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Abstract:

The objective of this paper is to examine efficiency, distributional, environmental (CO_2 emissions) and spatial effects of increasing different kinds of transport subsidies discriminating between household types, travel purposes and travel modes. The effects are calculated by applying a numerical spatial general equilibrium approach calibrated to an average German metropolitan area. In extension to most studies focusing on only one kind of subsidy, we compare the effects of different transport subsidies within the same unified framework that allows to account for two features not yet considered simultaneously in studies on transport subsidies: endogenous labor supply and location decisions. Furthermore, congestion, travel mode choice, travel related CO_2 emissions and institutional details regarding the tax system in Germany are taken into account. The results suggest that optimal subsidy levels are either small or even zero. While subsidizing public transport is welfare enhancing, subsidies to urban road traffic reduce aggregate urban welfare. Concerning the latter it is shown that making investments in urban road infrastructure capacity or reducing gasoline taxes may even be harmful to residents using predominantly automobile. In contrast, pure commuting subsidies hardly affect aggregate urban welfare, but distributional effects are substantial. All policies contribute to urban sprawl by raising the spatial imbalance of residences and jobs but the effect is relatively small. In addition, the policies induce a very differentiated pattern regarding distributional effects, environmental effects and benefits of landowners.

JEL-Classification: H24; R13; R14; R20; R48; R51

Keywords: urban general equilibrium model; transport policy; transport subsidy; commuting

1 Introduction

Different kinds of transport subsidies are granted in many countries. For example, some countries such as Finland, Norway, Sweden, Austria, Belgium, France and Germany allow commuters, at least partly, to deduct monetary commuting expenses from the income tax liability. Other examples are subsidized public transport fares, reduced indirect tax rates for public transport, gasoline tax exemptions, subsidizing automobile travel through absent parking fees or infrastructure investment not paid for by the users.[1]

The European Environment Agency calculates that transport subsidies in the European Union amount to about 270 billion € in 2005. Almost half of this is related to road transport infrastructure (EEA, 2007). Parry and Small (2009) cite evidence that across the 20 largest public transport systems in the United States (ranked by passenger miles), the subsidy – measured by the difference between operating costs and passenger fare revenues – ranges from 29 to 89% of operating costs for rail and from 57 to 89% for bus. In Europe, fares cover on average 50% of operating costs (Brueckner, 2005). According to Buehler and Pucher (2011) the share of operating costs covered by passenger fares amounted to 77% in Germany in 2007. For highways in the U.S., user fees, including gasoline taxes, license fees and related charges accounted for 60% of highway outlays in 2001 which include both capital and maintenance expenditures (Brueckner, 2005). In Europe the cost coverage rate amounts to 59% across 29 European countries (Doll and van Essen, 2008).[2] Delucchi and Murphy (2008) estimate that the total 'tax subsidy' to motor-vehicle users in the U.S. may be in the range of 19 – 64 billion $ per year or

[1] Although there is no single and unified definition of transport subsidies across countries, all these examples are regularly referred to as subsidies. According to the OECD (2005), a subsidy in general is a result of a government action that confers an advantage on consumers or producers in order to supplement their income or lower their costs. Rothengatter (2001, p. 175) defines transport subsidies as direct or indirect payments for which the transport sector does not provide goods or services in return. Delucchi and Murphy (2008) use the term 'tax subsidy' if there is a difference between actual tax payments and payments under some alternative tax baseline. Such a 'tax subsidy' reduces government tax revenues due to a preferential tax treatment in the form of deductions, credits, exemptions, or reduced tax rates. Parry and Small (2009) measure subsidies of passenger fares for public transportation as the difference between operating costs and passenger fare revenues. Road traffic is generally seen as subsidized if aggregate user payments do not cover the full cost of road construction and usage (see, e.g., Brueckner, 2005; OECD, 2005; Borck and Wrede, 2009).

[2] This cost coverage rate might actually be considerably lower when uninternalized external costs of road transport are explicitly taken into account, implying higher subsidy levels. Hirte (2009) calculates that total costs of road passenger transport in Germany including costs arising from externalities exceeded allowable overall payments (e.g. earmarked taxes and user charges) of private road users by about 61 to 95 billion € in 2005.

0.03 – 0.10 $ per liter of gasoline. Furthermore, in Germany subsidies resulting from a reduced sales tax rate on public transport fares amounted to 570 million € in 2005 (Boss and Rosenschon, 2006) and income tax deduction of commuting expenses caused total income tax savings of commuters of about 4 billion € in 2006 (Bach et al., 2007).

Although these figures are not intended to be exhaustive, they show that transport is significantly subsidized in a variety of ways. There is a differentiated literature exploring transport subsidies where the main focus is on examining whether subsidies are efficiency enhancing.

Basically the transport subsidy related literature distinguishes between research neglecting spatial location decisions and the labor-leisure choice (Parry and Small, 2009), approaches disregarding spatial location decisions but considering labor supply decisions (Wrede, 2000; Calthrop, 2001; van Dender, 2003; Richter, 2006; De Borger and Wuyts, 2009) and research where location choice is explicitly taken into account but labor supply is exogenously given (Zenou, 2000; Martin, 2001; Wrede, 2001; Brueckner, 2005; Borck and Wrede, 2005; Su and DeSalvo, 2008; Borck and Wrede, 2008; Wrede, 2009; Borck and Wrede, 2009). Accordingly, the non-spatial approaches do not take into account differences in commuting distances which might either stem from the choice of the residential location, the working location choice or both. In contrast, in approaches that explicitly consider location decisions other features – in particular the leisure-consumption choice – are usually ignored to keep models solvable. The non-spatial literature finds positive effects of subsidies in those cases where taxing leisure is efficiency enhancing (Wrede 2000), while the spatial literature finds positive effects if there are agglomeration economies (Borck and Wrede, 2009), spatial wage differences (Wrede, 2009) or if there is a spatial mismatch (Martin, 2001; Zenou, 2000). Despite that, congestion and urban sprawl (Brueckner, 2005) constitute adverse effects of subsidies. While endogenous labor supply as well as spatial location decisions are shown to be significant, to our knowledge there is yet no paper combining both decisions within one approach. Moreover, there is little knowledge on quantitative effects, the optimal level of subsidies and the relative performance of different kinds of subsidies.

The objective of this paper is to examine the impacts of transport subsidies on a metropolitan area and its residents. Our contribution to the literature is threefold: First, we combine – to the best of our knowledge for the first time – different modeling features. In particular, on the one hand we endogenize spatial location decisions (residential, employment and shopping locations) but on the other hand also consider labor supply decisions simultaneously. Accounting for both is important because the impact of subsidies may depend on spatial locations decisions and, thus, on commuting distances but also on labor supply decisions, thus, on commuting frequencies. Second, we examine transport subsidies within a spatial non-monocentric urban framework where the following features – besides endogenous location and labor supply decisions – are taken into account: household heterogeneity by considering multiple household types differentiated by skills and employment status, commuting and non-commuting (shopping) trips, non-linear progressive income taxation as well as other pre-existing taxes, financing issues of the subsidies (income tax versus lump-sum tax funding), travel mode choice, travel related externalities such as congestion and CO_2 emissions and feedback effects between urban land, labor and commodity markets. Although some of those features have already been analyzed in the urban/transport economics literature, they have never been treated simultaneously in an adequate spatial setting. This allows us to examine, e.g., the impact of subsidies on existing distortions caused by progressive income taxation, consumption and gasoline taxes. Third, we explicitly consider different types of subsidies distinguished according to their potential to discriminate between different population groups (workers versus non-workers and – within the group of workers – low versus high income workers), travel purposes (commuting versus non-commuting) and travel modes. The approach is applied to compare efficiency, distributional, environmental (CO_2 emissions) and spatial effects for a wide range of subsidy levels and used to derive optimal subsidy levels.

The analyses are based on a spatial urban computable general equilibrium model developed by Tscharaktschiew and Hirte (2010a) which is stimulated by the approach first suggested by Anas and Xu (1999) or Anas and Rhee (2006) and the extension provided by Tscharaktschiew and Hirte (2010b). We calibrate the model to an average German metropolitan area and calculate the effects of subsidies enacted in Germany given German institutional details such as a progressive income taxation, consumption taxes, energy (gasoline) taxes, as well as tax sharing among fiscal authorities.

The results of the present analyses suggest that all policies cause suburbanization of the urban population and contribute to urban sprawl by raising the spatial imbalance of residences and jobs. The magnitude of these spatial effects is, however, surprisingly small.

Aggregate welfare effects are stronger for subsidization policies that discriminate between travel modes rather than trip purposes. Under income tax funding, optimal subsidy levels are in almost all cases either small or even zero. However, distributional effects are substantial. Interestingly, subsidies to urban road transport may even be harmful to residents using predominantly automobile. The only policy that provides significant improvements in urban as well as non-urban welfare is the subsidization of urban public transport, implemented as a sales tax exemption of transit fares. Moreover, passenger travel related emissions of carbon dioxide decrease due to a higher modal split share of public transport and thus a lower congestion externality.

In order to illustrate the pure effects of the transport subsidies, we also examine the policies under less distortionary lump-sum funding. It is shown that, on the one hand, the funding scheme hardly affects the relative advantageousness of a policy compared to the other policies but, on the other hand, it significantly influences the distribution of welfare among urban residents.

The paper proceeds as follows: Section 2 provides a review of the transport subsidy related literature. In Section 3 we present a small model of a worker's decisions in a spatial setting in order to illustrate some important features accruing when urban workers may respond to transport subsidies by changes in spatial decisions as well as labor-leisure choice decisions. In Section 4 we describe the main characteristics of the spatial urban general equilibrium model and its calibration according to German data. Section 5 explains first the scenario design of the transport subsidization policies and subsequently presents the results of the simulations. Finally, in Section 6 we provide a discussion and implications of the results.

2 Review of the Literature

In the following we provide a short overview of the transport subsidies related literature.[3] The focus is first on research disregarding spatial location decisions and subsequently on studies taking location choices into account.

Employing non-spatial approaches Wrede (2000) and Richter (2006) focus on labor supply

[3]Here we do not review literature on the optimal internalization of congestion and other externalities because this is beyond the focus of the research presented here.

decisions. According to Wrede (2000) commuting expenses should be subsidized but should not be completely deductible from the income tax base. Commuting subsidies stimulate labor supply because they indirectly tax non-taxable gains from traveling, i.e. leisure. However, financing the subsidy by labor taxation requires to raise the wage tax in proportion to the subsidy level. This distorts the leisure-consumption decisions and, thus, provides a countervailing effect. This was also stressed by Richter (2006). He, however, emphasizes that this result depends on the property of commuting expenses. If commuting expenses are a ‘bad’ they should be taxed not subsidized.

De Borger and Wuyts (2009) explicitly implement employer-paid parking at the working place. Given these subsidies to car users recycling revenues from congestion taxes via subsidies to public transport is more favorable in terms of welfare than revenue recycling via a reduction in the labor tax. The reason is that subsidies to public transport lower automobile travel demand and so reduce the cost of parking for firms as well as the congestion externality.

Calthrop (2001) finds that in the presence of congestion and two travel purposes a uniform congestion toll should be accompanied by subsidies on commuting. This lowers distortions in the labor market caused by the congestion toll. If, however, a congestion toll is not available subsidies should not be granted. A similar result is given by van Dender (2003) who suggests that an optimal toll differentiation among trip purposes, i.e. subsidizing commuting trips by a lower toll, produces significant efficiency improvements. Parry and Bento (2002) show that the welfare effects of congestion taxes may depend on the extent of subsidies to public transport. Parry and Small (2009) provide a general framework for evaluating existing fare subsidies and potential pricing reforms by deriving a formula for the welfare effects from adjusting subsidies from their current levels. Accounting for, e.g., congestion and pollution as well as accident externalities they find that extending fare subsidies is welfare improving across modes of public transport and cities.

In the classical monocentric city subsidies to transport lower the slope of the bid-rent curve and imply lower population density, larger cities and less differences in rents between the center and the periphery (see e.g. Fujita, 1989). This may cause an increase in urban sprawl (Brueckner 2005, Su and De Salvo 2008). By studying the political economy of transport subsidies Borck and Wrede (2005; 2008) show that the redistributive effect of subsidies between renters, landowners, residents with different incomes and commuting distances plays a crucial role in understanding the political support for or against transport subsidies. Zenou (2000) and Martin (2001) study the impacts of transport subsidies in the presence of labor market imperfections. Both find that subsidies may reduce the spatial mismatch, i.e. the spatial gap between jobs and residential locations of low-income workers. Zenou (2000) additionally shows that the potential to reduce the spatial mismatch depends in fact on the specific arrangement of the transport subsidization policy. Wrede (2009) as well as Borck and Wrede (2009) provide a reason for granting commuting subsidies because they ensure that labor is allocated to the more productive region (place of employment). In these papers subsidies lower the distortion concerning the workplace choice in the presence of a wage tax (the former) or they serve to internalize positive agglomeration externalities on the production site (the latter). Wrede (2001) focuses on commuting subsidies through income tax deduction. He first confirms the results of the monocentric city framework, i.e. the inefficiency of subsidies for the case of a single employment location because they distort residential location decisions. However, he also shows that commuting expenses should be deductible from the income tax if production is not restricted to only one region.

Some basic conclusions of the literature can be summarized as follows: In the monocentric city subsidies are inefficient because they distort residential land use. However, in the presence of multiple employment centers subsidies improve the allocation of labor if there are productivity differences among regions (employment locations). Generally, externalities, pre-existing distortions in the economy and market imperfections such as 'spatial mismatch' may constitute arguments for subsidization of transport. In addition, subsidies reduce commuting and/or other travel costs and may increase the value of time and, thus, constitute an indirect taxation of leisure. The latter effect depends on the type of the subsidies. This in turn implies effects on the labor-leisure choice.

While the first line of research studying transport subsidies encompasses non-spatial approaches, the second line does not take into account labor supply decisions. However, since both features are important, treating them simultaneously would allow to account for various transport subsidy induced feedback effects arising in the urban economy. In order to illustrate these aspects in the following section we consider a stylized model of household behavior in a spatial urban setting.

3 Theoretical Background

The model considers endogenous non-spatial as well as spatial decisions of a representative urban worker and illustrates some of the main features of the individual decisions in the case of passenger transport subsidies.[4]

3.1 A Workers' Decision in a Simple City Model

Assume there is a linear city with a Central Shopping District (CSD) meaning that all shopping activities take place in the center but residences and production activities are spatially distributed across the city. The places of residence and employment are defined by their distance from the CSD, denoted by x and y, respectively. One-way commuting distance is $X = |x - y|$. The identical households consisting of one working member derive utility u from consumption (shopping) z, land use q, as an approximation for housing, and leisure ℓ. The budget constraint is

$$[p(1+\tau^z) + cx - \delta^c x]\, z + r\ (x)\, q = [(1-\tau^m)\, Lw(y) - (C-\delta)\, X]\, D + I. \tag{1}$$

The budget constraint states that monetary expenditures for shopping and housing equal disposable income. It is assumed that shopping requires traveling to the center where each unit of consumption of the composite commodity z requires one shopping trip. Hence, the full consumer costs of shopping consist of the mill price p, the sales tax rate τ^z and the shopping trip costs cx, where c denotes round-trip travel cost per unit of distance of shopping trips. These round-trip costs include gasoline taxes. A subsidy granted for non-work-related trips, lowering shopping trip costs, is represented by δ^c. The bid rent per square meter and period of land demand (lot size) is denoted by $r(x)$. The daily net return to labor is the after tax wage where the hourly wage rate $w(y)$ might differ according to the location of the workplace and τ^m is the marginal wage tax rate. The number of working hours per workday is denoted by L. Net labor income is diminished by the net costs of commuting. These are commuting costs CX, with C as round-trip travel costs per unit of distance of commuting; minus commuting subsidies where δ is the commuting subsidy rate per unit of distance. D is the number of workdays (or working

[4]The full set of subsidies is introduced in the numerical analysis.

shifts) and equals the number of commuting trips. Hence, there is full complementarity between the number of workdays D and the frequency of commuting trips and between the consumption quantity of the composite commodity z and the frequency of shopping trips. Non-labor income.is denoted by I.

The worker is also subject to the following time constraint:

$$(L + TX)\, D + txz + \ell = E. \tag{2}$$

The time constraint states that the total time endowment E can be allocated to work, traveling (commuting + shopping) and leisure. The round-trip travel time required per unit of distance for commuting trips and shopping trips is T and t, respectively.[5]

3.1.1 Location and Non-location Decisions

Concerning the non-location decisions the household maximizes utility $u(z, q, \ell)$ with respect to consumption (shopping) z, housing q, leisure ℓ and the number of workdays D subject to the monetary budget constraint (Eq. (1)) and time constraint (Eq. (2)). The corresponding first-order conditions of a representative worker are:[6]

$$\frac{u_z}{u_\ell} = \frac{p\,(1 + \tau^z) + (c + \theta t - \delta^c)\, x}{\theta} \qquad \frac{u_q}{u_\ell} = \frac{r\,(x)}{\theta}, \tag{3}$$

where

$$\theta = \frac{(1 - \tau^m)\, Lw\,(y) - (C - \delta)\, X}{L + TX} \tag{4}$$

is the value of time (VOT) of a worker facing commuting distance X. The VOT is the ratio of the daily disposable labor income, i.e. labor income net of commuting costs plus a commuting subsidy, to the daily amount of time required to earn labor income which gives the transformation ratio of one unit of leisure into working hours.

Concerning the location decisions the worker maximizes utility u subject to the monetary budget constraint (Eq. (1)) and time constraint (Eq. (2)) with respect to the location of

[5] On account of congestion both are endogenous in the simulation model.

[6] The subscripts denote the first derivative.

employment y and the location of residence x. The respective first-order conditions are:[7]

$$(1-\tau^m)\, w_y(y)\, L = C + \theta T - \delta, \tag{5}$$

and

$$r_x(x) = -\left(c + \theta t - \delta^c\right)\frac{z}{q} - \left(C + \theta T - \delta\right)\frac{D}{q}. \tag{6}$$

Condition (5) states that the optimal workplace location is found if the change in daily net labor income caused by a marginal change in the location of employment is exactly offset by additional full commuting costs. The left-hand side, i.e. the marginal change in daily after tax labor income can be interpreted as some kind of reservation compensation needed to move to another workplace location.

Condition (6) is a modified Muth-condition for the optimal residential location. The optimal residential location is found if the marginal change in housing costs equals the negative marginal change in travel costs. The latter is composed of changes in shopping trip costs and commuting costs caused by a marginal change in distance to shopping location x and commuting distance X, given the employment location y.

3.1.2 Discussion

As can be seen, the VOT affects all non-spatial first-order conditions. Commuting subsidies raise the value of time and lower the distortion arising from income taxation. For example, granting a commuting subsidy at rate $\delta = \tau^m L w(y)/X$ would eliminate the distortion on the VOT. As a consequence, the leisure-housing choice is now undistorted but the distortions concerning the consumption-leisure as well as the consumption-housing choice remain due to the presence of τ^z. Besides the non-spatial choices, granting such a commuting subsidy also distorts the spatial location decisions. For example, the subsidy distorts the residential location decision by flattering the slop of the bid-rent curve. This raises the willingness to pay for housing farther away from the CSD and, consequently, raises travel distances, all together implying urban sprawl. A non-commuting subsidy δ^c also affects the consumption-leisure and consumption-housing decision and the residential location decision. However, it does not impose an impact on the VOT and also not on

[7] See Appendix A.

the working location decision. Therefore, both differently affect substitution effects.

Furthermore, employing such a framework also allows us to take various feedback effects into account. Granting a commuting subsidy, ceteris paribus, causes the VOT to increase. This raises the incentive either to commute more frequently (to increase labor supply) or to commute longer distances (e.g. due to relocation such that the distance between home and work location increases), or even both. As a consequence, urban automobile traffic may increase such that congestion and travel time increase which causes the VOT to decrease. Consequently, the net effect on the VOT and thus on the effective return to labor is in fact ambiguous. In addition, the funding procedure also affects this relationship. If the subsidy is financed by income tax, the raise in the marginal tax rate τ^m constitutes another countervailing effect on the VOT. Now suppose that household heterogeneity is taken into account along with progressive income taxation applied in many countries. Then, the countervailing effect on the VOT is disproportionately stronger for the high-skilled workers. Considering different types of workers, aggregate effects not only depend on the type of workers considered, but also on the relative share of each type of worker on the total urban population. This becomes even more important when considering non-working households along with comparing the impacts of different kinds of transport subsidies. Then, strong distribution effects might occur. If non-workers contribute to finance the subsidy, the adverse effects of a subsidy on workers are smaller compared to a situation where non-workers are not taken into account.[8]

This analysis reveals that it is not possible to derive one subsidy rate eliminating all non-spatial and spatial distortions arising from taxation. Obviously, a first-best subsidy does not exist. If there is no full set of instruments a second-best issue arises and the optimal subsidy has to be derived in an optimal tax approach. The appropriate approach would be to solve a welfare maximizing problem subject to the time constraints, the public budget constraint, the resource constraint of the economy and conditions concerning local markets. Because this cannot be solved analytically without imposing additional re-

[8] See Tscharaktschiew and Hirte (2010b) discussing the importance of household heterogeneity in a spatial urban setting.

strictions on a wide range of significant modeling features described above[9] we direct our attention now to the spatial simulation model. Its most striking feature is the household heterogeneity taken into account and the endogeneity of both the non-location and the location decisions shown to be important by the analytical model.

4 The Spatial Simulation Model

The spatial urban general equilibrium model we employ is a modification of the model described in Tscharaktschiew and Hirte (2010a). Here institutional details concerning different kinds of transport subsidies and their funding procedure are added. In the following we only sketch main characteristics of the model and its calibration. Figure 1 shows the spatial decision structure of urban households and basic interdependencies between the agents inside and outside the urban economy.

Figure 1: Spatial decision structure and interdependencies between urban and non-urban economic agents

4.1 Decisions within the Urban Economy

The model explicitly takes into account the interactions between different markets (land, labor, commodities), households and firms. All location decisions of households and firms are determined endogenously in the model. Households can vary in idiosyncratic tastes for locations within the urban area such that decisions of households create mixed land use and various possible travel patterns. Hence, the endogenous spatial structure is not restricted to the assumption of a monocentric city.

The metropolitan area encompasses $I = 9$ zones (locations), where the innermost zone

[9] However, it should be noted that, of course, many of the features described above have already been considered in the transport subsidy related literature. For example: congestion is taken into account by, e.g., Calthrop (2001), van Dender (2003), De Borger and Wuyts (2009); multiple trip purposes are considered by, e.g., Zenou (2000), van Dender (2003); while, e.g., Borck and Wrede (2008) as well as Su and DeSalvo (2008) take travel mode choice into account. However, we treat those and more features simultaneously, calibrate an appropriate structure of the urban population and implement institutional details of a real-world tax system along with tax interdependencies among fiscal authorities.

$i = 5$ is assumed to be the city center.[10] All zones have a length of $d_i = 4.5$ kilometers (km) so that the whole urban area expands over 40.5 km. The zones 3–7 shape the city of the complete circular urban area while zones 2 and 8 (1 and 9) form the surrounding inner (outer) suburbs. In each zone there is a given homogeneous land area available for residences, establishments and roads. Supply of land increases with distance from the city center. The urban locations are linked via a transport network with distance d_{ij} between the centers of the zones.

There are two main household types in the urban economy: non-working households and working households. In the latter case, each household encompasses one working member. Households with working members are differentiated in regard to the exogenously given skill levels of their members either as low-skilled or high-skilled households. Households endogenously decide where to reside, where to work (working households), where and how much to shop, how much labor to supply and, thus, how often to commute (working households), how much land to rent, and which travel mode to use. Households face monetary travel cost and opportunity cost of travel time. They maximize utility subject to a monetary budget and a time constraint.

Depending on residential location i and working location j (only working households), urban households derive utility from consumption z_{ijk} in shopping location k,[11] lot size q_{ij} as an approximation for housing and leisure ℓ_{ij}.

The monetary budget constraint of a typical urban worker facing location choice set $\iota = \{i, j\}$ is

$$\sum_{k=1}^{I} \underbrace{\left[(1+\tau^z)\, p_k + c_{ik}\,(tm, \Gamma)\right]}_{\text{monetary gross consumer price}} z_{\iota k} + r_i q_\iota + D_\iota c_\iota\,(tm, \Gamma) = \underbrace{Inc_\iota^{gross} - Tax^{ls} - Tax_\iota^{Inc}}_{\text{monetary net income } Inc_\iota^{net}}, \quad (7)$$

[10] Note that due to accessibility advantages the innermost zone of the city will in fact endogenously become the city center where, e.g., land rents are highest.

[11] Shopping is implemented by a C.E.S. subutility function reflecting spatial tastes for shopping variety (Dixit and Stiglitz, 1977). Consumption quantities in shopping location k and, thus, the number of shopping trips depends on the location specific full economic shopping prices in the whole urban area, i.e. the prices of the commodity plus travel and time costs needed to travel to the shopping locations.

where the monetary gross income (Inc_ι^{gross}) and the income tax (Tax_ι^{Inc}) are:

$$Inc_\iota^{gross} = \underbrace{w_j^h L D_\iota}_{Inc_\iota^{labor}} + \delta d_\iota D_\iota + R, \tag{8a}$$

$$Tax_\iota^{Inc} = \mathcal{F}\left[TInc_\iota\left(Inc_\iota^{labor}, R, \Pi, \Upsilon, \delta^\tau\right)\right]. \tag{8b}$$

Location specific mill prices are denoted by p_k; the sales or value-added tax rate by τ^z; two-way (i.e. round-trip) shopping trip costs from home location i to shopping location k by c_{ik}; housing costs (rent in zone i) per square meter by r_i; gross wages specific for working location j and skill level h by w_j^h; and two-way monetary commuting costs by c_ι. Inc_ι^{net} is monetary net income, i.e. gross income (composed of labor income $w_j^h L D_\iota$, direct and uniform commuting subsidies $\delta d_\iota D_\iota$ with δ as the commuting subsidy rate [€/km], and non-wage income R) net of a lump-sum tax Tax^{ls} imposed by the local urban government and the income tax liability Tax_ι^{Inc} which depends on the income taxation scheme $\mathcal{F}$ and taxable income $TInc_\iota$. Households are subject to a non-linear progressive income taxation scheme $\mathcal{F}$ (Tariff of Germany in the version of 2009; see EStG, 2009) where deductions of commuting expenses are income tax deductible at rate δ^τ [€/km]. From a worker's perspective the income tax deduction rate δ^τ is only relevant if commuting expenses per year, $\delta^\tau d_\iota D_\iota$, plus other work related expenses, Υ,[12] exceed a general employee tax allowance Π. The number of workdays is endogenously determined and denoted by D_ι whereas L is the fixed number of daily working hours. Two-way travel costs (commuting c_ι and shopping c_{ik}) are determined as expected values over the available travel modes $tm \in \{walking, public\ transport, automobile\}$, where travel mode choice is implemented by a multinomial logit model. Travel costs are composed of, e.g., the gasoline consumer price and an energy tax τ^g in the case of automobile usage and a transit fare in the case of public transport. They further encompass sales taxes with tax rates τ^{tm} corresponding to travel mode tm. Automobile travel costs and travel times (see below) depend on $\Gamma \equiv F/K$, i.e. the ratio of road traffic flow F to the exogenously given road infrastructure capacity K (in the following road capacity) which is proportional to the land allocated to roads.

[12] For example expenditures caused by a double housekeeping or expenditures for work related clothing.

In addition to the monetary budget constraint each worker is also subject to a time constraint stating that the total time endowment E can be allocated to work, leisure and traveling (shopping+commuting):

$$D_\iota L + \ell_\iota + \underbrace{\sum_{k=1}^{I} t_{ik}\left(tm, \Gamma\right) z_{\iota k}}_{\text{travel time shopping}} + \underbrace{t_\iota\left(tm, \Gamma\right) D_\iota}_{\text{travel time commuting}} = E, \tag{9}$$

where $t_{ik}\left(tm, \Gamma\right)$ denotes the expected two-way travel time for a shopping trip from zone i to zone k and $t_\iota\left(tm, \Gamma\right)$ is the expected two-way commuting time from residential location i to employment location j, depending on travel mode tm. Travel times are also determined as expected values over the available travel modes tm.[13]

All spatial location decisions implicitly determine commuting and shopping trip distances, frequencies and – along with travel mode specific travel speeds – travel times. Individual automobile travel causes three kinds of externalities: congestion (travel time delays), additional gasoline consumption, and additional CO_2 emissions, all caused by the fact that the marginal driver may affect travel speed of all other drivers being on the road. Since all travel decisions are endogenous, the extent of the externalities is endogenous as well. Automobile travel times, gasoline consumption and CO_2 emissions – all depending on road traffic flow F and road capacity K – are endogenously determined and specified by empirically determined functional relationships.

A sufficiently large number of profit maximizing firms produce in each location a zone specific composite commodity in competitive markets by applying a Cobb-Douglas technology that combines land and labor supplied by low-skilled and high-skilled workers. These commodities are sold at the place of production.

4.2 Interdependencies between the Economic Agents

The federal government levies progressive income taxes, sales taxes and energy (gasoline) taxes, grants transport subsidies and income transfers to non-working households and redistributes – according to fiscal interdependencies among public authorities in Germany – shares of its revenues to the local urban government. The federal tax revenues not

[13] Note that in Eqs. (7)–(9), $d, \tau^z, L, \delta, \delta^\tau, \Pi, \Upsilon, E$ and the income taxation scheme $\mathcal{F}$ are exogenous whereas $p, c, z, r, q, D, Tax^{ls}, Tax^{Inc}, w, R, \ell, t, \Gamma$ are endogenously determined.

redistributed to the urban private households and the city government are used for public consumption consisting of purchasing locally produced commodities. The city government receives its shares of federal tax revenues and levies a local lump-sum tax to finance local goods such as roads. Infrastructure costs consist of opportunity costs due to land used for infrastructure. Absentee landowners use their rent income and an external transport sector monetary travel costs (except for travel-related taxes) accruing from urban travel activities to purchase urban commodities (e.g. used for maintenance purposes).

At spatial urban general equilibrium, endogenous land rents, wages and commodity price clear the spatially differentiated markets for land, low-skilled labor, high-skilled labor and commodities.

4.3 Model Calibration

The model was calibrated to replicate a representative household composition (e.g. the relative shares of low-skilled and high-skilled workers), economic figures (e.g. rents, wages, incomes, income tax rates, federal tax revenues), travel characteristics (e.g. modal split, relative importance of trip purposes, travel demand elasticities, average commuting distances and average automobile travel speeds, average gasoline consumption and CO_2 emission per vehicle km) and spatial patterns (e.g. residential and employment densities, job-housing-balance, the share of urban land allocated to roads) of an 'average' German metropolitan area. For example, the 'Benchmark' urban economy reflects a realistic spatial pattern regarding the job-housing-balance which is defined as the ratio of the number of jobs in a specific location to the number of employees residing in that location. According to evidence cited by Siedentop (2007) the job-housing-balance exceeds unity for central cities and falls short of unity in the suburbs which is fully in line with the spatial pattern of the 'Benchmark' city.

5 Results of the Simulation Model (German Case)

5.1 Scenario Design

In general transport subsidies may be linked to specific travel purposes, e.g. commuting only, may be granted to specific travel modes, e.g. public transport, may be differentiated according to household characteristics such as employment status (working versus non-working) or income (high versus low), or may be based on monetary or time costs. In the following we examine five subsidization policies reflecting different ways of discrimination. The transport subsidies considered are chosen from a basket of subsidies discussed or enacted in Germany keeping in mind that there are similar subsidies in other countries working in a similar way. In each case we simulate a revenue-neutral policy by adjusting the income tax rate. To get an impression of the pure effects of the subsidy we also calculate the results with lump-sum tax funding.

Table 1: Discrimination of the different subsidization policies

Policy		Discrimination			
		Skills	Travel purpose	Travel mode	Employment status
1	δ^{τ} (↑)	high	commuting	–	working
2	δ (↑)	–	commuting	–	working
3	K (↑)	(high)	–	automobile	–
4	τ^{g} (↓)	(high)	–	automobile	–
5	τ^{public} (↓)	(low)	–	public transport	–

Note: Indirect discrimination in brackets

One of the most important and controversial discussed types of subsidies on urban passenger travel in Germany constitutes income tax deductibility of commuting expenses. This regulation has been heavily discussed for many years and had been subject to some changes during the last decades. In 2007 the arrangement was changed by elimination of deductibility in the case of commuting distances of less than 20 km. However, in 2008 the German Constitutional Court canceled this discrimination with respect to commuting distances. Currently, commuters are allowed to deduct 0.3 €/km from the income tax base which is therefore already considered in the calibrated 'Benchmark'. Given this reference level, **Policy 1** allows commuters to deduct individual commuting expenses at rates higher than 0.3 €/km. One of the objections is that this regulation implies that high-wage earner receive higher subsidies than low-wage earners (Kloas and Kuhfeld, 2003) on account of progressive income taxation, implying that income tax deductibility discriminates between skill groups. It also discriminates between travel purposes because only commuting is subsidized and according to the employment status because non-workers do not benefit directly from such a policy (see Table 1).

In **Policy 2** a direct and uniform commuting subsidy with rate δ per kilometer is granted by the federal government. This policy is not an institutional feature of the current German system, thus, the benchmark level is $\delta = 0$ €/km. In contrast to the income tax deductibility policy, such a direct subsidy does not discriminate between different skill levels.

Policy 3 is referred to as 'time cost subsidy' representing an additional investment in road capacity in the city characterized by an increase in the share of land allocated to roads in the city (zones 3–7), where the calibrated 'Benchmark' share amounts to 0.153.[14] This implies that capacity is increased by providing additional road infrastructure. It is assumed that costs associated with an investment in road capacity consist only of the rental costs (opportunity cost) of additional urban land allocated to (new) roads. The federal government grants payments to the city which constructs new or improves existing infrastructure.[15] This policy directly discriminates between travel modes and indirectly favors high-income workers who more intensively travel by automobile.

Policy 4 represents a subsidy on automobile use by reducing the energy tax on gasoline, τ^g, where $\tau^g = 0.65$ €/liter is the tax imposed in the 'Benchmark'.[16] This policy, like Policy 3, discriminates in favor of automobile usage and indirectly in favor of high-skilled

[14] The objective of this policy is making urban road traffic faster implying a subsidy on time costs. However, because of the various features of the CGE model this is not a predetermined outcome. The reason is that under spatial general equilibrium conditions, investments in road capacity may cause several feedback effects. For example, an increase in road capacity may induce (additional) automobile travel demand, where – according to Cervero and Hansen (2002) – induced travel reflects all changes in trip-making that are unleashed by a road improvement: newly generated trips; longer journeys; changes in modal splits; route diversions; and time-of-day shifts.

[15] We assume that this policy is equivalent to a subsidy keeping in mind that the degree of road traffic subsidization depends in fact on the extent taxes on road traffic are earmarked for road transport (see Doll and van Essen, 2008). For Germany in 2005, Hirte (2009) shows that costs of passenger road traffic exceeded corresponding payments of road users significantly even if external costs are neglected.

[16] This policy is well suited to show differences between subsidies to monetary travel costs in contrast to (indirect) subsidies on travel time costs (Policy 3). However, it should be noted that, strictly speaking, this is only a subsidy if the new tax rates are below the socially optimal level of the tax (see e.g. Parry and Small, 2005).

workers. However, in contrast to Policy 3 it directly lowers the burden of monetary travel costs.

Policy 5 is a subsidy on urban public transport characterized by a reduction of the sales tax rate on transit fares, where $\tau^{public} = 0.07$ is the – compared with the German sales tax rate on general consumption $\tau^{z} = 0.19$ – already reduced sales tax rate in the 'Benchmark' urban economy. This policy directly discriminates between travel modes and indirectly between skill levels because low-skilled workers use public transport relatively more compared with high-skilled workers.[17]

To summarize, the following subsidies on urban passenger transport are considered:

Policy 1: Income tax deductibility of commuting expenses

Policy 2: Direct uniform commuting subsidy

Policy 3: 'Time cost subsidy' (investment in road capacity)

Policy 4: Private automobile subsidy (reduction of energy taxes on gasoline)

Policy 5: Public transport subsidy (reduced public transport sales tax rate)

In contrast to Policies 1 and 2, Policies 3–5 neither do discriminate between trip purposes nor between household types (employment status).[18] Also in contrast to Policies 1 and 2, Policies 3–5 rather discriminate between travel modes. While primarily public transport users benefit from Policy 5 (reduced transit fares), automobile drivers primarily benefit from investments in road capacity (Policy 3) and from lower energy taxes (Policy 4).

Considering the VOT of a typical worker with location choice set $\iota = (i, j)$, i.e. residential location i and workplace location j, provides an intuition why it is in a particular interest

[17] Alternative public transport subsidies constitute, e.g., reduced fares granted to students, pensioners, or unemployed. These subsidies work similar to a reduction in the sales tax rate but would additionally discriminate directly according to employment status and income. Parry and Small (2009) provide an excellent overview on the rationales for public transport subsidies (see also Vickrey, 1980).

[18] But note that the categorization in Table 1 should not be interpreted that strict. For example, e.g., even Policy 4 (slightly) discriminates between household types because workers may benefit more from a lower energy tax on gasoline because they commute to work and travel to stores whereas non-working residents only travel for shopping purposes. However, it is referred to the main effect in the sense that basically neither working nor non-working residents can be excluded from a lower energy tax and thus, e.g., Policy 4 is denoted as a policy not discriminating between household types.

to focus on these specific policy arrangements.[19] Taking the subsidization policies into account, the endogenous VOT of a typical urban worker with skill level h (high-skilled or low-skilled) within the spatial CGE framework can be written as follows:

$$\theta_\iota^h = \frac{(1-\tau_\iota^m)\, w_j^h - \overbrace{c_\iota\,(tm,\Gamma)}^{(3)/4/5} + \overbrace{\delta^\tau}^{1} d_\iota \tau_\iota^m + \overbrace{\delta}^{2} d_\iota}{L + \underbrace{t_\iota\,(tm,\Gamma)}_{3/(4)/(5)}}. \tag{10}$$

As can be seen, the policies considered affect different components of the VOT. Ceteris paribus, all transport subsidies associated with Policies 1, 2, 4, and 5 directly cause the numerator in Eq. (10) to increase, whereas Policy 3 decreases the denominator in Eq. (10) provided that the worker travels by automobile.[20] As a result, ceteris paribus, all policies cause the VOT to increase implying similar impacts on relative prices. Besides, the subsidies also affect other prices. For example, Policies 3, 4 and 5 also change the cost of shopping trips while Policies 1 and 2 do not. Policies 3 and 4 directly lower the cost of automobile usage but Policy 5 the user cost of public transport. Moreover, under income tax funding the VOT is additionally affected by changes in the endogenous marginal income tax rate τ_ι^m. Accordingly, the first-order conditions are differently affected by these distinct policies implying different changes of distortions under different funding schemes.

5.2 Implementing the Policies: Results

In the following we present the results of the simulations carried out for the different policies. Our point of departure is the 'Benchmark' level of the corresponding subsidy.

[19] In the 'Benchmark' the VOT of an employed worker amounts to 9.30 €/h (averaged over all locations and skill levels). This corresponds to 52% and 77% of the average hourly gross and the net wage, respectively which is in line with the literature (see Small and Verhoef, 2007; De Borger and van Dender, 2003).

[20] However, due to various feedback effects within the spatial general equilibrium model even, e.g., lower energy taxes (Policy 4)/lower transit fares (Policy 5) may indirectly affect automobile travel times and so the denominator in Eq. (10). The reason is that changes in monetary travel costs may cause changes in travel mode choice which in turn might affect travel times through changes regarding the congestion externality. Equivalently, changes in travel times caused by an increase in road capacity (Policy 3) may affect travel cost and so the numerator in Eq. (10) through the relationship between travel speed and gasoline consumption. These policy induced indirect effects on travel time and cost are denoted by brackets in Eq. (10). De Borger and van Dender (2003) show the importance of the endogeneity of the VOT in order to account for the various feedback effects of transport tax reforms in the economy.

In each case the subsidy is increased over a wide range of levels. We consider funding by income taxation and lump-sum taxation and discuss effects on aggregate welfare, distribution, environmental and spatial effects of these policies and identify optimal subsidy levels. Welfare effects are measured by the equivalent variation. Environmental effects are reflected by changes in travel related CO_2 emissions.

5.2.1 Aggregate Urban Welfare Effects

Figure 2 shows aggregate urban welfare effects for all policies under both funding schemes, i.e., income tax funding (left panel) and lump-sum tax funding (right panel). In the figure (and the subsequent figures) the horizontal axis depicts the overall amount of subsidies of each policy accruing from varying the respective subsidy levels. For example, a direct commuting subsidy of 0.26 €/km (Policy 2) implies an overall amount of aggregated subsidies of about 800 million €/year. The same amount corresponds to a tax deduction rate equal to 1.09 €/km in the case of granting subsidies via income tax deduction of commuting expenses (Policy 1).

Figure 2: Aggregate urban welfare effects of transport subsidization policies

Generally, the figure shows that lump-sum tax funding results in slightly higher aggregate welfare gains (or smaller welfare losses) than income tax funding. In the latter case higher marginal income tax rates strengthen the distortion concerning the labor-leisure choice and thus impose an adverse effect on welfare. Nonetheless, the funding scheme hardly affects the relative advantageousness of a policy compared to the other policies.

Let us first consider pure commuting subsidies which are neutral concerning the travel mode. Aggregate urban welfare is almost identical for Policy 1 (income tax deduction) and Policy 2 (direct commuting subsidy) under both funding schemes. However, as is shown below, distributional effects differ considerably and thus depend significantly on the funding scheme. In particular under income-tax funding the net effect on urban welfare is quite small so that aggregate urban welfare is almost unchanged compared with the 'Benchmark'. In this case, higher marginal tax rates due to the funding requirement constitute an adverse effect to higher subsidy levels (see Eq. (10)) which ceteris paribus lower the initial distortion of income taxation on relative prices.

Next let us focus on travel mode specific subsidies. The results suggest that subsidies on public transport (Policy 5) increase urban welfare while subsidizing road transport (Policies 3 and 4) reduces urban welfare. Here, additional investment in road capacity is the worst policy for urban residents. A major reason for this is the strong impact of road transport subsidizing policies on the congestion externality. To illustrate this let us consider a subsidization level of 79 million €/year as reference. At this level Policy 5 reduces congestion costs by 6% compared with a 2% reduction in the case of Policy 3, where induced road traffic weakens the gain from the expansion of the road capacity. The simulations actually support empirical evidence that road capacity investments cause induced automobile travel, thus dampening the reduction of congestion expected from this policy.[21] Under both funding schemes changes in travel mode choice (increase in the automobile modal split share) make the strongest contribution to the induced travel. In contrast, reducing the energy tax on gasoline (Policy 4) stimulates automobile traffic without the countervailing effect of road infrastructure capacity expansion so that congestion costs increase by even 6%.

In addition, there are further important effects besides congestion. First: though the extension of road capacity reduces the congestion externality, it is by far less beneficial for urban residents than any other policy. The raise in the demand for land in the city arising from higher land use for road increases competition on the land market which drives up rents. This causes firms to shift some shares of their production to the suburbs where, however, wages are lower (there is a loss in productivity, see also Wrede, 2009). As a consequence, more urban workers earn lower wages while housing rents increase. Besides, the marginal benefit of additional road capacity is unequally distributed in the urban area because the congestion externality declines with distance from the city center and is almost zero at the city fringe. Consequently, while the benefits of additional road infrastructure are low at the city fringe, the funding requirement lowers disposable income and, particularly in the case of income tax funding, distorts the tax system of the whole

[21] Numerous studies provide empirical evidence for the induced traffic 'hypothesis'. Those studies find that the elasticity of vehicle distance traveled with respect to road infrastructure capacity (measured e.g. in lane-miles) is positive, ranging from (+0.1)–(+1.0) in the long-run (see e.g. Santos et al. 2010; Cervero and Hansen, 2002; Hansen and Huang, 1997; Goodwin, 1996). Employing additional calculations we find that the elasticity of vehicle kilometers traveled with respect to road infrastructure capacity (measured as the land area [in m^2] allocated to roads) is about +0.3 in our model (but it should be kept in mind that the model can actually not distinguish whether an increase in road infrastructure capacity constitutes, e.g., an increase in road length or an additional lane).

urban economy. Second: aggregate urban welfare effects are also influenced by the relative strength of the different urban population groups. Because low-income workers and non-working household, constituting the urban majority, use public transport to a relatively larger extent the positive effects of road investments for these groups are rather small. However, they contribute to finance roads and also face higher rents and lower wages.

5.2.2 Welfare Distribution Effects

Besides overall welfare, in particular its distribution may affect political support for or raise objections against a specific policy. As Table 2 indicates, welfare distribution effects among urban residents are substantial and depend, e.g., on the funding scheme.

Table 2: Aggregate distribution effects of transport subsidization policies

		Subsidy [million €/year]		
		79	432	800
	Welfare [million €/year]			
Policy 1	Working HH (low-skilled)	+27/+15	+118/+56	+210/+93
	Working HH (high-skilled)	–4/+16	–17/+90	–41/+164
	Non-working HH	–15/–21	–84/–107	–161/–200
Policy 2	Working HH (low-skilled)	+35/+23	+164/+102	+301/+181
	Working HH (high-skilled)	–15/+11	–73/+53	–145/+94
	Non-working HH	–19/–25	–88/–118	–167/–225
Policy 3	Working HH (low-skilled)	–43/–56	–237/–315	–459/–586
	Working HH (high-skilled)	–36/–10	–214/–63	–424/–121
	Non–working HH	–15/–21	–88/–120	–170/–225
Policy 4	Working HH (low-skilled)	–34/–60	–175/–295	–
	Working HH (high-skilled)	–21/+20	–154/+81	–
	Non-working HH	–17/–28	–94/–150	–
Policy 5	Working HH (low-skilled)	+93/+85	–	–
	Working HH (high-skilled)	–8/+9	–	–
	Non-working HH	+11/+7	–	–

Changes in relation to the 'Benchmark'
Income tax funding/Lump-sum tax funding

Although the simulations exhibit a very differentiated pattern of distributional effects, at least two unambiguous patterns emerge: First, an increase in road capacity in the city causes urban welfare to decline for all population groups in the city regardless of how the subsidies are financed. Second, reducing transit fares by diminishing the sales tax rate improves welfare of all urban households, except for the high-skilled workers under income tax funding.

Not surprisingly, non-working households suffer from Policies 1 and 2 where subsidies are exclusively granted to commuters. They contribute to finance this policy but do not receive any subsidy. Moreover, they also do not benefit from subsidies on automobile travel (Policies 3 and 4) due to their lower travel demand and their lower automobile usage. Their losses are higher under lump-sum funding because their marginal tax rates are relatively low and, thus, they suffer from income tax funding to a smaller extent. They only benefit from subsidizing urban public transport (Policy 5) because they use public transport relatively strong.

Concerning high-skilled workers, the simulations suggest that the distorting effect of higher income tax rates overcompensates any benefits associated with the subsidization policies. As a consequence, in the case of income tax funding high-skilled workers are worse off regardless of the policy instrument considered. However, if subsidies are financed by a lump-sum tax, they benefit from the policies, except for Policy 3. The exception of Policy 3 is surprising. The reason for this outcome is induced traffic caused by road capacity expansion. Hence, congestion is only weakly reduced. Consequently, benefits of the high-skilled workers as the most mobile population group using predominantly private automobile are relatively weak compared to the additional tax burden. For this reason they are adversely affected from an increase in road capacity, even under lump-sum funding.

In the case of the low-skilled workers it turns out that they are less sensitive to the funding scheme. This group of workers is better off by commuting subsidies (Policies 1 and 2) as well as by subsidizing public transport usage (Policy 5) regardless of how the subsidies are financed. However, income tax funding makes them better off due to their lower income along with progressive income taxation. In contrast, subsidizing automobile traffic (Policies 3 and 4) causes their welfare to decrease unequivocally. This group favors commuting subsidies and subsidizing urban public transport.

Considering welfare distribution effects at the household level shows that although funding higher transport subsidies is overall more beneficial under lump-sum taxation, this might provoke resistance of the lower skilled urban majority whose individual (per HH) welfare gain is considerably smaller than that of the higher skilled workers. As Table 3 exemplarily shows for subsidization of commuting, aggregate commuting subsidies in the form of, e.g., income tax deduction (Policy 1) amounting to 800 million €/year result in an average per HH welfare gain of the higher skilled that is roughly seven times as high as the welfare gain of an average low-skilled household where the wedge increases with an increase in the subsidy level. This raises the question of the feasibility of this kind of policy.

Table 3: Distributional effects of commuting subsidies

		Subsidy [million €/year]		
		79	432	800
		Welfare per HH [€/year]		
Policy 1	Working HH (low-skilled)	+29/+16	+127/+60	+226/+100
	Working HH (high-skilled)	–17/+69	–73/+387	–176/+705
	Non-working HH	–26/–36	–143/–183	–275/–341
Policy 2	Working HH (low-skilled)	+38/+25	+176/+110	+323/+194
	Working HH (high-skilled)	–64/+47	–314/+228	–623/+404
	Non-working HH	–32/–43	–150/–201	–285/–384

Changes in relation to the 'Benchmark'
Income tax funding/Lump-sum tax funding

Besides urban residents, there is another group of interest which might influence political support for or against the different kinds of policies.

Figure 3: Effects of transport subsidization policies on landowners

Figure 3 shows the welfare effects of the subsidization policies on absentee landowners. In contrast to urban residents, absentee landowners benefit most from an increase in road capacity. In this case, higher competition on the land market increases their land rent income[22]. Furthermore, also in the case of absentee landowners, the effects depend on the funding scheme. While for Policies 3–5 the funding scheme only determines the magnitude of the effects, it is crucial in the case of commuting subsidies (Policies 1 and 2). Because commuting subsidies stimulate labor supply under lump-sum funding due to the absence of the adverse effect of higher marginal income tax rates disposable income of workers in the city increases. As a result, competition on the land market raises and so do benefits of

[22] The local 'landlords' also benefit through this chanel. But the adverse effects of induced traffic, higher rents, lower wages etc. more than offset these benefits.

absentee landowners. For example, direct commuting subsidies amounting to 800 million €/year cause total urban labor supply to decrease by 0.3% under income tax funding and to increase by 1.3% under lump-sum funding.

5.2.3 Environmental Effects

Figure 4 shows subsidy induced effects on total CO_2 emissions generated by passenger travel activities in the urban area.

Figure 4: Effects of transport subsidization policies on CO_2 emissions

The results of the simulations suggest that subsidizing urban public transport (Policy 5) is the only policy that reduces travel related CO_2 emissions regardless of how the subsidies are financed. Here two effects are significant: first, the modal split share of public transport increases and second, as a side-effect, remaining automobile traffic is less congested resulting in lower automobile emissions per vehicle kilometers.

In contrast, lowering energy taxes on gasoline (Policy 4) increases emissions regardless of the funding scheme. The modal split share for private automobile increases which aggravates congestion in the urban area. As a result, CO_2 emissions per vehicle kilometer increase.

Interestingly, road capacity extension (Policy 3) may result in lower or higher CO_2 emissions depending on how subsidies are financed. Generally, there are two countervailing effects that influence the change in emissions. On the one hand, an increase in road capacity lowers congestion. On the other hand, however, if congestion decreases traveling by automobile becomes more attractive. This in turn induces additional automobile traffic resulting in higher emissions. Which of these countervailing effects dominates is a priori ambiguous. However, as already seen the funding scheme of the subsidies also affects travel demand. While under income tax funding adverse effects on the VOT accrue implying further distortions on the labor market so that the number of commuting trips and thus travel demand declines. This implies less congestion and, thus, less emissions per vehicle kilometer. Adverse effects on the VOT through an increase in marginal tax rates are, however, absent under lump-sum funding. This favors faster travel modes such as automobile and thus, more emission intensive travel modes. Because the VOT also enters the full economic cost of shopping, this effect is strengthened by non-commuting trip purposes such as shopping. The analyses here suggest that the adverse effect under income tax funding may be strong enough to lower total emissions of CO_2 even though a road capacity extension favors the more CO_2 intensive travel mode.

Finally, Figure 4 also shows that commuting subsidies (Policies 1 and 2) unambiguously increase travel related CO_2 emissions, where the increase is higher under lump-sum funding due to the absence of the adverse effect on the VOT.

5.2.4 Spatial Effects

In the following the focus is on the spatial effects of the transport subsidization policies. In particular we look at changes in the spatial distribution of residences and employment as well as changes in spatial travel patterns. The effects of transport subsidies have been analyzed extensively in monocentric city frameworks. However, almost no attention has been paid to the effects of transport subsidies on urban sprawl in dispersed urban areas.[23]

The main finding of our analysis is that all policies contribute to an increase in the imbalance of the spatial allocation of residences of jobs because the suburbanization of residents is stronger than the suburbanization of jobs (see Table 4). As a consequence, all policies indeed strengthen urban sprawl according to the definition of sprawl used here. The strongest effect occurs with respect to Policy 3 because road capacity expansion directly competes for urban land use. However, for all policies the effect is surprisingly modest in magnitude. Interestingly, a reduction in the tax on gasoline is the only policy that actually raises the number of jobs in the city. In particular the number of high-skilled job raises because congestion is reduced to the largest extent under that policy which is most beneficial for high-skilled (high-income) households.

In addition, the adverse effect on the VOT under income tax funding is also important when considering how the subsidization policies change the spatial distribution of travel

[23] There is no standardized procedure of how to measure urban sprawl. Nechyba and Walsh (2004) point out that a common way to document the presence of urban sprawl is to look first at the evolving relationship of population levels between suburbs and central cities. Anas and Rhee (2006) use changes in the daily average travel time per worker as a measure of sprawl. Ewing et al. (2002) operationalize, or measure, sprawl using several variables that represent different aspects of development patterns (e.g. neighborhood mix of homes, jobs, and services). We use the spatial mix of residences and jobs, i.e. the job-housing-balance to measure urban sprawl.

Table 4: Effects on the spatial allocation of residences and jobs

	Policy				
	1	2	3	4	5
Income tax funding					
Residences in the city	–1621	–1725	–7589	–241	–340
Residences in the city [%]	–0.23	–0.25	–1.09	–0.03	–0.05
Jobs in the city	–584	–768	–338	+164	–260
Jobs in the city [%]	–0.09	–0.12	–0.05	+0.03	–0.04
Lump–sum funding					
Residences in the city	–1514	–1650	–7489	–124	–329
Residences in the city [%]	–0.22	–0.24	–1.08	–0.02	–0.05
Jobs in the city	–435	–616	–167	+448	–240
Jobs in the city [%]	–0.07	–0.10	–0.03	+0.07	–0.04

Changes in relation to the 'Benchmark'
City: Zone 3–7 Suburbs: Zone 1–2 + Zone 8–9
Losses of the city = gains of the suburbs
Policies 1–4: Subsidization level 432 million €
Policy 5: Subsidization level 79 million €

patterns. Table 5 shows changes in the share of extreme cross commuting/shopping trips as well as intrazonal commuting/shopping tips. The figures reveal changes in the spatial travel patterns in the urban area. In most cases, the policies encourage extreme cross commuting and decrease intrazonal commuting (the trip originates and terminates in the same zone) where the strongest effect accrues for the policies which grant subsidies exclusively for commuting. In contrast, policies not discriminating between trip purposes, i.e. Policies 3–5 are more balanced in the sense that the gap between the impact on the spatial pattern of commuting and shopping is smaller.

In particular, three trends arouse interest. First, the increase in extreme cross commuting is stronger if subsidies are funded by the income tax. In this case the adverse effect of marginal tax rates lowers, ceteris paribus, the VOT implying lower time costs. This in turn makes long distance and time consuming trips more attractive. Second, there is a spill-over effect of commuting subsidies on the spatial shopping trip pattern, mainly occurring via changes in the value of time. While there is a large increase in extreme cross commuting for Policies 1 and 2, in these cases extreme cross shopping actually decreases under lump-sum funding. Here, subsidies are only granted for commuting purposes. Nonetheless, the VOT increases with commuting subsidies and, thus, raises the full economic cost of shopping so that long distance shopping becomes less attractive. Third, lowering energy taxes on

Table 5: Effects of subsidization policies on spatial travel patterns

		Subsidy [million €/year]		
		79	432	800
Policy 1	Extreme cross commuting	+1.3/+1.3	+6.7/+5.3	+12.0/+9.3
	Extreme cross shopping	0.0/0.0	0.0/–1.0	0.0/–1.0
	Intrazonal commuting	–1.3/–1.3	–4.4/–4.4	–7.0/–6.3
	Intrazonal shopping	0.0/0.0	0.0/0.0	0.0/+0.6
Policy 2	Extreme cross commuting	+1.3/0.0	+5.3/+5.3	+12.0/+10.7
	Extreme cross shopping	0.0/0.0	0.0/–1.0	0.0/–1.0
	Intrazonal commuting	–1.3/–1.3	–3.8/–3.2	–6.3/–5.7
	Intrazonal shopping	0.0/0.0	0.0/0.0	0.0/0.0
Policy 3	Extreme cross commuting	0.0/0.0	+1.3/0.0	+2.7/+1.3
	Extreme cross shopping	0.0/0.0	+2.0/+1.0	+2.9/+2.0
	Intrazonal commuting	–0.6/0.0	–0.6/0.0	–0.6/0.0
	Intrazonal shopping	0.0/0.0	0.0/0.0	0.0/0.0
Policy 4	Extreme cross commuting	0.0/–1.3	0.0/–1.3	–
	Extreme cross shopping	0.0/–1.0	0.0/–1.0	–
	Intrazonal commuting	–0.6/–0.6	–1.9/–0.6	–
	Intrazonal shopping	0.0/0.0	–1.6/0.0	–
Policy 5	Extreme cross commuting	+1.3/0.0	–	–
	Extreme cross shopping	+1.0/+1.0	–	–
	Intrazonal commuting	–1.3/–0.6	–	–
	Intrazonal shopping	–0.6/–0.6	–	–

Percentage changes in relation to the 'Benchmark'
Income tax funding/Lump-sum tax funding

gasoline (Policy 4) not necessarily results in higher shares of extreme cross commuting and shopping. The reason for this is that there are again several feedback effects that countervail the effect of lower monetary travel costs. The automobile traffic induced due to lower gasoline costs increases congestion particularly in the city center. This in turn makes extreme cross travel more time intensive and, thus, less attractive.

6 Concluding Remarks

We have examined the impact of different policies aiming at reducing travel costs of urban residents and calculated optimal subsidy levels. Starting with a stylized spatial model of household behavior, it has been demonstrated how transport subsidies may distort a worker's non-spatial and spatial location decisions and how several effects arising in the urban economy interact when endogenous location as well as labor-leisure decisions are considered simultaneously. To calculate effects and optimal subsidy rates we then used a spatial urban general equilibrium model calibrated to an average German metropolitan area.

The paper innovates studying passenger transport subsidies by taking the following features simultaneously into account: endogenous labor supply decisions and location decisions within a spatial general equilibrium where the urban area is not restricted to be monocentric, household heterogeneity by considering multiple household types differentiated by skills and employment status, commuting and non-commuting (shopping) trips, non-linear progressive income taxation (the German case), financing issues (income tax versus lump-sum tax funding), travel mode choice, travel related externalities such as congestion, and feedback effects between urban land, labor and commodity markets. Although some of those features have already been considered in the literature, they have never been treated simultaneously in an adequate spatial setting. However, due to the existence of a wide range of interdependencies and feedback effects implementing those features together is important.

General results can be summarized as follows: First, all policies cause a suburbanization of the urban population but the magnitude of the effects is surprisingly small. Because the suburbanization of residences is stronger than the suburbanization of jobs, implying a larger job-housing imbalance, urban sprawl is strengthened. Second, concerning aggregate urban welfare the funding scheme hardly affects the relative advantageousness of a policy compared to the other policies (see Figure 2). However, stronger distortions accruing under income tax funding[24] suggest that welfare gains (losses) of urban residents and landowners are smaller (higher) under income tax funding compared to lump-sum funding (without welfare effects induced by changes in carbon dioxide emissions). But since these distortions in the tax system also distort labor supply and thus travel decisions of urban residents, aggregate emissions of carbon dioxide are lower under income tax funding. Third, policy induced distributional effects among urban residents and landowners are considerably large and depend crucially on the funding scheme. In particular high-skilled workers are adversely affected by income tax funding. Fourth, aggregate welfare effects are suggested to be stronger for subsidization policies that discriminate between travel modes

[24] See Feldstein (1999) who shows the distorting potential of the income tax.

rather than trip purposes. While subsidizing public transport (road traffic) is welfare improving (reducing) pure commuting subsidies hardly affect aggregate urban welfare.

Finally, the results make clear that labor supply effects (frequency of commuting trips) as well as location decisions (length of trips) matter. Both affect congestion which in turn affects the value of time and, therefore, labor supply as well as location decisions.

In addition to these more general results, Table 6 summarizes the main results of the different transport subsidization policies focusing on income tax funding.

Table 6: Summary of the transport subsidy effects under income tax funding

Policy	'Benchmark' level	Additional subsidy	Policy level	Spatial effects	CO_2 emissions	Absentee landowners
1: δ^{τ} (↑)	0.3 €/km	≤0.2 €/km	0.5 €/km	Sprawl	increase	better off
2: δ (↑)	0.0 €/km	0.0 €/km	0.0 €/km	Sprawl	increase	worse off
3: K (↑)	0.153	0.0	0.153	Sprawl	decrease	better off
4 : τ^g (↓)	0.65 €/km	0.0 €/km	0.65 €/km	Sprawl	increase	worse off
5 : τ^{public} (↓)	0.07	0.07	0.0	Sprawl	decrease	better off

Implications:
Policy 1: raising the income tax deduction rate of commuting expenses up to 0.2 €/km
Policy 2: not granting a direct commuting subsidy
Policy 3: no road capacity expansion
Policy 4: no reduction of energy taxes on gasoline
Policy 5: granting full sales tax exemption of public transport fares

Concerning policies where subsidies are granted exclusively for commuting, the analyses suggest that aggregate urban welfare gains are rather small if subsidies are funded by the income tax. Taking welfare effects on landowners into account, it turns out that the introduction of a direct commuting subsidy (Policy 2), keeping the tax deduction rate at the 'Benchmark' level, would actually cause a decline in overall welfare. However, especially the income tax deduction of commuting expenses (Policy 1) is controversial discussed and already implemented in Germany. It is suggested to be from particular interest because according to our simulations welfare could either increase or decrease depending on the level of the subsidy. Interestingly, as Figure 5 shows, overall welfare (urban welfare + absentee landowners) is higher for a (still) moderate tax deduction rate compared with both extreme cases , i.e. $\delta^{\tau} = 0.0$ and $\delta^{\tau} = 1.2$, resulting in an overall welfare peak in between both extremes. This implies that there is a trade off between the burden of higher marginal income tax rates and the benefit of higher tax deduction rates. The optimal rate at which commuting expenses should be income tax deductible amounts to about 0.5 €/km while abolishing the subsidy would generate welfare losses. Nonetheless, even the rate of 0.5 €/km is considerably lower than actual commuting costs. According to our calculations monetary round-trip commuting costs lie on average between 0.73 €/km for low-skilled and 1.00 €/km for high-skilled workers. Adding time costs imply aggregate full economic commuting costs of 1.61 €/km and 2.20 €/km, respectively. Figure 5 also displays social costs of CO_2, assuming marginal social damage costs of 70 €/tCO_2. This shows that lowering the subsidy actually dampens social costs of CO_2 but raising the subsidy from 0.3 €/km to 0.5 €/km raises those costs. Considering those costs in an extended welfare analysis and taking further externalities additionally into account would imply that the optimal subsidy rate would be even lower than 0.5 €/km.

Figure 5: Income tax deduction of commuting expenses under income tax funding

Stronger subsidization of road transport either through additional investments in road capacity or through tax cuts on gasoline turns out to be less favorable for urban residents. Surprisingly, the simulations suggest that there is actually no urban population group that benefits from both policies, even high-income income households are worse off. However, both policies are characterized by significant differences. While road capacity expansion causes emissions of CO_2 to decrease and benefits of landowners to increase, reducing energy taxes on gasoline exhibits the reverse pattern. In this case total emissions of CO_2 actually rise most compared with the other policies. The reason is that additional automobile traffic is induced so that congestion is strengthened while a countervailing effect (increase in road capacity) contributing to reduce congestion is absent. However, there are some important features not considered in this study implying demand for further research. In particular, neither noise nor external accident costs are taken into account. Because noise constitutes a disamenity for urban residents it may lower rents and, thus, may diminish potential benefits of the landowners regarding the road capacity policy (see e.g. Brandt and Maennig, 2011; Kim et al., 2007).

Finally, granting higher subsidies to urban public transport not only lowers travel related emissions of carbon dioxide but also raises aggregate urban welfare as well as welfare of landowners. Moreover, the distribution analyses suggest that even the high-skilled workers are better off from such a policy (but only if subsidies are funded by a lump-sum tax). Hence, there might be a clear majority for raising subsidies on public transport. Interestingly, by applying a model to cities such as Los Angeles and London Parry and Small (2009) also find that subsidizing public transport via transit fare reductions is welfare improving on a large scale. Although their model is highly differentiated regarding the transport market (e.g. rail and bus, peak and off-peak, cost structure of transit agencies) they ignore many of the features considered here (e.g. heterogeneous agents, spatial equilibrium including location decisions, interdependencies of different markets, interactions with the broader tax system). However, it should be noted that the model employed in this analysis does not take into account supply side effects associated with public transport. In many countries public transport is heavily subsidized by the fact that transit fare revenues do not cover operating costs of the transit system (see Parry and Small, 2009; Buehler and Pucher, 2011; Brueckner, 2005). As a result, there might be a need to finance the operating deficits of public transit agencies via the tax system. Consequently, an increase in the use of public tran·sport might cause efficiency losses implied by the increase in distortionary taxes such as labor taxes. Whether this countervailing effect of the tax system causes public transit welfare gains (only) to decline or might in the end even cause welfare losses is an important issue for further research. Its strength also depends on how transit agencies respond to increases in passenger demand, i.e. whether they expand service through more vehicle miles or whether they increase the occupancy of vehicles. Buehler and Pucher (2011), however, cite evidence that productivity and financial efficiency have improved significantly in Germany. The share of operating expenses covered by passenger fares increased from 59% in 1991 to 77% in 2007 suggesting that such a countervailing effect of the tax system might be of only of moderate importance in Germany.

Further attention could be paid to the interaction between commuting subsidies and congestion. For example, granting commuting subsidies along with the imposition of a congestion toll might be welfare-improving as the subsidy counteracts the toll induced reduction in the return to labor (see Calthrop, 2001). In addition, in particular in regard to Policy 4 and 5 the present analyses only aimed at examining a decrease in taxes on travel but not aimed at examining the opposite direction of tax changes. Because we focused on subsidies we did not enquire tax increases though this might be socially optimal (see

Parry and Small, 2005). This is left for future work.

Moreover, a further extension of the present analyses for all policies is to examine the impacts of alternative funding schemes, e.g. funding the subsidies by cuts in the sales tax rate on general consumption or 'cross'-funding, i.e. financing a cut in the sales tax rate on public transport fares by, e.g., an increase in the energy tax on gasoline.[25] This would also allow additional comparisons between different funding schemes. For example, an increase in income tax rates as well as an increase in energy taxes on gasoline harm the high-income households, ceteris paribus, to a relatively larger extent because of progressive income taxation (if income taxation is progressive) in the former case and because of a larger share concerning automobile usage in the latter case. In addition, both kinds of taxes affect the VOT, ceteris paribus, in the same direction. Nonetheless, there would be differences concerning direct costs of traveling. Hence, general equilibrium analyses are required to examine differences in the effects of both funding measures.

APPENDIX-A: Spatial Derivations City Model

The location choice problem requires to maximize utility subject to the consolidated full economic budget constraint:

$$\max_{x,y} u\left(z,q,\ell\right)$$
$$\text{s.t.:} \left[p\left(1+\tau^{z}\right)+\left(c+\theta t-\delta^{c}\right)x\right]z+r\ (x)\,q+\theta\ell=\theta E+I. \tag{A-1}$$

The value of time is given by

$$\theta=\frac{\left(1-\tau^{m}\right)Lw\ (y)-\left(C-\delta\right)\left|x-y\right|}{L+T\left|x-y\right|}. \tag{A-2}$$

Differentiating with respect to y yields the first-order condition for the workplace location

[25] Barros and Prieto-Rodriguez (2008) analyze the potential of such a revenue-neutral tax reform to increase demand for public transport services. Their analyses suggest that such a policy induces a small loss in social welfare. However, they do not employ general equilibrium analyses and so do not take into account feedback effects on, e.g., congestion.

$$\theta_y \left[txz + \ell - E \right] = 0 \rightarrow \theta_y = 0 \tag{A-3}$$

which is equivalent to

$$\theta_y = \frac{\left(1 - \tau^m\right) Lw_y\ (y) + \delta - C - \theta T}{L + TX} = 0 \tag{A-4}$$

and eventually gives us the condition for the optimal place of employment (Eq. (5))

$$\left(1 - \tau^m\right) Lw_y(y) = C + \theta T - \delta. \tag{A-5}$$

Differentiating Eq. (A-1) with respect to x yields

$$r_x\,(x)\,q = \theta_x \left(E - \ell - txz\right) - \left(c + \theta t - \delta^c\right) z. \tag{A-6}$$

Substituting the time constraint (Eq. (2)) yields

$$r_x\,(x)\,q = \theta_x \left(L + TX\right) D - \left(c + \theta t - \delta^c\right) z. \tag{A-7}$$

After substituting

$$\theta_x = \frac{\left(\delta - C - \theta T\right)}{L + TX} \tag{A-8}$$

we obtain the condition for the optimal place of residence (Eq. (6))

$$r_x\,(x) = -\left[c + \theta t - \delta^c\right] \frac{z}{q} - \left[C + \theta T - \delta\right] \frac{D}{q}. \tag{A-9}$$

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Figure 1: Spatial decision structure and interdependencies between urban and non-urban economic agents

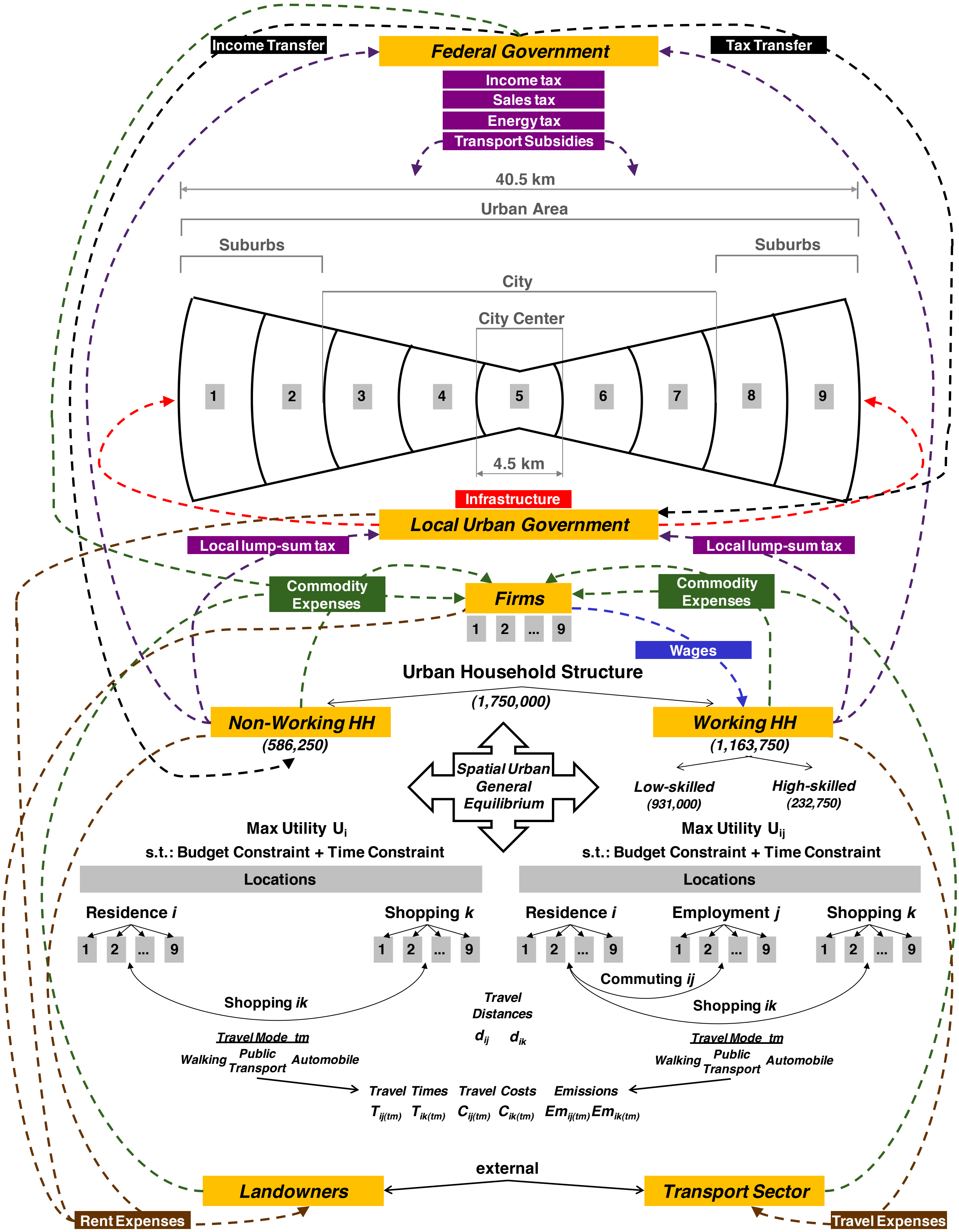


Figure 2: Aggregate urban welfare effects of transport subsidization policies

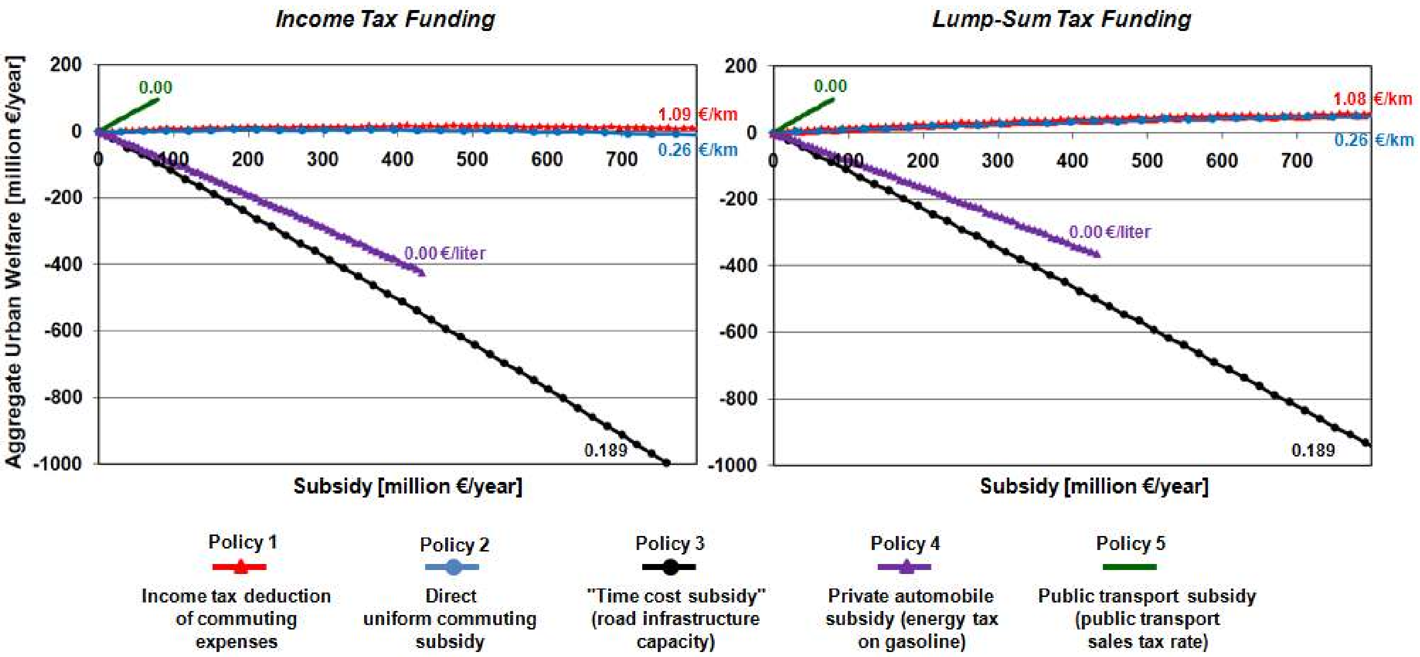


Figure 3: Effects of transport subsidization policies on landowners

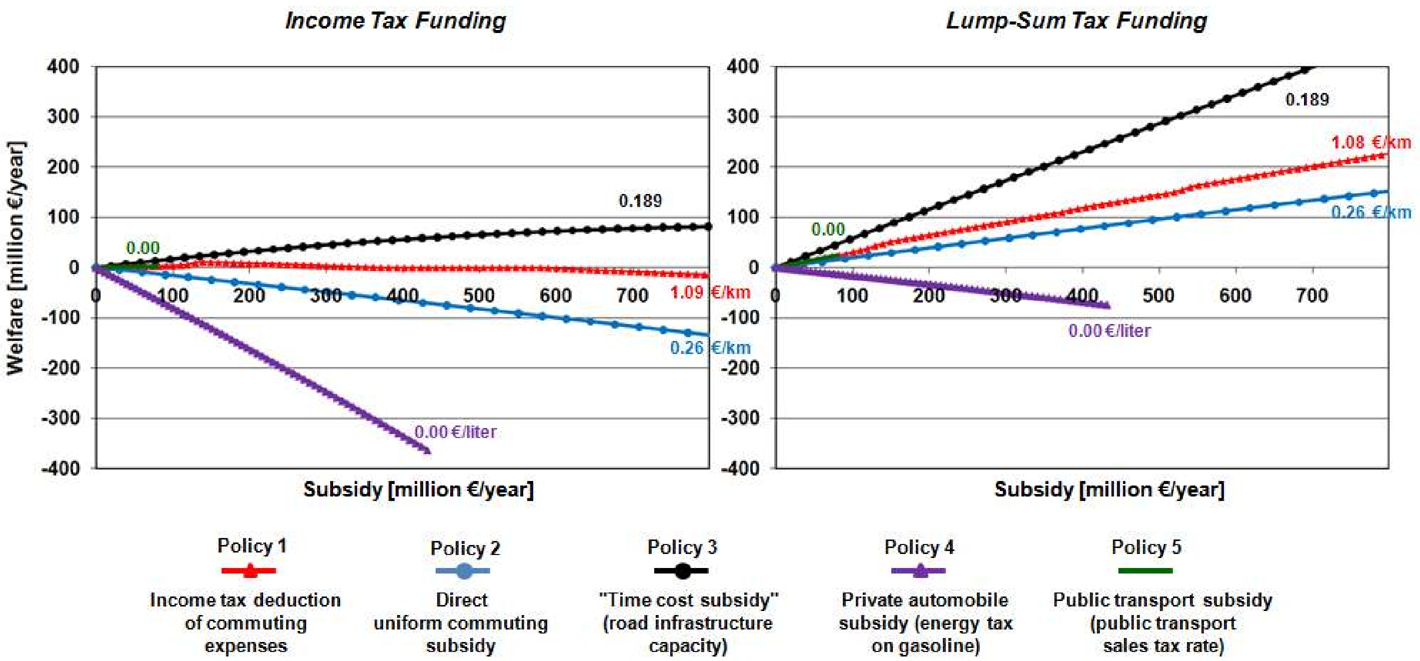


Figure 4: Effects of transport subsidization policies on CO_2 emissions

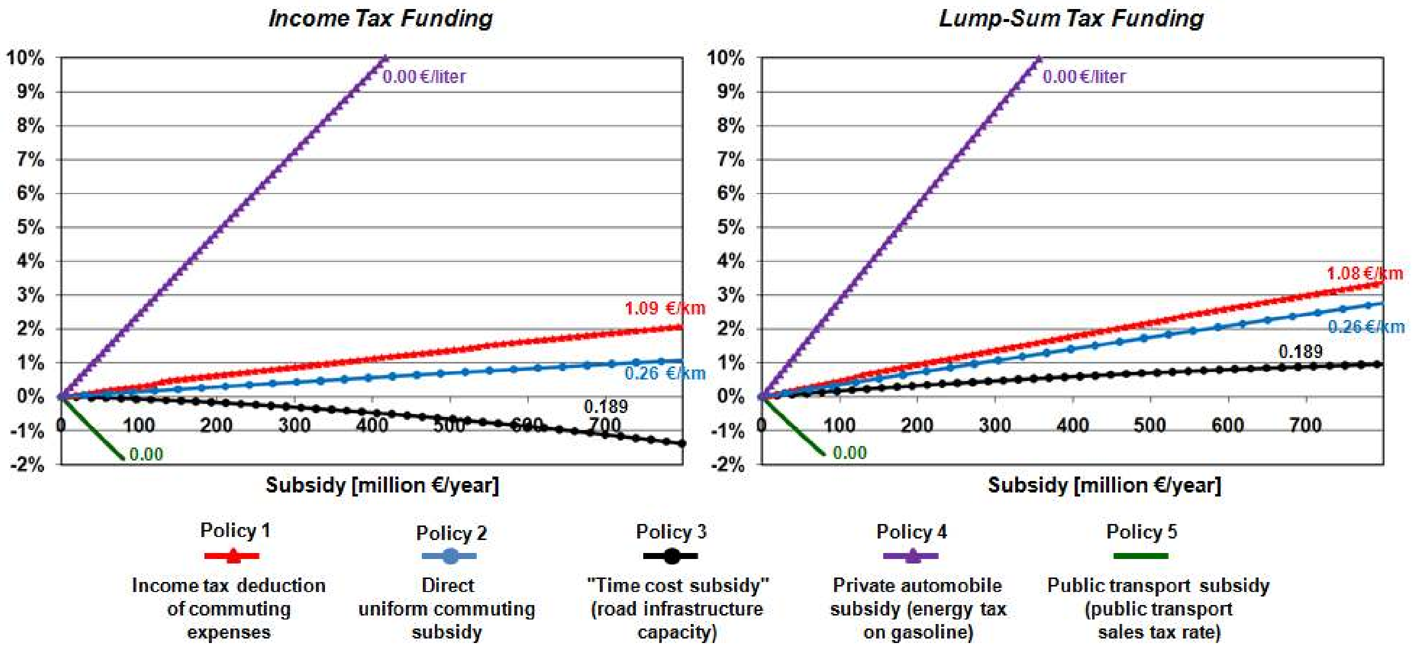
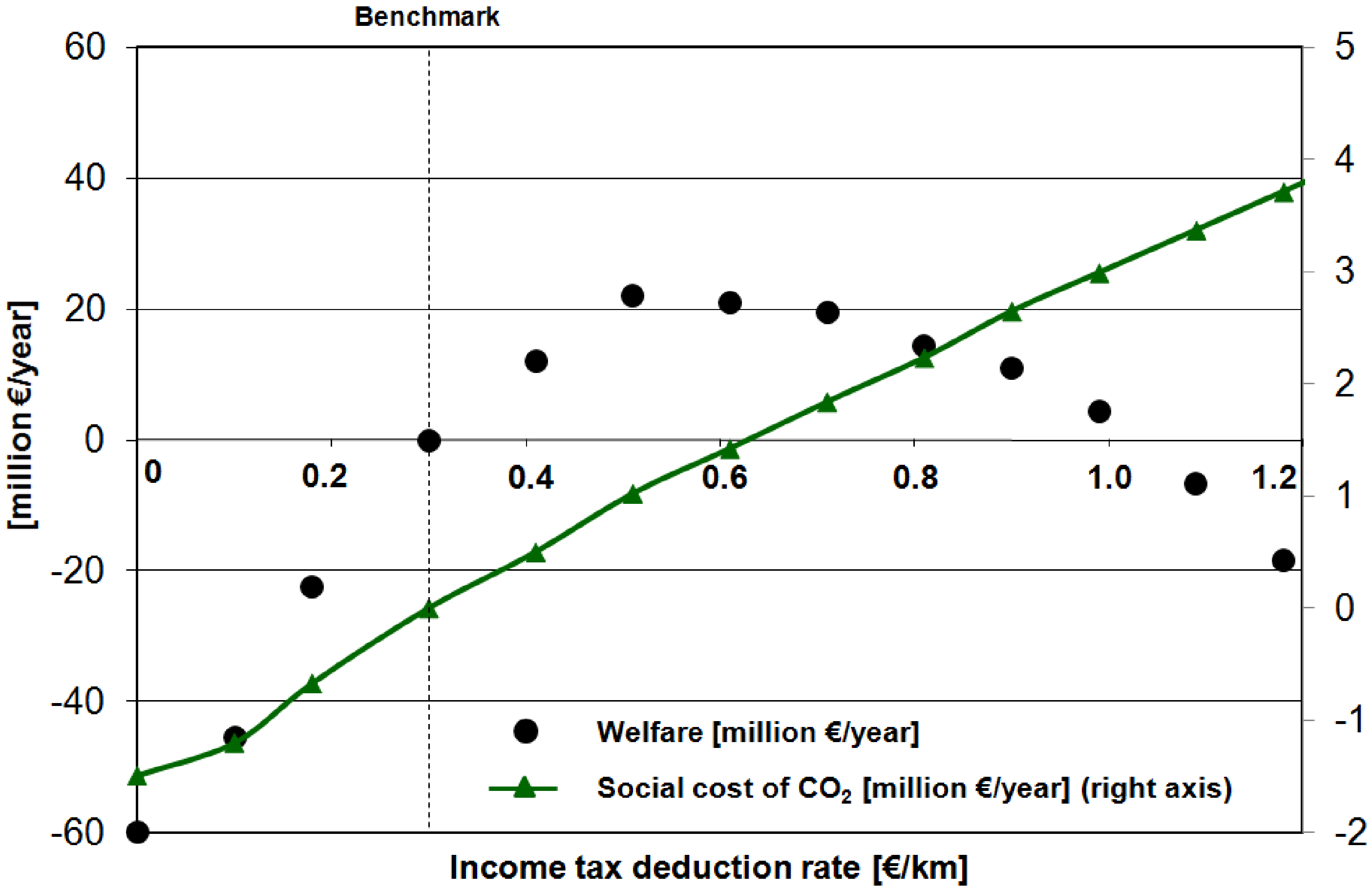


Figure 5: Income tax deduction of commuting expenses under income tax funding



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