	57
Noise costs	-4	19	10	1	-2	-3	10
Pollution costs	12	6	6	--	3	--	6
Changes in tax revenue							
Toll revenue		568	765				
Energy tax revenue	-239	-224	-220	-2	-49	-2.2	

Welfare effects in millions of Euro. The urban GDP amounts to about 67 billion Euros. Positive values represent positive net benefits in millions of Euro per year. Negative values represent negative net benefits in millions of Euro per year. Changes in Carbon emission in millions of Euro. The Welfare measure is the Hicksian Equivalent Variation (EV). Only changes larger than one million Euros are displayed. Columns (3a) and (3b) are based on the maximum reduction achievable with the respective instrument.

Table 6 displays the EVs and some of the components of the welfare change: changes in externalities evaluated in income terms as well as changes in tax revenue that are components of the tax interaction terms (see Parry and Small, 2005, and for the random utility approach see Hirte and Tscharaktschiew, 2013c). The most important figures are presented in the row “Aggregate EV” and in row “CO_2 emission costs”.

Two policies, i.e. policies 2a and 2b, provide welfare gains while all other policies generate welfare losses. This is the most important result: there are at least two policies that can be used to achieve a high emission goal even for transport without net costs to society. If a cordon toll is levied on passenger travel, i.e. Policy 2b, the EV is about 670 million Euros. That means a 24 per cent reduction of carbon emission can be achieved by levying a cordon toll on passenger traffic without causing a welfare loss. In fact, in our specific case welfare even improves due to this policy. Although transport is getting more expensive, responses of households lower the burden of this raise in transport costs and imply that externalities decline to a large extent and toll revenue is generated. This result will hold even if there are costs of the toll system as long as they stay below 670 million Euros per year. One of the major reasons is that the toll provides additional tax revenue that can be recycled.

In contrast, all other scenarios that are effective to achieve the emission goal generate clear welfare losses. The general speed limit of 30 kmh, the fuel price increase of 221 per cent and the highway passenger toll of 10.60 € are, thus, very costly scenarios. They induce less consumption and less labor supply, hence, less employment. Even though they lower externalities by reducing travel, the costs unambiguously exceed the benefits.

The main objection against these findings might be that we consider a specific case and that some of the assumptions, for instance, the size of the accidents costs are in dispute in the literature and might be too high. Of course, we do not simulate these policies for a variety of cites. Nonetheless, the main findings will be robust. These are not of quantitative but of qualitative nature and coincide with findings from the literature[17]. Because households can respond to policies, they can mitigate adverse effects of policies by changing locations, shortening trips, shifting transport mode, adjusting labor supply and substituting other goods for traveling. In addition policies that provide additional tax revenue that can be funneled back into the economy are supposed to be better than policies that raise travel costs but do not generate such revenue, such as a speed limit. Further, pricing policies allow avoiding stopping traveling for those households that have a high marginal utility of traveling.

The major difference among the scenarios arises from the way changes in revenue are redistributed. If tolls are used for measures that do not generate utility, such as wasteful public consumption, this policy would perform much worse. We consider full redistribution of revenue but there might be better ways to use toll revenue in a welfare enhancing way. Forinstance, subsidizing public transit could provide additional incentives to switch away from car using and, thus, to lower emissions. In that case, the toll could even be lower[18].

7. Conclusion

In this study we examine different policies that can be used by cities to lower carbon emissions in transport. We consider feedback effects among different systems: the transport system, the land use system and economic markets. Our findings show that these feedback effects matter.

[17] Mayeres and Proost (2005) also find that cordon pricing is a very effective and efficient instrument but cordon pricing on trucks is not an effective measure to reduce emissions.

[18] Using revenue generated from taxing passenger transport for subsidizing public transit has been considered by different authors. The results are usually the same: this lowers the costs of the policy (e.g. Tscharaktschiew and Hirte, 2012).

The main finding is that there are policies that allow achieving strong emission goals even in transport. While this is intuitively clear – one could stop all traffic and no emissions would occur – the costs of these policies vary considerably. There are policies, such as a general speed limit or highway tolls on passenger travel that are effective concerning the carbon goal. However, the costs of these policies are so high that the cost-benefit, i.e. welfare analysis, provides a clear negative overall welfare change. Then there are policies that are not effective at all. For instance imposing a cordon toll or highway toll only on freight traffic lowers welfare but there is no payoff with respect to carbon emissions. The reasons are, first, that freight traffic in a city is only a small share of overall traffic and, second, that freight traffic is inelastic and can hardly be avoided. There is a clear policy implication: the highway charge for freight transport should be not levied on highways within metropolitan areas.

Despite that, there are policies that are both effective concerning the reduction of carbon emissions and do not burden society. In our case cordon tolls on passenger transport as well as cordon tolls on all transport both enhance welfare. These policies are the most efficient among the discussed scenarios and net costs are small or even positive. This finding is consistent with the results of Anas and Hiramatsu (2013) in their study of the effects of cordon tolls in Chicago. While there are some uncertainties concerning the exact numbers there are some reasons why this finding is robust. As already reasoned we underestimate welfare gains of these policies because we do not choose the best way to recycle toll revenue. Further, even if we reduce the accident cost component, welfare benefits though smaller do not turn into net losses. And, if we consider a city with a smaller number of routes that allow circumventing the city, the toll could even be lower and welfare would be higher. Therefore we can conclude that achieving emission goals in transport is possible and not expensive to society. Our results also carry over to other greenhouse gases, too.

Our study shows also that changes in travel choices depend also on economic decisions on relocation, labor supply and shopping trips. Therefore, they deviate from findings in a pure traffic model. For instance, in a pure traffic model the reduction of carbon emissions always implies social net costs. Such a model does not consider the beneficial effects of the use of toll revenue.

Eventually, it becomes clear that feedback effects via the tax system, i.e. tax interaction and tax recycling, are decisive for the sign and size of the welfare outcome of the policies. It turns out that the generation and use of these revenues matter.

In the future we will study those policies for Hamburg. We are currently building a RELUTRAN kind of model for the city of Hamburg. Further studies will focus on policies not considered yet, such as parking and land use policies. Concerning the policies considered above we expect that results for Hamburg will look similar concerning the signs and rankings of the policies. However, the specific feature of the harbor might add some additional effects via changes in exports and imports, trade related services or traffic. Therefore, quantitative results of this future research will deviate from those found in this tudy.

The approach we apply has its strength because it links economic, transport and land use decisions and outcomes. It, thus, provides a general picture of the effects of different policies and the interactions among the different fields. If one wants to get more details it would be useful to apply in addition a transport or a land use model and use the CGE results as restriction in those models.

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Abstract

We explore and evaluate different ways to achieve emission goals in urban transport by applying a spatial simulation approach for a metropolitan area. The policies we consider are: a general speed limit in the city, a cordon toll, a cordon toll only on passenger travel, a cordon toll only on freight transport, a highway toll on passenger travel and a highway toll on freight transport. As a control scenario we examine a raise in fuel prices on the market. We find that, except for highway tolls and a cordon toll on freight transport, all other policies as well as the increase in fuel prices are effective with respect to a strong emission goal. However, a toll only on freight transport is ineffective. The welfare analysis shows that both the speed limit and the fuel price increase are very costly for society. In contrast, a cordon toll on passenger travel and a general cordon toll even generate social net benefits. Hence, a cordon toll is an efficient and effective instrument for achieving emission goals on the urban level.

Kurzfassung

In diesem Beitrag werden unterschiedliche Politiken untersucht und bewertet, die es möglicherweise erlauben, städtische Emissionsziele auch im Verkehrsbereich zu erreichen. Betrachtet werden ein generelles Tempolimit in der Stadt, eine Cordon-Maut für den gesamten Straßenverkehr, eine für den privaten Verkehr und eine für den Wirtschaftsverkehr, sowie eine Maut auf den innerstädtischen Schnelltrassen für den Personenverkehr und eine für den Wirtschaftsverkehr. Alternativ wird untersucht, welche Wirkung ein starker Anstieg der Benzinpreise hat. Die räumlichen Gleichgewichtssimulationen in einem polyzentrischen Random Utility Ansatz zeigen, dass ein hohes Emissionsziel sowohl mit einer Cordon-Maut für den Straßenverkehr als auch einer Cordon-Maut für den privaten Verkehr, einer Geschwindigkeitsbegrenzung und einem Preisanstieg für Benzin erreicht werden kann. Eine Belastung des Güterverkehrs alleine ist kein geeignetes Instrument. Eine Geschwindigkeitsbegrenzung sowie der Preisanstieg führen allerdings zu hohen Kosten für die Gesellschaft und sind daher ineffizient. Die Cordon-Maut auf den gesamten Straßenverkehr bzw. eine Cordon-Maut auf den privaten Straßenverkehr können hingegen sogar zu Wohlfahrtssteigerungen führen. Sie sind damit effektiv und effizient. Damit zeigt sich, dass Städte durchaus ehrgeizige Emissionsziele auch im Straßenverkehr umsetzen könnten.

References

Anas, A.(2013). The optimal pricing, finance and supply of urban transportation in general equilibrium: A theoretical exposition. Economics of Transportation, 1, S. 64-76.

Anas, A., &Hiramatsu, T. (2013).The economics of cordon tolling: General equilibrium and welfare analysis. Economics of Transportation, 2, S. 18-37.

Anas, A., &Lindsey, R.(2011).Reducing urban road transportation externalities: road pricing in theory and practice. Review of Environmental Economics and Policy, 5, S. 66-88.

Anas, A.,& Liu, Y.(2007). A regional economy, land use, and transportation model (RELU-TRAN): formulation, algorithm design, and testing. Journal of Regional Science, 47, S. 415-455.

Anas, A., &Timilsina, G. R. (2009).Lock-in Effects of Road Expansion on CO_2 Emissions: Results from a Core-Periphery Model of Beijing. Policy Research Working Paper 5017, The World Bank.

Anas, A., &Rhee, H.-J. (2006). Curbing urban sprawl with congestion tolls and urban boundaries. Regional Science and Urban Economics, 36, S. 510-451.

Anas, A., &Xu, R. (1999). Congestion, land use and job dispersion: a general equilibrium analysis. Journal of Urban Economics, 45, S. 451-473.

Ben-Akiva, M., &Lerman, S. (1985). Discrete Choice Analysis: Theory and Application to Travel Demand. Cambridge:MIT Press.

Bovenberg, A. L.(1999). Green tax reforms and the double dividend: an updated reader’s guide. International Tax and Public Finance, 6, S. 421-433.

Bovenberg, A.L., & de Mooij, R. A. (1994). Environmental levies and distortionary taxation. American Economic Review, 84, S. 1085-1089.

Bröcker, J.(2012). Discrete choice in spatial CGE models.Mimeo, Kiel.

Calthrop, E., De Borger, B.,&Proost, S.(2007). Externalities and partial tax reform: Does it make sense to tax road freight (but not passenger) transport?. Journal of Regional Science, 47, S. 721-752.

Calthrop, E.,&Proost, S. (2006). Regulating on-street parking. Regional Science and Urban Economics, 2006, S. 29-48.

Calthrop, E., Proost, S., &van Dender, K.(2000). Parking policies and road pricing. Urban Studies, 37, S. 63-76.

Daniel, J., &Bekka, K.(2000).The environmental impact of highway congestion pricing. Journal of Urban Economics, 47,S. 180-215.

Delucchi, M., &McCubbin, D. (2009). External Costs of Transport in the U.S., in: de Palma, A., Lindsey, R., Quinet, E., &Vickerman, R. (eds.), Handbook in Transport Economics.Edward Elgar, Cheltenham.

Eliasson, J. (2009). Cost-benefit analysis of the Stockholm congestion charging system. Transportation Research Part A, 43, S. 468-480.

Essen, H.P. van, Boon, B. H., Schroten, A., Otten, M., Maibach, M., Schreyer, C.,Doll, C., Jochem, P., Bak, M., &Pawlowska, B.(2008). Internalisation measures and policy for the external cost of transport.Produced within the study Internalisation Measures and Policies for all external cost of Transport (IMPACT) – Deliverable 3.CE Delft, Delft.

EU (2011).White Paper.Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System.European Commission, Brussels.

Federal Ministry of Transport, Building and Urban Affairs(2012).Kraftfahrzeugverkehr in Deutschland 2010. Keine Wirtschaft ohne Verkehr! Empirischer Einblick in die häufig unterschätzen Dimensionen des Wirtschaftsverkehrs.

Federal Ministry of Transport, Building and Urban Affairs (2010).Mobilität in Deutschland 2008- Ergebnisbericht.

Federal Ministryof Transport, Buildingand Urban Affairs (2004). Mobilität in Deutschland 2002 - Ergebnisbericht.

Federal Statistical Office(2012).Pressemitteilung, Nr. 93 vom 15.03.2012.

Federal Statistical Office (2011).Statistical Yearbook 2011 for the Federal Republic of Germany.

Federal Statistical Office (2010). STATmagazin. Umwelt. Trend zum spritsparenden Auto bremst Kraftstoffverbrauch. 21.01.2010.

Federal Statistical Office, 2004. Datenreport 2004.

Hamburg,Bürgerschaft der Freien und Hansestadt Hamburg (2011). Hamburger Klimaschutzkonzept 2007-2011. Fortschreibung 2010/11.

Hensher, D.A.,& Button,K.J. (eds.)(2003). Handbook of Transport and the Environment.Amsterdam:Elsevier.

Hirte, G.(2008). Abgaben als Instrumente zur Kostenanlastung von externen Kosten und Wegekosten im Straßenverkehr (Appraisal on behalf of“Allianz pro Schiene“). Dresden, Berlin.

Hirte, G. (2009). Führt das Verursacherprinzip zu einer Mehrbelastung für den Straßenverkehr?.InternationalesVerkehrswesen, 61, S. 149-154.

Hirte, G.,&Tscharaktschiew, S. (2013a). Income tax deduction of commuting expenses in an urban CGE study: the case of German cities. Transport Policy, 28, S. 11-27.

Hirte, G., &Tscharaktschiew, S. (2013b). Labor supply in transportation and urban economics. Paper prepared for the Kuhmo/Nectar 2013 conference at Chicago and the ERSA congress 2013 at Palermo.

Hirte, G., &Tscharaktschiew, S. (2013c). The optimal subsidy on electric vehicles in German metropolitan areas: a spatial general equilibrium analysis. Energy Economics, forthcoming.

Hymel, K., Small, K., &Van Dender, K. (2010).Induced demand and rebound effects in road transport. Transportation Research B, 44, S. 1220-1241.

IAB (Institute for Employment Research)(2011).IAB-Kurzbericht, Nr. 19/2011.

INFRAS (2007). Externe Kosten des Verkehrs in Deutschland. Aufdatierung 2005 (Study commissioned by the "Allianz pro Schiene").Zürich.

INFRAS/IWW(2004).External costs of transport. Update study. Final Report (Study commissioned by the ‚InternationalenEisenbahnverbandes UIC').Zürich/Karlsruhe, Paris.

Lindsey, R. (2010). Reforming road user charges: a research challenge for regional science. Journal of Regional Science, 50, S. 471-492.

Link, H., Stewart, L. H., Doll, C., Bickel, P., Schmid, S., Friedrich, R., Krüger, R., Droste-Franke, B., &Krewitz, W.(2002). (UNITE) Deliverable 5, Appendix 1:The pilot accounts for Germany, Version 2.5.ITS, University of Leeds, Leeds.

Maibach, M., Schreyer, C., Sutter, D., van Essen, H. P., Boon, B. H., Smokers, R., Schroten, A., Doll, C., Pawlowska, B., &Bak, M. (2008). Handbook on estimation of external cost in the transport sector.Produced within the studyInternalisation Measures and Policies for All external Cost of Transport (IMPACT). CE Delft, Delft.

Mayeres, I., &Proost, S.(2005). Towards better transport pricing and taxation in Belgium.Working Paper Series no. 2005-04, Catholic University of Leuven.

Mayeres, I., &Proost, S. (2001). Marginal tax reform, externalities and income distribution. Journal of Public Economics, 79, S. 343-363.

McFadden, D. (1974). Conditional logit analysis and qualitative choice behavior, in: Zarembka, P. (ed.), Frontiers in Econometrics. Academic Press,New York.

Nitzsche, E., &Tscharaktschiew, S. (2013). Efficiency of speed limits in cities: A spatial-computable general equilibrium assessment. Transportation Research Part A, 56, S. 23-48.

Parry, I.W. H. (1995). Pollution taxes and revenue recycling. Journal of Environmental Economics and Management, 29, S. 64-77.

Parry, I.W. H.,& Bento, A. (2001). Revenue recycling and the welfare effects of road pricing. Scandinavian Journal of Economics, 99, S. 261-279.

Parry, I.W. H.,& Small, K. (2009).Should Urban Transit Subsidies Be Reduced?.American Economic Review, 99, S. 700-724.

Parry, I.W. H.,& Small, K. (2005). Does Britain or the United States Have the Right Gasoline Tax?. American Economic Review, 95, S. 1276-1289.

Parry, I.W. H., &Timilsina, G. R. (2010). How should passenger travel in Mexico City be priced?. Journal of Urban Economics, 68, S. 167-182.

Parry, I.W. H., Walls, M., & Harrington, W. (2007). Automobile Externalities and Policies. Journal of Economic Literature, 45, 373-399.

Proost, S.,& Van Dender, K. (2013). Energy and environment challenges in the transport sector. Economics of Transportation, 1, S. 77-87.

Quinet, E. (2004). A meta-analysis of Western European external cost estimates. Transportation Research Part D, 9, S. 465-476.

Rabenstein, D.(2011). Trübe Aussichten für den Klimaschutz in Hamburg. Folgen der Veränderungen im Jahr 2011 für das Erreichen der Klimaschutzziele Hamburgs. 1. Fortschreibung der Stellungnahme zum Basisgutachten Masterplan Klimaschutz für Hamburg. Department Bauingenieurwesen, HafenCity Universität Hamburg, Hambug.

Rotaris, L., Danielis, R., Marcucci, E., &Massiani, J.(2010). The urban road pricing scheme to curb pollution in Milan, Italy: Description, impacts, and preliminary cost–benefit analysis assessment. Transportation Research Part A, 44, S. 359-75.

Santos, G., Li, W., &Koh, W. (2004). Transport policies in Singapore. In Road pricing: Theory and evidence. Research in Transportation Economics, 9, S. 209-35.

Siedentop, S.(2007). Auswirkungen der Beschäftigungssuburbanisierung auf den Berufserkehr- Führt die Suburbanisierung der Arbeitsplätze zu weniger Verkehr?.InformationenzurRaumentwicklung, Heft 2/3 2007, The Federal Institute for Research on Building, Urban Affairs andSpatial Development (BBSR).

Statistical Offices of the Länder(2010).Volkswirtschaftliche Gesamtrechnungen der Länder.

Transport for London(2006). Central London Congestion Charging Scheme Impacts Monitoring, Fourth Annual Report (http://www.tfl.gov.uk/assets/downloads/cc-vo-impact-assessment-2012.pdf, accessed 05.06.2013).

Transport for London (2012). Public and stakeholder consultation on a Variation Order to modify the Congestion Charging System.Impact Assessment (http://www.tfl.gov.uk/assets/downloads/cc-vo-impact-assessment-2012.pdf, accessed 05.06.2013).

Tscharaktschiew, S., &Hirte, G. (2012). Should subsidies to urban transport be increased? A spatial CGE analysis for a German metropolitan area. Transportation Research Part A, 46, S. 285-309

Tscharaktschiew, S., &Hirte, G. (2010).The Drawbacks and Opportunities of Carbon Charges in Metropolitan Areas - A Spatial General Equilibrium Approach. Ecological Economics, 70, S. 339-357.

Verhoef, E. (1996). The Economics ofRegulating Road Transport.Cheltenham:Edward Elgar.