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ANALYSIS

Sustainability impacts of car road pricing: A computable general equilibrium analysis for Austria

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ABSTRACT

Nationwide car road pricing schemes are discussed across Europe. We analyse the impacts of such schemes with respect to environmental, economic and social indicators of sustainability, also quantifying the trade-offs among these three dimensions under different charging principles and revenue recycling options. In our analysis we employ a computable general equilibrium (CGE) approach, develop a modelling structure for private transport and provide detailed empirical analysis for the case of Austria. Regarding the social dimension, it has often been argued that poorer households (and commuters) would have to bear a disproportionate share of the road pricing burden. We find the contrary, i.e. a stronger negative policy impact on richer households, and on a small group of intensive car users. The choice of revenue recycling is able to ameliorate the negative social and economic effects of road pricing, without reversing the desired positive environmental effects. For political feasibility, questions of distributional impacts are most urgent and therefore we address them systematically within a quantitative framework.

1. Introduction

Environmental challenges in transportation occurred repeatedly in history, an early example in modern times being the concern in the 1870s in London that, with a further growing population, the horse manure (an earlier form of transport-derived pollutant) would overwhelm the city.[1] For the current transport system, environmental concerns have become increasingly important since the 1970s. Transport is now responsible for at least a quarter of world primary energy use and for a comparable share of CO_2 emissions (Berechman, 2002).

While initial responses to the environmental challenge in transport were primarily technological, there has since been a focus also on reducing and re-structuring transport demand (Berechman, 2002) and on using transport pricing policies (Hensher and Button, 2000; Viegas, 2003). However, most of present transport policies still mainly centre on vehicle emission and safety standards, annual license duties and parking fees and thus may be classified as out-dated or, in the economist's jargon, "second-best" (see, e.g., Calthrop and Proost, 1998; Nash et al., 2001; Ubbels et al., 2002).

Road pricing, a vehicle user charge based on distance travelled, is clearly highly suitable in addressing transport-

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[1] The impact on daily life is captured in an example quoted by Weightman and Humphries (1985: 36): "But with all the horse traffic, there was an awful amount of dirt on the streets, some of them were in a dreadful state. There were crossing sweepers, rather oldish men, and if one gave them a coin they would be very pleased to sweep a path across the street in front of one."

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related environmental problems since it allows differentiation of charges across location, time, vehicle type etc. (see, e.g., Johansson and Mattsson, 1995; Button and Verhoef, 1998; Sterner, 2002; Santos, 2004). It combines the ability to untie congestion, to reduce air pollution, and to raise revenues for new infrastructure and other investment (Jakobssen et al., 2000; May et al., 2002; Parry and Bento, 2002).

For trucks, kilometre based road pricing systems have been introduced in Europe at various levels of sophistication, i.e. from section-charging on highways in various countries, and electronic charging on highways in Austria (2004) and Germany (2005), up to charging for use of the full road network in Switzerland (2001). In Sweden, a mileage tax for diesel trucks was in place from 1988 up to 2004.[2] For private cars, charging in Europe has been introduced either section-wise for highways or for urban areas mainly in the form of toll rings, e.g. in Scandinavian countries and more recently in London (and similar as in other parts of the world, such as in Singapore). The discussion of nationwide kilometre based charging also for private cars has slowly taken off in various European countries (see e.g. Nash et al., 2001; Ubbels et al., 2002).

The introduction of extensive, nationwide road pricing also for passenger transport requires careful impact analysis. In terms of sustainability impact assessment, the European Union (EU), for example, asks for "careful assessment of the full effects of a policy proposal [that] must include estimates of economic, environmental and social impacts" (EC, 2001). As set out in Böhringer and Löschel (2006) in some detail, the quantification of trade-offs in such an impact assessment analysis calls for the use of numerical techniques and that one of these approaches, CGE modelling, "can incorporate several key sustainability (meta-)indicators in a single micro-consistent framework, thereby allowing for a systematic quantitative trade-off analysis between environmental quality, economic performance and income distribution." (Böhringer and Löschel, 2006: 50-51). As passenger car road pricing remains a field of national policy responsibility, also within the EU,[3] we develop a CGE model for a sustainability impact assessment at the national level of such policy.

Within the different dimensions of sustainability, the economic one has been most broadly discussed for road pricing. The initial focus was the optimal pricing in the transport sector to combat congestion (e.g. Lindsey and Verhoef, 2001). Increasingly the environmental impacts of transport have been taken up in co-determining the optimal price (e.g. Mayeres et al., 1996).[4] In our view least effort has been devoted to the social dimension. However, social questions of distribution and equity are of major importance for the acceptance of road pricing (see also Mayeres and Proost, 2001). The low public acceptance for car road pricing derives from the perception of road pricing as intrinsically unjust (Oberholzer-Gee and Weck-Hannemann, 2002) and as infringing on personal freedom (Jakobssen et al., 2000). Since income constraints can be identified as the key determinant for transport demand reductions when travel costs increase (Jakobsson et al., 2000), the burden of road pricing is likely to fall on poor households (see also West, 2004) and on households living in peripheral regions (Hammar and Jagers, in press).

This article therefore aims to not only quantify economic and environmental impacts of road pricing, but to investigate the effects on those groups perceived as bearing the main burden of road pricing. A passenger transport focused computable general equilibrium (CGE) model is developed for this purpose. To better understand the distributional effects of road pricing, we distinguish four classes of income in our model. Thus, the present model goes beyond existing ones in several respects. First, and in some way parallel to earlier transport policy discussion, most of the models used so far to analyse road pricing are either limited to freight transport (e.g. Steininger, 2003; De Jong et al., 2004) or they target urban road pricing or toll ring pricing only (e.g. Mayeres et al., 1996; Proost and van Dender, 2001). We focus on nationwide car road pricing. Second, while an increasing number of papers addresses the welfare effects of a tax suitable for internalising external transport costs (e.g. Jansen and Denis, 1999; Nash et al., 2001), distributional aspects have hardly been considered in economic transport policy models. Third, in methodological terms, our approach unites modules from the sciences of transportation and economics to a consistent integrated assessment of economic, environmental and distributional impacts. The core ingredient in this merging is the calibration method of the economic passenger transport focused CGE model, integrating results of the pure heuristic passenger mode choice model.

The paper proceeds in four steps as follows. In Section 2, the passenger transport focused CGE model is developed. In Section 3, transport and consumption databases are merged, a social accounting matrix is constructed which differentiates sufficiently between the various cost components of private car transport, and transport elasticities of substitution are calibrated for this model. Section 4 reports on the simulation results of nationwide car road pricing in various implementation schemes. Section 5 discusses the distributional, economic, and environmental impacts of this policy. A final section summarises the main conclusions and outlines key factors for increasing acceptability prior to the introduction of a car road pricing system.

2. Transport demand CGE model

In order to analyse the economic, environmental and distributional impacts of car road pricing, we develop a CGE model which is a standard small open economy CGE model in many respects, but obviously with more detailed passenger transport modelling.

[2] The Swedish mileage tax for diesel trucks was introduced to counterbalance low diesel relative to gasoline taxes, with the former reflecting the practically identical composition of diesel and (also low-taxed) fuel oil. When Sweden joined the EU, this mileage tax was replaced by a diesel tax (Sterner, 2002).

[3] See EC (2006), Article 1, 1.e.

[4] E.g., for trucks EC (2006) asks for road pricing on the basis of external costs. Article 11 states, that "[...] the Commission shall present, after examining all options including environment, noise, congestion and health related costs, a generally applicable, transparent, and comprehensible model for the assessment of all external costs to serve as the basis for future calculations of infrastructure charges, and this model will be accompanied by an impact analysis on the internalisation of external costs for all modes of transport [...]".

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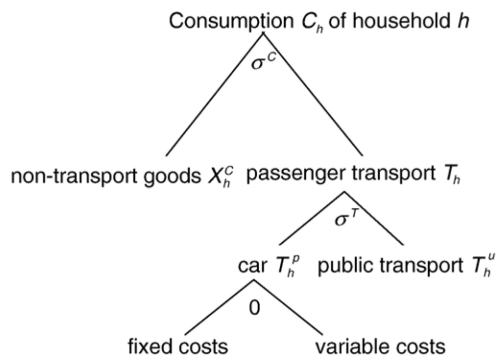

Fig. 1 – Structure of household final demand for income group *h*. Note: Non-zero values denote calibrated elasticities of substitution: σ^c = transport to non-transport substitution elasticity, σ^T = car to public transport substitution elasticity.

In the production of non-passenger-transport goods 35 sectors, j, are distinguished, and a nested constant elasticity of substitution (CES) structure is used. Capital K_j and labour L_j serve as primary inputs, and intermediate inputs enter in a Leontief fashion.[5] In describing the production of the various passenger transport intermediate and final consumption goods, the model structure reflects both the purpose of analysis as well as the nature of data availability. In preparing for the CGE analysis we disaggregate a standard social accounting matrix for Austria, constructed for the year 2000, in order to differentiate household expenditure across income groups in terms of public transport and private car use. For the latter the various elements of fixed and variable (i.e. kilometre-dependent) costs are distinguished, all of which are linked to respective sectors of supply or to government budget revenues, such as car and gasoline taxes. We thus manage to isolate a newly combined passenger-transport good of final household consumption, which in regular final demand statistics is dispersed across various sectors (refined oil, transport equipment, distribution, finance and insurance, and inland transport).

The structure of consumption, emphasising transport consumption is given in Fig. 1. Household demand C_h of household h is governed by a nested CES structure, with unity elasticity of substitution among non-passenger-transport goods $X_{i,h}^c$ (i.e. constant expenditure shares for non-passenger-transport goods), and calibrated elasticities of substitution between the aggregates of non-transport and transport goods T_k as well as among different passenger-transport goods, T_h^p and T_h^u, i.e. private and public transport.

As is seen in Fig. 1, fixed and variable cost components of car passenger transport combine in a Leontief fashion to private car transport T^p, i.e. the elasticity of substitution is exogenously set at zero. Basically, kilometre charges (as the most important variable cost element in the current analysis) cannot be substituted by fixed cost (such as technical equipment or the like).

We distinguish four representative households h (reflecting income quartiles), which differ in their respective transport expenditures. For all consumption expenditures other than transport, expenditure shares (but not levels) are assumed identical across income groups. This simplification is justified since on the aggregate level, only two consumption aggregates differ considerably across income groups, namely expenditures on housing and on transport.[6]

For substitution elasticities between transport and non-transport goods, due to lack of adequate data on differences across income groups, we assume them as uniform across household types. This last point is important. One could think of the shift between transport and non-transport goods being differently easy for poor and rich households. Using uniform substitution elasticities, distributional impacts of road pricing are driven by the different transport volumes and expenditure shares across income groups, based on different transport behaviour (e.g. intensity of driving). Accordingly, the same road pricing charge induces different reactions across income groups due to different relative increases in car user costs.

Foreign trade is modelled under the Armington assumption of product differentiation, i.e. a change in relative prices of domestic and foreign goods shifts the trade balance in the respective sector, the degree of which is determined by a sectoral foreign trade elasticity.

As the analysis of the labour market impact of transport policy is an issue, it is assumed that the labour market does not clear, and that unemployment is driven by classical, i.e. high minimum wage, unemployment.

The model is closed by a fixed foreign trade balance at the level of the reference year ("neoclassical closure", fixed foreign savings), such that investment is savings driven and the foreign exchange rate adjusts to achieve equilibrium.

3. Data set and calibration

Due to the lack of a database combining information on passenger trips (by purpose, mode, distance, and frequency) and income for Austria, we econometrically merged the Austrian mobility survey (Herry and Sammer, 1999), the Environmental Balance of Transport (Federal Ministry of Agriculture, Forestry, Environment and Water Management, unpublished) and the Austrian consumption expenditure survey (ST.AT, 2002). The challenge here was to have disaggregated data on both *transport expenditures* and on *transport demand* in terms of quantity (passenger and vehicle kilometres and mode per year), distinguished by household *income levels* and *region types* (urban, semi-urban, peripheral).

We find that the richest income quartile households drive their cars more than four times more intensively than the poorest (see Fig. 2). This strong difference in mileage across

[5] A full list of variables and the core equations as a reference for the reader are given in the Appendix.

[6] Expenditures on rent, heating and lighting (relative to total consumption expenditures) vary for the example of Austria from 30.4% for the lowest income group to 20.6% for the highest; an opposite trend can be observed for transport: expenditures on transport increase from 8.5% for low income households to 17.5% for high income households (ST.AT, 2002).

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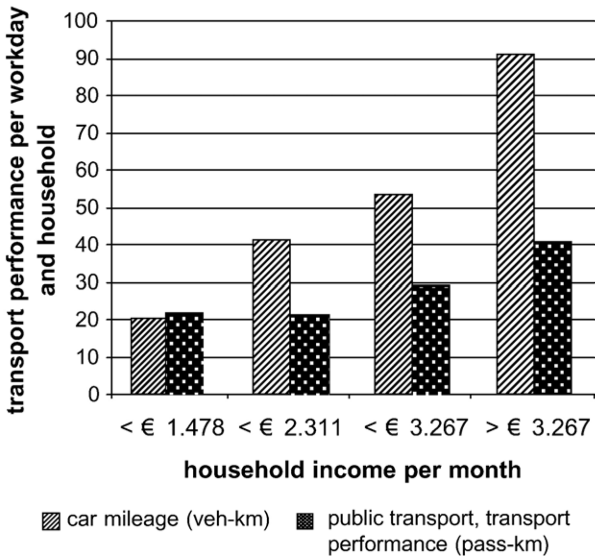

Fig. 2 – Passenger transport mileage by household and workday across income classes, Austria 2000.

income groups also translates to a difference in consumption budget shares across income groups. In accordance with published results on significantly positive income elasticities for car ownership and car use (see, e.g. Dargay, 2001; Johansson-Stenman, 2002; Pucher and Renne, 2003; Kletzan et al., 2006), the fraction of transport expenditures in Austria increases from 9.6% for low income households to 18.6% for high income households (ST.AT, 2002; see also Table 1). Furthermore, in rural areas at least 50% of the households spend nothing on public transport while in urban areas many households do not even own a car (ST.AT, 2002). This initial situation and its implication for the availability of reaction options to car road pricing are important for the road pricing impacts we will later find.

A price change in car travel, such as it is triggered by road pricing, induces a modal shift and a change in overall transport volume. In the CGE approach elasticities of substitution denote the strength of these reactions.[7] The parameter values for these transport elasticities of substitution (between car and public transport, denoted by σ^T, and between total passenger transport and demand for non-transport goods, denoted by σ^C in Fig. 1) were calibrated from a choice switch passenger transport demand model (Kriebernegg, unpublished). In this model, individual reaction patterns to car road pricing were distinguished, namely reactions within the demand structure for car passenger transport (e.g. a change of route or destination) and reactions in demand for public and other transport (e.g. a modal shift from car to public transport). Reactions differ with respect to trip purpose, type of region in which the trip originates, and road pricing scenario. The resulting aggregate elasticities of substitution are quite low due to the cautious assumptions of the choice switch transport demand model: $\sigma^C = 0.275$ and $\sigma^T = 0.635$. Thus, the CGE simulations refer to the – in terms of economic welfare and distributional impacts – "strongest impact", in terms of environmental implications "lowest impact". If, however, easier substitution between transport and non-transport goods and/or between car and public transport were possible (i.e., if larger values of σ^C and σ^T apply), negative impacts on economic welfare would be smaller, and emission reduction would be larger.

4. Road pricing policy simulations

We distinguish policy scenarios with respect to (a) the type of road network charged, (b) whether there is (peak hour) time differentiation, (c) two different charging levels per kilometre, and (d) two different ways of revenue use. The specific combinations and detailed information of policy scenarios considered are stated in Table 2. The road pricing charge is either uniform for the entire network (scenarios A-5, B-5) or is doubled during peak times in urban areas to internalise congestion externalities (scenarios C-5, D-5).[8] The base rate of 5 Euro-Cents and 10 Euro-Cents is chosen to internalise half or all of estimated marginal external costs (based on *average* external cost for diesel and petrol cars as the lower bound for *marginal* external costs) for Austria (Herry and Sedlacek, 2003).

After covering system costs (an approximate 15% of revenues), road pricing revenues are used, a third each, for road infrastructure investment, public transport improvement, and household refund. In scenario D-5, a much higher share is used for public transport improvement (5/9). We will first analyse the impacts of road pricing for one policy scenario in more detail, before we report on the merits of the five policy scenarios relative to each other.

4.1. *Road pricing base scenario B-5*

Implementing car road pricing on the road network nationwide at a level of 5 Euro-Cent/km, without time differentiation and applying the straight forward "third-each" revenue use rule, we find the economic impacts as stated in Tables 3 and 4 (first two columns). In a comparative static analysis we "shock" the economy in the base year 2000.

Let us first look at the overall transport, environmental and macroeconomic impacts (Table 3). A reduction of 6.5% in car vehicle kilometres (some 4 billion veh-km in absolute terms) is observed, with a simultaneous increase in public transport passenger kilometres by 6.3%.

As the specific emission intensity per passenger kilometre of cars (strongly) exceeds the one of public transport,[9] net

[7] An elasticity of substitution between private and public transport with a value of 0.5, for example, means that a 1% price rise of car travel relative to public transport induces a 0.5% change in the modal split, here in favour of public transport.

[8] According to a recent survey for Europe, Proost et al. (2002) confirm that marginal external costs vary considerably between off-peak and peak periods. They are at least twice as high during peak hours.

[9] For example, in 2000 a public transport passenger kilometre on average was connected to 8% (CO_2), 1.5% (CO) and 35% (NO_x) of emissions of one vehicle kilometre of a car in Austria (Federal Ministry, 2006).

transport emission decline as a result of this modal shift and overall transport volume reduction, with net emission reductions reported for CO_2, CO and NO_x in Table 3.[10]

Using the foreign price level as numeraire, GDP increases. A new service, the environment, is now paid for, which raises the overall price level relative to abroad. The relevant measure therefore is GDP in purchasing power parity (PPP) terms, which we find to decline (by 0.3%). While this decrease in physical production lowers indirect tax revenues and exerts a declining pressure on employment, the latter is outweighed by the employment increase due to a sectoral shift in production. More specifically, the sectors of construction, textiles and public transport gain at the cost of the sectors machinery, transport equipment and all types of energy supply. In total, public revenues decline, but lost public tax revenues are more than compensated for by the (semi-public) net revenues from car road pricing (which account for 1.7 billion Euros in this scenario).

We find a considerable variation in car road pricing impact across household income groups (see Table 4, first two columns). Due to the introduction of road pricing, private car transport expenditure rises most for the poor by far, increasing by almost a fifth. Nevertheless, the original pre-policy mileage level of this group is so low, that overall welfare reduction, as measured by the Hicksian equivalent variation,[11] is smallest for this group. Public transport increases degressively across income groups, due to the pre-policy situation that the share of public transport decreases with income.

In order to quantify the net welfare benefit of this policy scenario at the aggregate level, we differentiate the benefit of congestion and other external costs reduction and the cost of consumption reduction (visible in its direction also in PPP GDP decline). Based on average external costs per kilometre, as quantified in Herry and Sedlacek (2003), as approximation for marginal external transport costs,[12] we get a value of welfare benefit of 329 million Euros. However, since external transport costs will rather rise progressively with transport volume than linearly as we assume, our benefit quantification can be considered a very conservative one (for more details see Steininger et al., 2005).

Table 1 – Transport expenditures across income groups, Austria 2000

Monthly earnings per household	Income group			
	1	2	3	4
	Less than € 1478	Less than € 2311	Less than € 3267	More than € 3267
Transport expenditures as % of monthly household income				
Car exp.; fixed costs	5.97	11.00	12.39	14.57
Car exp.; variable costs	2.49	3.71	3.84	3.58
Public transport exp.	1.13	0.76	0.63	0.47
Total transport exp.	9.58	15.47	16.86	18.61
Variable transport expenditure in Euro per km				
Car	0.050	0.058	0.061	0.046

Source: ST.AT (2002), Federal Ministry of Agriculture, Forestry, Environment and Water Management (unpublished), own calculations.

4.2. *Impacts across road pricing policy scenarios*

When we also simulate the other policy scenarios in this comparative static analysis, we obtain the results shown in the further columns in Table 3. The most significant impacts arise when the charge is raised to 10 cents/km (scenario C-10): road pricing revenues rise to a level of 5.7 billion Euros (3.5 billion Euros net of system costs and household refunds). Nationwide car vehicle kilometre reduction comes close to 15%, transport CO_2 emissions decrease by 1.5 million tons (which corresponds to 2.5% of overall Austrian CO_2 emissions). GDP in purchasing power parity terms declines by 1%. Net welfare benefits are at least 644 million Euros, including 170 million Euros congestion reduction benefits.

In scenario D-5, the elasticity of substitution between private and public transport is raised to 0.9 in order to model that a larger share of revenues is directed towards public transport (i.e. service improvement). The resulting rise in the use of public transport is significant.

Across policy scenarios we find the relevance of two opposing effects in the labour market. When road pricing revenue use, e.g. for secondary road infrastructure maintenance, increases (e.g. from A-5 to B-5), labour demand (and employment) increases due the high labour intensity of this use.[13] However, road pricing revenue use also increases prices of consumer relevant goods (e.g. construction or electronics), which increases wage rate demands and reduces employment. For high road pricing scenarios (C-10), the latter effect dominates, which then reduces employment.

Analysing the results across household income groups (see Table 4), we find a rise in car transport cost by up to almost 35% for the poorest group (C-10), but also by up to some 25% for the other income groups. Variable costs of car transport in scenario C-10 roughly triple (with a higher factor for the richest and poorest, a lower one for the other groups).

Consumption reduction impacts, which are the income group specific costs of the road pricing instrument, remain

[10] We employ a simple emission modeling here, using emission coefficients for private and public transport respectively for all relevant air and greenhouse gas transport emissions (including those given in Table 3). As car road pricing in the policy scenarios usually discussed (and in the ones we implemented in this analysis) is based on the charging principles of distance and/or time of use (but not of airborne emission intensity) this simplification appears justified.

[11] The equivalent variation gives the amount of income necessary to compensate an individual (in the pre-policy situation) in order to be able to claim equality with the post-policy utility level (see, e.g. Just et al., 2004). Thus, in the present analysis, the lowest income households would be willing to pay a fraction of 0.56% of their income to avoid the implementation of road pricing (B-5 scenario, Table 4). As we only look at the user costs of road pricing across income groups, this Hicksian welfare impact of road pricing is negative.

[12] Herry and Sedlacek (2003) take account of the following external costs categories: infrastructure costs, external accident costs, environmental costs (noise, local pollutants, climate effects), each differentiated by type of street and user, and net of public revenues raised, e.g. from taxes on insurance, vehicle registration and fuels.

[13] But see the sensitivity analysis section in the Appendix for the relevance of the assumption on the type of revenue use for the net direction of the labour market impact.

Table 2 – Policy scenarios

Scenario	A-5	B-5	C-5	C-10	D-5
Network charged	Urban: full network rest of Austria: primary road network	Full network	Full network	Full network	Full network
Time differentiation	None	None	7–9 a.m. and 4–6 p.m. + 100%	7–9 a.m. and 4–6 p.m. + 100%	7–9 a.m. and 4–6 p.m. + 100%
Charging level	5 cents/km	5 cents/km	5 cents/km	10 cents/km	5 cents/km
Revenue use	1/3 each: road infrastructure, public transport, household refund				1/9 road infrastructure, 5/9 public transport, 1/3 household refund

progressive with rising road pricing charge level across households (Table 4). Even though total car transport expenditures in scenario C-10 rise by a quarter for the rich, their consumption decline is confined to below 4%, and even lower for the other income groups. This consumption impact, which is negative across all scenarios, has to be counterbalanced with the welfare benefits of an improved environmental situation, lower accident costs or the reduction in time spent in transport, to get the overall net welfare benefit depicted in Table 3 at the national aggregate level.

Overall, we thus find that purchasing power parity GDP slightly declines, and due to reduced transport volumes environmental benefits strongly increase as the scope of application is widened (i.e. from primary roads only as in scenario A-5 to total road network) and as the road pricing rate is raised. Further, in our burden analysis we find consumption welfare declines, but – contrary to public discussion – with a significantly stronger impact on rich households. This progressive impact of car road pricing occurs because poor households spend a smaller share of their income on transport, and use more intensively public transport. Both factors diminish the relative burden of car road pricing on poor households, and the latter factor also eases the modal switch to public transport for such households.

5. Discussion

Despite the modest impact of the road pricing scenarios considered, two further points need to be discussed regarding the social consequences of road pricing. The first is usage of road pricing revenues and the second the impact on severely

Table 3 – Transport, environmental and macroeconomic impacts across road pricing policy scenarios

	Reference level (year 2000)	Policy Scenario B-5	Policy Scenario A-5	Policy Scenario C-5	Policy Scenario C-10	Policy Scenario D-5
Transport variables						
Road pricing rate	0	0.05 €/km	0.05 €/km	0.05 €/km	0.10 €/km	0.05 €/km
Revenue use (beyond system costs) for road infrastructure, public transport, household refund		1:1:1	1:1:1	1:1:1	1:1:1	higher share public transport
Revenues from road pricing (mn Euro)	0	2949	1915	3073	5720	3066
Car vehicle kilometres (mn veh-km)	63,068	−6.48%	−5.12%	−6.73%	−14.44%	−6.96%
Public transport (mn pass-km)	21,613	+6.29%	+4.56%	+6.55%	+14.77%	+12.32%
Environmental variables						
CO_2 emissions pass. transport (1000 t)	12,395	−722	−569	−744	−1,581	−798
CO emissions pass. transport (1000 t)	189.9	−12.1	−9.5	−12.5	−26.7	−13.0
NO_x emissions pass. transport (1000 t)	38.0	−2.0	−1.6	−2.1	−4.4	−1.9
Macroeconomic variables						
Welfare change (mn Euro) (lower bound)		329	273	399	644	
GDP (mn Euro)	204,616	+1.37%	+0.87%	+1.43%	+2.51%	+1.39%
GDP in PPP (mn Euro)	204,616	−0.34%	−0.27%	+0.35%	−0.96%	−0.41%
Number of employees		+1364	−833	+1454	−9194	+2103
Unemployment rate	5.84%	5.80%	5.86%	5.80%	6.12%	5.78%
Price of capital		0.07%	0.05%	0.07%	0.15%	0.09%
Budgetary effects (mn Euro)						
Due to change in revenues from direct taxes		+57	+12	+60	−63	+81
Due to change in revenues from indirect taxes		−285	−192	−297	−601	−430
Due to change in labour market expenditures		+14	−8	+14	−91	+21
Change in government demand		−424	−338	−441	−1,087	−655
Revenues from road pricing (semi-public)		1671	1085	1742	3489	1737

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Table 4 – Distributional impacts across road pricing policy scenarios and household income groups

	Transport expenditure impacts									
	Scenario B-5		Scenario A-5		Scenario C-5		Scenario C-10		Scenario D-5	
	Car	Public transport	Car	Public transport	Car	Public transport	Car	Public transport	Car	Public transport
	Expenditures		Expenditures		Expenditures		Expenditures		Expenditures	
Income										
< € 1478	+19.3%	+8.6%	+11.2%	+6.2%	+20.2%	+9.0%	+34.6%	+19.8%	+19.1%	+16.0%
< € 2311	+14.0%	+6.1%	+8.1%	+4.4%	+14.7%	+6.4%	+25.3%	+14.5%	+14.3%	+12.0%
< € 3267	+12.4%	+5.4%	+7.2%	+3.9%	+13.0%	+5.7%	+22.5%	+12.9%	+12.8%	+10.7%
> € 3267	+13.5%	+5.8%	+7.9%	+4.2%	+14.1%	+6.0%	+24.3%	+13.6%	+14.0%	+11.7%

	Consumption impacts				
	B-5	A-5	C-5	C-10	D-5
	Consumption change relative to reference scenario [%]				
Income					
< € 1478	−0.56%	−0.35%	−0.58%	−0.98%	−0.59%
< € 2311	−1.41%	−0.92%	−1.47%	−2.83%	−1.47%
< € 3267	−1.46%	−0.95%	−1.52%	−2.98%	−1.52%
> € 3267	−1.95%	−1.28%	−2.03%	−3.96%	−2.03%

impaired groups lacking possibilities of modal shift due to settlement structures and income (referred to as captives).

5.1. *Revenue use*

Testing for alternative uses of road pricing revenue, we find significant changes in impacts. First, to obtain greater social redistribution, we only give household refunds (the total of which remains constant at 1/3 of net road pricing revenue) to below-median income households. This has only a marginal impact on vehicle mileage (and thus environmental impacts), public transport passenger kilometres, and macroeconomic indicators. But as the refund is in sum significant, distribution of welfare impacts across income groups changes substantially. The consumption of the poorest household group now increases by 0.7%, that of the second-poorest declines by 0.7% modestly, while consumption of the richer households decreases by up to 2.3%, which is 0.4%-points more than in B-5. It has to be noted, however, that the practical implementation of such a strong redistribution may be difficult and connected to substantial control costs in many countries.

It is evident that another often discussed mode of redistributive revenue recycling, setting road pricing charges for poor and peripheral households to zero, is not only of extensive administrative demand, but obviously eliminates the core idea of the instrument. Refunding for distributional matters needs to be completely independent of car mileage driven, with a basis for example solely in terms of income and/or residence location in order to sustain the intended incentives.

Second, when – instead of the use options discussed so far – road pricing revenues (net of system costs) are used fully for reducing payroll fringe costs, we find a change in macroeconomic impacts relative to the earlier result of scenario B-5. Road pricing revenues are sufficient to reduce payroll fringe costs by 4% of net wages, which – in the medium term – causes unemployment to decline by 2%. Employment of a former idle labour force increases GDP in PPP terms by 2%. Feedback effects on the transport sector include a smaller overall reduction in vehicle mileage of a mere 5.4% (instead of 6.5% earlier) relative to the reference level. There is also a feedback on the direction of distributional impact. With the rise in labour supply, the relative scarcity of capital increases, which induces a capital price rise by 3.5%. As owners of capital are primarily the rich households, under this revenue use option, car road pricing no longer has a progressive distributional impact overall.

5.2. *Captives*

Hammar and Jagers (in press), for the instrument of a fuel tax in Sweden, find that in general households' perception is that car transport users should contribute their share in greenhouse gas emission reduction, and therefore fuel taxes to be raised. However, they find this overall preference for justice to be dominated by self-interest for the sub-group of intensive car users. Our approach allows us to quantify how intensive car users are hit by road pricing, and how these costs relate to the average household costs.

In our distributional analysis so far we distinguished between four income groups. This allows us to draw general conclusions concerning the direction of distributional impact. However, within these income groups themselves, impacts are also subject to a within-group distribution. When we want to take a look at those households potentially hit hardest, we have to further disaggregate within the income groups. The strongest impact will arise with those households that are simultaneously characterised by high mileage, low income, and peripheral living location (with a low supply level of alternative transport options). We select households that have below-median income, drive more than 15,000 km a year, and are sited in a peripheral region. We refer to them as "captives", and our database identifies this group as accounting for 1.8%

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Table 5 – Impacts on intensive car use households in peripheral regions with below-median income ("captives")

	Scenario B-5			Sensitivity analysis considering captives		
	Car	Public transport	Overall consumption	Car	Public transport	Overall consumption
	Expenditures			Expenditures		
Income			[change in %]			
<€ 1.478	19.3%	8.6%	−0.6%			
non-captives				19.5%	8.7%	−0.5%
captives *				12.1%	3.6%	−6.1%
<€ 2.311	14.0%	6.1%	−1.4%			
non-captives				14.0%	6.2%	−1.3%
captives *				12.8%	4.6%	−3.6%
<€ 3.267	12.4%	5.4%	−1.5%	12.4%	5.4%	−1.5%
>€ 3.267	13.5%	5.8%	−2.0%	13.5%	5.8%	−2.0%

* Captives are defined as households in peripheral regions with below-median income and an annual car mileage>15,000 vehicle-km.

of Austrian households (0.3%-points of which are from the lowest income quartile, 1.5%-points from the second). In Table 5 we show the impact of scenario B-5 on these captives. We find a significantly stronger impact on the households so defined within the respective income groups. For the poorest income quartile as a whole, the average consumption reduction is 0.56%, while for captives within this quartile it is 6.1%. In the second-poorest income quartile the reduction is 3.6% for captives (versus a quartile average of 1.4%).

6. Conclusions

In our analysis of car road pricing we explored the use of a transport oriented computable general equilibrium model for sustainability impact assessment. As in the literature so far the coverage of social impacts is rare, we put a main emphasis on quantifying distributional implications of car road pricing and potential trade-offs with the environmental and economic objectives.

Based on an in-depth analysis of the effects of environmental transport policies, West (2004) concludes in a – partial equilibrium – joint analysis of vehicle choice and mileage that (i) demand elasticities of vehicle miles driven decline with income levels, and that thus (ii) distance-dependent policies, such as a gasoline tax or road pricing, are regressive only across higher income households but progressive across low income households. The higher degree of price-responsiveness of lowest income households produces this result.

We find, however, in a general equilibrium model, and thus within a more integrative assessment acknowledging also overall feedback effects, that road pricing has a progressive impact across all income ranges, at least if consumption based welfare effects are chosen as an indicator for fairness. This result is steered by two effects which work in opposite directions. On the one hand, the strongest percentage reductions in car kilometres can be observed for the lowest (and the highest) income households: The lowest income household group experiences a high reduction since they usually drive small cars (with relatively low variable costs per kilometre driven) and a price increase of 5 Euro-cent implies a doubling of their variable costs (see Table 1). Households in the highest income group have low variable costs per kilometre, and therefore their reduction in mileage is higher than for the medium income households. This makes both groups less vulnerable to the implementation of car road pricing than other income groups. On the other hand, pre-policy car transport demand levels strongly increase with income. This works clearly progressive in car road pricing implementation, and tends to dominate the former effect.

Investigating the burden on different income groups should be a starting point to be further addressed by future research. It may well be that many of the "really poor" households are categorised not within the lowest income group (which surely includes many young single households, students, single retired, etc.), but within the second lowest income group, which may include households with single income, but more household members.

Also, we focus on the distribution of costs of car road pricing policies only. While we quantify overall benefits, such as health benefits or benefits from reduced congestion, we do not analyse their distribution across income groups. For a final evaluation of distributional impacts this would be necessary. Of these health and reduced congestion benefits, a pre-analytic assumption could be that the former might more strongly benefit the poor (since they are less able to flee environmental burdens), the latter the rich (who both drive more and have higher time costs).

However, questions of fairness are not the only ones relevant for increasing the acceptance of road pricing prior to introduction. Obviously, one natural extension here is proper communication of the purpose and effects of road pricing, i.e. road pricing should be anchored as a justifiable environmental policy, not only as an instrument for revenue raising or as a measure primarily addressing congestion, and it should be discussed relative to other policy options (see, e.g. Odeck and Bråthen, 1997; Oberholzer-Gee and Weck-Hannemann, 2002; Hammar and Jagers, in press). Also, the design of compensation is essential, in order to meliorate the effects on certain groups, particularly on those identified as "road pricing victims" (or captives). As argued before, the characteristics used to identify these groups need to be investigated more intensively (income and household location being only two of many possible indicators).

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Furthermore, revenue spending can have a significant impact on the effects of road pricing. In particular, if households are compensated in a lump-sum fashion for higher transport expenditures (as is assumed in policy scenarios A to D), small welfare burdens for the poor come at the price of GDP reductions and ambiguous employment impacts (whereas if revenues are spent such as to lower labour taxes, the effects of road pricing on GDP and employment are clearly positive). Thus, we can confirm that revenue spending is an important element in the appropriate design of a road pricing scheme, in addition to the "sales arguments" put forward by others (Calthrop and Proost, 1998; Jakobssen et al., 2000; Oberholzer-Gee and Weck-Hannemann, 2002; Proost et al., 2002).

Finally, in discussing the benefits of introducing nation-wide road pricing, fuel taxes are often seen as a preferable substitute. While fuel taxes are easier in administration, a road pricing scheme has mainly three advantages. First, it allows for regional and peak-time differentiation, possibly even in short-term response to weather related emission dispersion conditions. Second, while the range of potential fuel tax increments is limited due to potential tax avoidance caused by refilling in neighbouring countries (see Calthrop and Proost, 1998; or Ubbels et al., 2002, for a formal analysis; for an empirical application, see De Borger et al., 2004), road pricing allows for national independence to set (car) road pricing rates, by which also all users (domestic and foreign) within one's territory are charged. Third, the visibility of full user costs per kilometre travelled is higher for a permanent cost counter, like the road pricing on board unit (OBU), than for a fuel tax.

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Appendix A. Supplementary material

A.1. *Sensitivity analysis of transport elasticities of substitution and transport sector investment*

Cutting the elasticity of substitution between private car and public transport in half implies hardly any difference in macro-economic impacts relative to those found in section 4 of the main text, but implies a significant change in public transport demand (which now declines). On the other hand, raising elasticity leads to a more pronounced impact on both private car and public transport demand, and thus environmental impacts.

We further find that model results are not strongly sensitive to changing the elasticity of substitution between transport and other goods in consumption; results hardly change at all.

In testing the sensitivity of labour market results with the model, we find that these react strongest to revenue use, particularly to the way road infrastructure investments are carried out. The larger the share that is devoted to road maintenance, which is more labour intensive, the stronger the net overall increase in labour demand. If road infrastructure investment, on the other hand, is assumed to follow the average production structure of the overall construction sector, employment decreases in all scenarios. Model results presented in the main text assume a 50% share for maintenance within road infrastructure investment, since much of the secondary road network is of poor quality and requires maintenance.

A.2. *Variables*

Factor demand	
L	total labour demand
K	total capital demand
Production	
X_j	gross production of sector *j*
K_j	capital input in sector *j*
L_j	labour input in sector *j*
H_j	factor aggregate in sector *j*
A_j, a_{ij}	Leontief–input–output-coefficients in sector *j*
δ	CES-distribution parameter in sector *j*
σ_j	elasticity of substitution in production between labour and capital in sector *j*
Transport	
T^p	Private car passenger transport
T^{pf}	Private car passenger transport production fixed input
T^{pv}	Private car passenger transport production variable input (mileage dependent)
T^u	Public passenger transport
A^{pf}, A^{pv}	Leontief–input–output-coefficients in private car passenger transport
A^{kmp}	kilometre input-coefficient in private car passenger transport
A_i^u	Leontief–input–output-coefficients in public transport
km^p	vehicle kilometres driven in private car transport
Foreign trade	
EX_j	export of sector *j*
M_j	import of sector *j*
P_j	production price of goods aggregate *X* in sector *j*
P_j^W	world market price of goods aggregate *X* in sector *j*
EX_j^0, M_j^0	export and import quantities in sector *j* in the reference year
ε_j	foreign trade price elasticity of demand in sector *j*
Labour market	
w	nominal wage rate
$\overline{w_{low}}$	lower bound on the real wage rate
p_p	Paasche index of the aggregate price level
u	rate of unemployment
Consumption	
C_h	Total consumption of household type *h*
X_h^c	Consumption of non-transport goods of household *h*
T_h	Transport consumption of household *h*
δ_h^c	CES-distribution parameter in consumption for household *h*
δ_h^T	CES-distribution parameter in transport demand for household *h*
$\delta_{h,i}^X$	CES-distribution parameter in non-transport consumption for household *h*

(*continued on next page*)

Appendix A.2 (*continued*)

σ^C	elasticity of substitution between transport and non-transport consumption
σ^T	elasticity of substitution between car transport and public transport demand
σ^X	elasticity of substitution between non-transport goods in household h consumption

A.3. *List of core model equations*

Production

$$X_j = \min\left(H_j/A_j, X_{ij}/a_{ij}\right) \quad \text{for } i, j = 1,....35 \quad (1)$$

$$H_j = \left(\delta_j L_j^{(\sigma_j-1)/\sigma_j} + (1-\delta_j)K_j^{(\sigma_j-1)/\sigma_j}\right)^{\sigma_j/(\sigma_j-1)} \quad \text{for } i, j = 1,....35 \quad (2)$$

Transport

$$T^P = \min\left(T^{pf}/A^{pf}, T^{pv}/A^{pv}\right) \quad (3)$$

$$T^{pf} = \min\left(X_i/A^{pf}\right) \quad i = 1,....35 \quad (4)$$

$$T^{pv} = \min\left(X_i/A^{pv}, km^p/A^{kmp}\right) \quad i = 1,....35 \quad (5)$$

$$T^u = \min(X_i/A^u) \quad i = 1,....35 \quad (6)$$

Foreign trade

$$EX_j = EX_j^0\left(P_j^w/P_j\right)^{\varepsilon_j} \quad \text{for } j = 1,....35 \quad (7)$$

$$M_j = M_j^0\left(P_j^w/P_j\right)^{\varepsilon_j} \quad \text{for } j = 1, ...35 \quad (8)$$

Labour market

$$\frac{w}{p_P} \geq \overline{w_{low}} \quad \perp u \quad (9)$$

Household demand

$$C_h = \left(\delta_h^C X_h^{c\,(\sigma^C-1)/\sigma^C} + (1-\delta_h^C)T_h^{(\sigma^C-1)/\sigma^C}\right)^{\sigma^C/(\sigma^C-1)} \quad \text{for } h = h_1,....h_4 \quad (10)$$

$$X_h^c = \left[\sum_i \left(\delta_{h,i}^X X_{h,i}^{c\,(\sigma^X-1)/\sigma^X}\right)\right]^{\sigma^X/(\sigma^X-1)}$$

$$\text{with } \sum_i\left(\delta_{h,i}^X\right) = 1 \quad \text{for } h = h_1,....h_4 \quad (11)$$

Household demand

$$T_h = \left(\delta_h^T T_h^{p\,(\sigma^T-1)/\sigma^T} + (1-\delta_h^T)T_h^{u\,(\sigma^T-1)/\sigma^T}\right)^{\sigma^T/(\sigma^T-1)} \quad \text{for } h = h_1,...h_4 \quad (12)$$

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