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# The Welfare Effects and Distributional Impacts of Road User Charges on Commuters - An Empirical Analysis of Dresden

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## **Abstract**

Congestion, air pollution and noise caused by increasing use of the car are nowadays perceived as some of the most pressing problems in urban areas. The introduction of road user charges (road pricing) is a common proposal to solve or reduce these problems, however, its public acceptance is rather low because it is considered as unjust. Therefore, this study investigates in detail the equity issue of road user charges and analyses the distribution of costs and benefits among different groups. One group particularly affected by road pricing and analytically separable is the group of commuters. So, this paper analyses empirically the issue of the distributional impacts of road user charges on this group. After specifying the decision of the commuters within a microeconomic framework, a binary logit model for mode choice was developed and estimated using disaggregated work trip data from Dresden. Subsequently, measures of users' benefit that were derived for discrete choice demand models were applied to the estimated demand functions for the different modes. In this way it was possible to calculate the changes in commuters welfare for the introduction of different simple toll

schemes. This analysis was conducted for commuters from different income groups. Finally, measures of inequality for situations with and without road pricing were compared.

## **1 Introduction**

Increasing traffic causes congestion, air and noise pollution in almost all big cities in the world. Up to now, the chosen countermeasures (such as the expansion of the transportation infrastructure and promotion of public transport) have either not been as effective as desired or are proved limited in their effectiveness. Therefore, in the search for another remedy, albeit one which is seen mainly as an economic solution to the problem, a proposal which is often advanced is the introduction of road user charges (road pricing).

Road pricing is proposed as a means of achieving three different tasks: Firstly, road pricing is seen as an environmental charge which internalises the negative external effects of traffic on the environment. Secondly, road pricing is seen as a fee for financing the maintenance and extension of transport infrastructure. Thirdly, road pricing in a narrower sense means congestion pricing, namely the price for the scarce good "road use" is settled in a way that the demand for using the roads will adapt optimally to the capacity of the roads and thus no more congestion takes place.

Congestion pricing was first proposed by PIGOU (1920) and KNIGHT (1924) and has since then been accepted as being an efficient means of avoiding congestion. The basic idea of congestion pricing is to internalise the external costs of congestion. If traffic exceeds a certain volume, every additional vehicle in the road network has a negative external effect on every other road user who uses the network at the same time. The additional costs for the other road users consist mainly of the additional time they need, since their average speed diminishes because of the extra car. The private costs (i.e. the time plus operating costs for the car) differ from the social costs (i.e. private costs plus external costs). From an economic point of view, the road network is overburdened and consequently society suffers welfare losses. Optimal congestion charges can, however, internalise these external costs if the user is charged with the external costs he/she imposes on the others at the optimal level of road use. Optimal congestion pricing equalises private and social costs of road use, reduces the level of road use to its optimum and consequently reduces travel time of the road users in the network (for the theory of road pricing see MORRISSON, 1986 and HAU, 1992).

The technology to levy road user charges electronically is now available to a great extent. More field trials and pilot projects will help to solve the remaining technical problems in the foreseen future (MAY, 1996). Therefore, the biggest obstacle to implementing road pricing in cities is lack of social acceptance (SCHLAG/TEUBEL, 1997). By arguing that the introduction of road pricing redistributes income (and welfare) in an unequal way, most

commentators hold a negative attitude about it. They suspect that the poor are excluded from driving as a result of the introduction of road pricing or at the very least that road pricing has a regressive effect on the distribution of income (i.e. it charges the poor relatively more than the rich).

This paper analyses the distributional effects of introducing road user charges on a special group of road users, the commuters. Section 2 reviews the various effects of road pricing on the behaviour of road users and defines the subject of the subsequent empirical investigation. Section 3 develops an econometric model of modal-split and presents the results of the estimation. Based on this model, the distributional and welfare-effects on different groups of commuters are calculated in section 4. Additionally, section 4 summarises some results of a more simple method of measuring welfare changes through road pricing. Section 5 completes the article with some reflections on how the revenues arising from road pricing can be used and how this effects income distribution and welfare. Section 6 presents the conclusions of this paper.

## **2 Impacts of Road User Charges - a Brief Review**

The introduction of road user charges affects the behaviour of road users in many different ways. They might change their trip frequency (more or less trips by car), use another transportation mode, drive to another destination at another time on another route. In the long run, it can also result in a shift of the locations of work and living places and impact upon other markets (e.g. property and labour market). Figure 1 summarises the various distributional impacts.

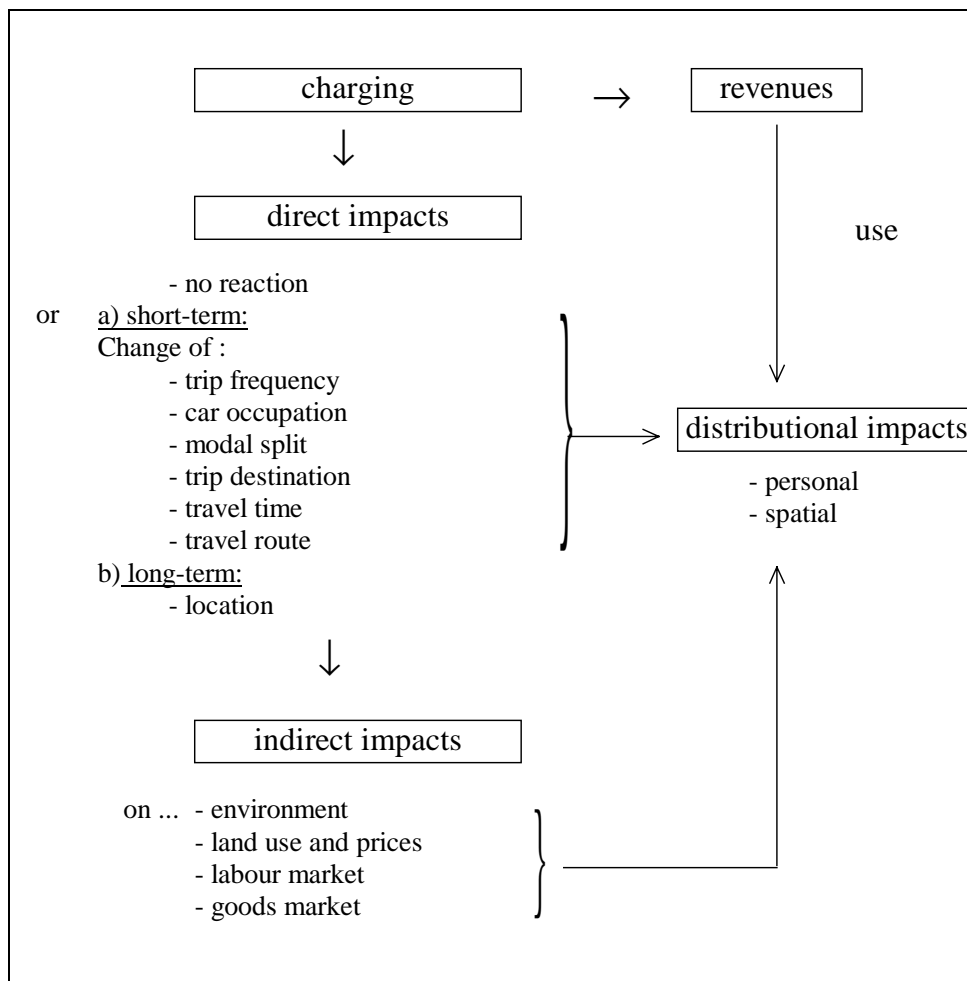
These potential reactions influence the welfare of society as a whole, and the welfare position of the individual. Therefore, a complete theoretical or empirical investigation of all distributional impacts of road pricing may appear to be too complex to achieve. FOSTER (1974), LAYARD (1977), COHEN (1987) and SEGAL/STEINMAIER (1980) have analysed theoretically some of these effects. In this paper, an empirical analysis is carried out and in order to keep the analysis as simple as possible, we restrict the focus of research to of the welfare effects of road pricing on a particular group of road users who are affected: the commuters.

Besides of the availability of data, there are two points in favour of empirical analysis concentrating on this group of commuters: Firstly, the commuters are, to a large extent, jointly

responsible for congestion on urban roads during peak periods. Secondly, this group has relatively few options to change behaviour after the introduction of road pricing. Leaving aside the possibility of undertaking the trip at another time (because of flexible work schedules), and assuming a charge covering the entire urban area, motorists have only two options in the short term: either to pay the charge and to go on driving the car or to select another mode of transport for the work trip. Hence, the effects considered in this analysis are only the following:

- increase the costs for a trip by car through road user charges,
- time gains through the decrease of travel time caused by a reduction of road traffic,
- welfare losses through the selection of another mode of transportation,
- use of the resulting revenues.

**Figure 1: Distributional Impacts of Road User Charges**



However, even if we restrict the analysis to commuters and concentrate only on some of the possible impacts, it is difficult to judge *theoretically* which distributional effects will result.

Three groups are likely to gain when charges are applied to an entire urban area, even though we only investigate commuters (GOMEZ-IBANEZ, 1992, 347):

1. Motorists who would drive with and without the charge and who place a high value on travel time savings. For these road users, the gains from reduced travel time are higher than the extra costs through the charge.
2. Users of public transport (especially bus users) and car pools. They benefit from an increased speed while paying little or no charge.
3. Recipients of the charge revenues.

Two groups are likely to lose:

4. Motorists who would continue to drive despite the charge and who place a relatively low value on travel time savings. For this group, the value of the saved time is lower than the charge, nevertheless, their utility from driving is still larger than their utility after changing behaviour.
5. Motorists who switch from car travel by public transport or car pool. Some of those who switch may benefit if the speed is improved greatly by the charge, which overcompensates for the welfare loss through the change of behaviour.

Neither the winners nor the losers are predominately rich or poor, so the distributional effects will depend on the relative sizes and the absolute magnitude of the gains or losses of the various groups. The motorists who place a high value on travel time (group 1) are likely to have high incomes, while the users of public transport (group 2) are likely to have a modest or low income. Needless to say, the distributional effects will depend crucially on how the toll revenues are used.

### **3 The Model and Estimation Results**

The empirical study presented in the following chapters aims to estimate quantitatively the welfare changes caused by the introduction of road user charges with regard to their magnitude and their distribution among different income groups. For this purpose, we

estimate as the first step, demand functions for different travel modes between which each commuter can choose for the daily work trip. Then various scenarios combining assumptions about the level of charging and the resulting changes in travel times are set up. Finally, we calculate the welfare changes for different groups of commuters with the help of Hicksian welfare measures (for similar research see SMALL, 1983 and RAMJERDI, 1995).

### 3.1 Derivation of a Binary Logit Model for Mode Choice

For the daily work trip, each commuter  $n$  can choose between several transport modes out of a choice set  $A_n$ . The commuter is assumed to have consistent and transitive preferences over the alternative modes that determine a unique preference ranking. Thus a real-valued utility index  $W$  associated with every mode can be defined. This utility index is a function of the attributes of the mode and of the characteristics of the commuter. The commuter tries to maximise his/her utility and chooses the mode  $i$  if the utility of the chosen alternative is greater than the utilities of all other alternatives in the choice set:

$$(1) \quad W_{in}(z_{in}, s_n) > W_{jn}(z_{jn}, s_n) \quad \forall i \in A_n, i \neq j$$

where  $z_{in}$  is a vector of characteristics of mode  $i$  (travel time, costs, ..) for commuter  $n$  and  $s_n$  is a vector of characteristics of the commuter  $n$ .

A key assumption in the “traditional” consumer theory is a continuous set of alternatives where each good is perfectly divisible. It is then possible to derive conditions of optimality and demand functions with the help of calculus (see VARIAN, 1992). However, this procedure is not possible if we analyse the choice between discrete goods or alternatives like the choice between transportation modes. The **random choice theory** provides some useful ideas about how to extend the traditional consumer theory and deal with discrete choice problems (see BEN-AKIVA/LERMAN, 1985). As with the consumer theory, each commuter selects the mode with the highest utility. But the utility  $W_{in}$  is treated as a random variable because not all characteristics of the alternatives or of the individual are known with certainty or are observable by the analyst (BEN-AKIVA/LERMAN, 1985, 55). The total utility  $W_{in}$  may be separated into two parts: a systematic or deterministic and a random component:



$$(2) \quad W_{in} = \underbrace{V(z_{in}^*, s_n^*)}_{\substack{\text{systematic utility} \\ \text{component}}} + \underbrace{\varepsilon_{in}}_{\substack{\text{random utility} \\ \text{component}}} \quad \forall i \in A_n,$$

where  $z_{in}^*$  is a vector of *observable* characteristics of mode  $i$  (travel time, costs, ..) for commuter  $n$  and  $s_n^*$  is a vector of *observable* characteristics of the commuter  $n$

Since  $W_{in}$  is a random variable statements about the probability  $P_{in}$  that commuter  $n$  selects mode  $i$  can be attained. The probability that mode  $i$  is chosen equals the probability that mode  $i$  has the maximum (random) utility for commuter  $n$ :

$$(3) \quad \begin{aligned} P_{in} &= Prob(W_{in} \geq W_{jn}, i \in A_n, i \neq j) \\ &= Prob(V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{jn}, i \in A_n, i \neq j). \end{aligned}$$

If the distribution of the disturbances is known or if the parameters can be estimated under plausible assumptions, the choice probability can be calculated. Here, we assume that all the disturbances  $\varepsilon_{in}$  are independently identically GUMBEL-distributed. The choice set of the commuter is limited to the alternatives “car“ (C) and “public transport“ (PT).

The result is a binary logit model. The probability that the commuter  $n$  chooses the mode  $i$  is given as (for derivation of the binary logit model see BEN-AKIVA/LERMAN, 1985):

$$(4) \quad P_{in} = \frac{\exp \mu V_{in}}{\sum_{j=1}^2 \exp \mu V_{jn}} \quad , i \in \{C, PT\}.$$

The parameter  $\mu$  is a scale parameter of the GUMBEL-distribution.

Following the concept developed by TRAIN and MCFADDEN (1978) (see also JARA-DIAZ/FARAH (1987)) we derive the functional form of the deterministic part of the utility function from an individual microeconomic decision model. Each commuter can make two decisions: the choice of mode  $i$  for the work trip, as well as the choice of the number of working hours and of the consumption pattern if he uses a certain mode. The whole decision is, therefore, a two-staged process: firstly, each commuter maximises a direct utility function (depending on leisure time  $F$  and consumption goods  $X$ ) for each possible mode under an income and a time budget constraint with respect to the number of working hours. The result is the maximum attainable utility (the conditional indirect utility) for each mode  $i$ . Then, in a second stage, each commuter chooses the mode with the highest indirect utility.

We assume a direct utility function of the *COBB-DOUGLAS*-type. We also suppose that the time  $t_i$  spent on travel to work with mode  $i$  has a “leisure value“ and is not seen only as

lost labour time. Therefore, each commuter maximises his/her utility dependent on the effective leisure time  $\tilde{F}$  and on the consumed quantity of other goods  $X$ . The effective leisure  $\tilde{F}$  can be written as (SMALL, 1992a, 40)

$$(5) \quad \tilde{F} = F + \theta \cdot t_i .$$

The parameter  $\theta$  measures the “leisure value“ of a time unit spent on travelling to work. It is assumed that the parameter is identical for all modes. If  $\theta$  equals one, the travel time is considered by the commuter as pure leisure time, if  $\theta$  equals zero, it has no leisure value.

The conditional indirect utility function of commuter  $n$  for mode  $i$  is (we omit the index  $n$  for convenience):

$$(6) \quad V(t_i, c_i) = \max_L \left\{ U(X, \tilde{F}) = X^{1-\alpha} \cdot \tilde{F}^\alpha \mid X + c_i = w \cdot L \wedge T = \tilde{F} + L + (1-\theta) \cdot t_i \right\}$$

where  $X$  is a vector of consumption goods (prices are constant and normalised to one),  $c_i$  is the cost of travelling with mode  $i$ ,  $w$  is the net wage rate,  $L$  is the number of work hours,  $t_i$  is the time spent on travelling with mode  $i$  and  $T$  is the total amount of time. The exponents  $\alpha$  and  $1-\alpha$  are the expenditure shares of the commuter for leisure and consumption goods.

Maximising the direct utility function  $U(X, \tilde{F})$ , the number of desired work hours will be:

$$(7) \quad L = (1-\alpha) \cdot T - (1-\alpha) \cdot (1-\theta) \cdot t_i + \frac{\alpha}{w} \cdot c_i .$$

Equation (7) combined with the direct COBB-DOUGLAS-utility function results in the conditional indirect utility function

$$(8) \quad V(t_i, c_i) = -(1-\theta) \cdot w^{1-\alpha} \cdot t_i - w^{-\alpha} \cdot c_i \quad \text{with } 0 \leq \alpha \leq 1 .$$

For the estimation of the binary logit model, it is necessary to make some additional assumptions. Instead of the unknown individual net wage rate, we use the net income  $I$ . This is possible because the desired work time is almost independent of the net wage rate, if a COBB-DOUGLAS-utility function is used. The labour time depends heavily on the expenditure shares  $\alpha$  and  $1-\alpha$  for consumption goods and leisure, so, the net income is almost proportional to the net wage rate.

This is easy to show. We separate the labour time (equation (7)) in a wage rate dependent part  $L_w$  and in a wage rate independent part  $L_c$ .

$$(9) \quad L = L_c + L_w,$$

$$\text{with} \quad L_c = (1 - \alpha) \cdot (T - (1 - \theta) \cdot t_{Fi}) \quad \text{and} \quad L_w = \alpha \cdot \frac{c_i}{w}.$$

We assume for the net income  $I$

$$(10) \quad I = w \cdot L.$$

This results in

$$(11) \quad \frac{L_w}{L} = \frac{w \cdot L_w}{w \cdot L} = \frac{w \cdot L_w}{I} = \alpha \cdot \frac{c_i}{I} < \frac{c_i}{I}.$$

If the share of transport costs for work trips in the total net income is five percent, then the wage dependent part of work time is less than five percent (the value of  $\alpha$  is between zero and one).

Replacing the net wage rate through the net income, the conditional indirect utility function is:

$$(12) \quad \begin{aligned} V(t_i, c_i) &= -(1 - \theta) \cdot \left(\frac{I}{L}\right)^{1-\alpha} \cdot t_i - \left(\frac{I}{L}\right)^{-\alpha} \cdot c_i \\ &= -(1 - \theta) \cdot L^{\alpha-1} \cdot I^{1-\alpha} \cdot t_i - L^\alpha \cdot I^{-\alpha} \cdot c_i \end{aligned}$$

Besides of the generic variables „travel time“ and „travel costs“ which vary between the travel modes, other variables are also included in the estimated model: firstly, a so-called alternative-specific constant for the car ( $D_3$ ). This constant reflects the difference in the utility of the mode „car“ from that of „public transport“ when „everything else is equal“. Four alternative-specific socio-economic variables are also included, all of which relate to the car. These variables are car-availability (number of cars per person over 18 years in the household) ( $D_4$ ) as well as a dummy variable for sex ( $D_5$ ), a variable if the commuter is between 30 and 50 years old ( $D_6$ ) and a variable if the working place is in the city-centre of Dresden ( $D_7$ ).

Combining these additional variables with equations (4) and (12) the probability for commuter  $n$  to choose mode  $i$  is given as

$$(13) \quad P_{in} = \frac{\exp\left(\beta_1 \cdot I_n^{1-\alpha} \cdot t_{in} + \beta_2 \cdot I_n^{-\alpha} \cdot c_{in} + \sum_{k=3}^7 \beta_k \cdot D_{kin}\right)}{\sum_{j=1}^2 \exp\left(\beta_1 \cdot I_n^{1-\alpha} \cdot t_{jn} + \beta_2 \cdot I_n^{-\alpha} \cdot c_{jn} + \sum_{k=3}^7 \beta_k \cdot D_{kjin}\right)},$$

where  $i \in \{C, PT\}$ ,  $\beta_1 = -\mu \cdot (1-\theta) \cdot L^{\alpha-1}$  and  $\beta_2 = -\mu \cdot L^\alpha$ .

### 3.2 Description of Data

The model (13) was estimated with data from a survey carried out in Dresden 1993 (for details see LANDESHAUPTSTADT DRESDEN, 1994). 920 data sets with complete and consistent information about the work trip and socio-economic variables (income group, age, sex etc.) were used for the estimation (see Table 1). All persons in the research had at their disposal at least one car for the work trip and had access to public transport.

**Table 1: Characteristics of the data**

Income group (household net income in DM/month)	Household average net income (DM/month)	Persons in sample	Chosen Mode		Available cars
			Car	Public transport	
all	3868	920	64%	36%	1.3
1: under 2000	1402	89	71%	29%	1.1
2: 2000-3000	2562	178	60%	40%	1.1
3: 3000-4000	3480	257	63%	37%	1.2
4: 4000-6000	4784	324	64%	36%	1.4
5: more than 6000	7839	72	72%	28%	1.7

The necessary information about the travel time and the travel cost for both modes was calculated on the basis of travel time- and travel distance-matrices generated by the commercial trip assignment programmes VISUM-IV and VISUM-ÖV. The travel costs for a trip by public transport were calculated with 0.43 DM per trip and the costs for a trip by car with 0.20 DM per kilometre.

### 3.3 Estimation of the Binary Logit Model

The binary logit model (13) was estimated with the maximum likelihood-method (BEN-AKIVA/LERMAN (1985), 79). Estimations for different values of  $\alpha$  - in other words, for different expenditure shares of leisure and consumption goods - were carried out (see Table 2). However, in the following presentation we will only discuss the case  $\alpha=0.5$  as the differences in the results for various expenditure shares are small.

The coefficients of the generic variables travel time and travel costs have the expected signs. An increase of travel time or travel costs of one mode reduces c.p. the probability of selecting this mode. The signs of the alternative-specific variables are similarly unsurprising. The number of available cars, age 30 - 50 and males all have a positive influence on the probability of selecting the car as the mode of. A work place located in the city-centre increases the probability of selecting public transport as the mode of travel. All coefficients except travel cost are significantly different from zero, with 95 percent confidence.

**Table 2: Estimation results for different values of  $\alpha$**

	$\alpha = 0$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 1$
Variable	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Constant for car	-2.42 (-7.44)	-2.43 (-7.30)	-2.43 (-7.21)	-2.45 (-7.16)	-2.46 (-7.16)
Time * (income) <sup>1-<math>\alpha</math></sup>	-4.5E-06 (-2.08)	-6.5E-05 (-2.21)	-0.0004 (-2.24)	-0.002 (-2.21)	-0.0247 (-2.10)
Cost * (income) <sup><math>\alpha</math></sup>	-0.0712 (-0.57)	-1.37 (-1.05)	-8.58 (-1.45)	-48.23 (-1.87)	-530.83 (-2.42)
Sex (specific to car)	1.83 (11.11)	1.83 (11.13)	1.83 (11.15)	1.84 (11.17)	1.85 (11.21)
Car availability (specific to car)	2.88 (8.34)	2.89 (8.36)	2.91 (8.39)	2.93 (8.41)	2.94 (8.43)
Dummy = 1, if age between 30 and 50 years (specific to car)	0.36 (2.21)	0.35 (2.19)	0.35 (2.16)	0.34 (2.12)	0.34 (2.10)
Dummy = 1, if workplace in inner city (specific to car)	-0.40 (-2.53)	-0.40 (-2.55)	-0.41 (2.57)	-0.41 (2.58)	-0.41 (-2.59)
Sample size	920	920	920	920	920
Log likelihood:					
Initial value L(0)	-637.70	-637.70	-637.70	-637.70	-637.70
Constant only L(c)	-601.60	-601.60	-601.60	-601.60	-601.60
Final value L( $\beta$ )	-485.81	-485.58	-485.29	-484.95	-484.28
Likelihood ratio test -2 [L(0)-L( $\beta$ )]	303.78	304.24	304.82	305.50	306.84
Likelihood ratio index $\rho^2$ (with L(0))	0.24	0.24	0.24	0.24	0.24
Corrected likelihood ratio index $\bar{\rho}^2$ (with L(0))	0.23	0.23	0.23	0.23	0.23

With the help of the coefficients  $\beta_1$  and  $\beta_2$ , it is possible to calculate the parameter  $\theta$  (“leisure value“ of a time unit spent on travel to work). Division of  $\beta_1$  (unit: utility units per minute) through  $\beta_2$  (unit: utility units per DM) and rearrangement results in :

$$(14) \quad \theta = 1 - L \cdot \frac{\beta_1}{\beta_2}.$$

If we assume that the leisure value of a time unit spent on travel to work is zero ( $\theta = 0$ ), this would result in a monthly labour time of 358 hours (for  $\alpha = 0.5$ ). Since this value is too high as monthly labour time for a household, we conclude that  $\theta$  must be positive and that the travel time has a leisure value for the commuter. If we suppose, for instance, that an average household labour time of about 240 hours per month (this is equivalent to the assumption of 1.5 fully employed persons per household) we obtain a value for  $\theta$  of about 0.33. In other words, a commuter values an hour spent on travelling to work as much as twenty minutes worth of leisure time.

It is now possible to calculate the valuation of a (saved) hour travel time (= value of time, VOT). The value of time is the marginal rate of substitution between travel time and travel costs:

$$(15) \quad VOT = \frac{\frac{\partial V}{\partial t_i}}{\frac{\partial V}{\partial c_i}} = \frac{(-\beta_1 \cdot I^{1-\alpha})}{(-\beta_2 \cdot I^{-\alpha})} = \frac{\beta_1}{\beta_2} \cdot I .$$

For the estimated values of  $\beta_1$  and  $\beta_2$  ( $\alpha=0.5$ ) we can calculate a valuation of saved travel time of 2.72 DM/hour per 1000,-- DM net income.

## 4 Calculations of Welfare Changes

### 4.1 Welfare Measurement with Consideration for Mode Substitution

In “traditional“ consumer theory, three measures based on normal or compensated demand functions are usually applied to evaluate welfare changes caused by price changes: consumer surplus, compensating variation and equivalent variation (VARIAN, 1992). It is possible to utilise these measures in discrete choice models (SMALL/ROSEN, 1981 and HAU, 1985). In these models, the choice probabilities  $P_{in}$  replace the normal or compensated demand functions.

To calculate the money metric welfare changes, we must first transform the choice probabilities (equation (13)):

$$(16) \quad P_{in} = \frac{\exp\left[-\gamma \cdot \left(-\frac{\beta_1}{\beta_2} \cdot I_n \cdot t_{in} - c_{in} - \sum_{k=3}^7 \frac{\beta_k}{\gamma} \cdot D_{kin}\right)\right]}{\sum_{j=1}^2 \exp\left[-\gamma \cdot \left(-\frac{\beta_1}{\beta_2} \cdot I_n \cdot t_{jn} - c_{jn} - \sum_{k=3}^7 \frac{\beta_k}{\gamma} \cdot D_{kjn}\right)\right]} = \frac{\exp[-\gamma \cdot G_{in}]}{\sum_{j=1}^2 \exp[-\gamma \cdot G_{jn}]}$$

where  $i \in \{C, PT\}$  and  $\gamma = \beta_2 \cdot I_n^{-\alpha}$ . The term  $G_{in}$  is measured in monetary units and expresses the price, in form of generalised costs, for the use of mode  $i$ . The generalised costs sum up the monetary costs (e.g. costs of fuel, fare of public transport) and the non-monetary costs (e.g. time costs) of a trip to a single quantity.

We assume that transport expenditures are unimportant in the total consumer's budget (negligible income effects), so the compensated demand (choice probability) can be approximated by the market demand (choice probability) and the three welfare measures consumer-surplus, compensated variation and equivalent variation coincide. Then the money metric measure for the welfare change of commuter  $n$  after a change of transport prices and/or qualities of mode  $i$  from  $G_{in}^{old}$  to  $G_{in}^{new}$  is given by (JARA-DIAZ/FARAH, 1988)

$$(17) \quad \Delta welfare_n = \int_{G_n^{old}}^{G_n^{new}} \sum_{i=1}^2 (P_{in}(G_n) dG_{in}).$$

Equation (17) can be calculated for a binary logit model as (SMALL/ROSEN, 1981 and JARA-DIAZ/FARAH, 1988)

$$(18) \quad \Delta welfare_n = -\frac{1}{\gamma} \cdot \left[ \ln \sum_{i=1}^2 \exp[-\gamma \cdot G_{in}^{new}] - \ln \sum_{i=1}^2 \exp[-\gamma \cdot G_{in}^{old}] \right].$$

Different assumptions about the height of the introduced charges were combined through the scenario technique with assumptions about the changes of travel time as a consequence of the reduced traffic volume. We suppose a simple toll scheme with a constant charge per kilometre (Table 3). These charges are not necessarily optimal in an economic sense. The charge is usually not identical with the negative external congestion costs a road user imposes on the others at the optimal level of road use. But it seems quite probable that a road pricing system in an urban area will be implemented in such a simple way at the beginning. We assume amounts of the charge following similar studies (see e.g. ABAY/ZEHNDER, 1992). We have not set up an equilibrium model in which the optimal charge and the resulting changes of travel

time are calculated simultaneously (see SMALL, 1983 for such an approach). Instead we make plausible assumptions about the reduction of travel times.

**Table 3: The scenarios**

Scenario	Charge car (DM/km)	Charge public transport	Travel time car	Travel time public transport
<b>I</b>	-.20	none	-10%	unchanged
<b>II</b>	-.20	none	-20%	unchanged
<b>III</b>	-.10	none	-10%	unchanged
<b>IV</b>	-.40	none	-10%	unchanged
<b>V</b>	-.20	none	-10%	-10%

For the present we do not consider the use of the toll revenues. We investigate only the direct impacts of an introduction of road user charges on the welfare level of different income groups and obtain the results presented in Table 4 for different scenarios. All values are given in DM per single trip.

**Table 4: Welfare losses of different income groups caused by an introduction of road pricing (in DM per work trip)**

Income group	Scenario				
	<b>I</b>	<b>II</b>	<b>III</b>	<b>IV</b>	<b>V</b>
all	0.86	0.67	0.34	1.82	0.62
1	1.08	1.01	0.52	2.08	0.99
2	0.89	0.78	0.40	1.81	0.71
3	0.81	0.66	0.34	1.70	0.56
4	0.82	0.59	0.30	1.81	0.53
5	0.81	0.35	0.17	2.04	0.50

At first we look only at the results of scenario I. We observe that the absolute welfare losses per trip decrease with increasing income and that the losses of income groups 3 to 5 approximately equal each other.

We now analyse the different components of the welfare changes. Therefore we split the total welfare change into the welfare loss caused by the charge and the welfare gain (or negative welfare loss) caused by the reduced travel time (Table 5).



**Table 5: Components of welfare change - (scenario I) (in DM per work trip)**

Income group	Welfare loss through the charge	Welfare loss through the time gain	Total welfare loss
all	1.04	-0.19	0.86
1	1.15	- 0.08	1.08
2	1.01	-0.13	0.90
3	0.96	-0.16	0.81
4	1.04	-0.24	0.82
5	1.26	-0.47	0.81

We notice that the lower total welfare loss of the higher income groups is caused in the first place by the increasing welfare gains through reduced travel times. The reason for this effect is the increasing value of time when income raises. The separated welfare effect of the toll may not be judged regressive. The charge is mainly a burden for the lowest and the highest income group. This may be explained by their intense use of the car for work trips (see Table 1).

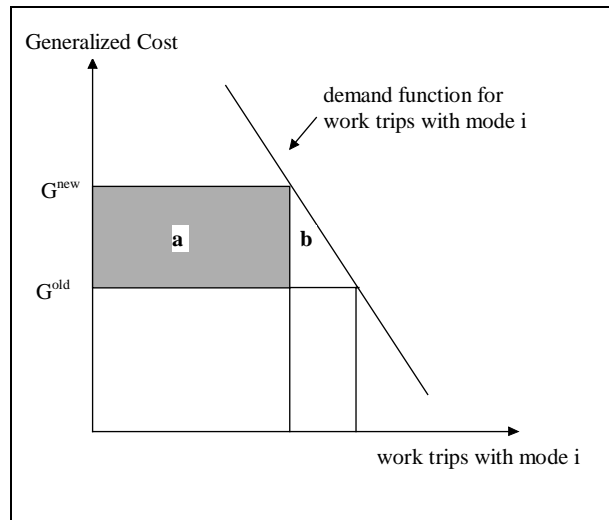
A comparison of scenario I with II stresses also the key function of welfare gains caused by reduced travel time (Table 4). If the charge reduces travel time about 20% instead of 10%. the higher income groups gain considerably because of their higher value of time. A comparison of scenario I with V shows that even if the travel time for public transport is also reduced by 10% the commuters with higher income gain more than the others although on a lower level.

#### **4.2 Simplified Welfare Measurement without Consideration of Mode Substitution**

The values presented in Table 4 and 5 are monetary welfare changes per trip caused by the payment of the charge, by time gains and by the possible substitution of the transportation mode. Now these values are compared with figures calculated with a simplified method of benefit measurement. For this we neglect the effects of mode substitution on commuters welfare. Other possibilities of substitution (trip frequency, time, route etc.) as reaction on road user charges are already excluded earlier. Thus, users benefit just equals the difference between the generalised costs of a work trip before and after the introduction of road pricing. Figure 2 explains this simplified welfare measurement graphically.

The demand for work trips with mode  $i$  is a negative function of the generalised costs. We assume an increase of the generalised costs through road user charges from  $G^{old}$  to  $G^{new}$ . Then the welfare changes presented in Table 4 and 5 are equivalent to the area  $a+b$  in Figure 2. The welfare loss estimated by the simplified method is equivalent to the area  $a$ .

**Figure 2: Welfare measurement**



So, we have calculated the welfare changes once more under the assumption of no mode substitution taking place (Table 6). The change in commuters benefit have been calculated as the difference between his generalised costs for a work trip (monetary costs plus time costs) before and after the introduction of charges. We use the monetary valuation of travel time estimated in the logit model for  $\alpha=0.5$ .

The results in Table 6 show that the welfare losses are a little lower if mode substitution is permitted. However, the differences are small for both analysed scenarios. Therefore one can justify to estimate welfare changes with this simplified method neglecting any change in commuters behaviour.

**Table 6: Welfare losses with and without consideration of mode substitution (scenarios I and II, in DM per work trip)**

Income group	Scenario I		Scenario II	
	with substitution	without substitution	with substitution	without substitution
all	0.86	0.88	0.67	0.69
1	1.08	1.15	1.01	1.06
2	0.89	0.95	0.78	0.82
3	0.81	0.85	0.66	0.69
4	0.82	0.81	0.59	0.58
5	0.81	0.90	0.35	0.38

So far only commuters were considered who use their own car or public transport for work trips and who own at least one car. To get a complete statement about the average welfare losses of commuters in different income groups it is necessary to consider also those people

who walk or use the bicycle (short: slow mode). And the analysis has to include commuters without a car available who use public transport as well.

The presented method of simplified benefit measurement now permits a consideration of all these groups within a second investigation. So, the following calculations are based on an extended sample of the Dresden 1993 survey. The sample is described in Table 7.

**Table 7: Characteristics of the extended sample**

Income group	Household average net income (DM/month)	Persons in sample	Share of households with car	Available cars per household	Chosen mode			Average distance home/work (km)	Average trip length (min)
					Slow mode	Public transport	Car		
all	3.671	1.436	77%	1.14	21%	32%	47%	6.9	29.7
1	1.386	189	51%	0.80	23%	35%	42%	6.7	29.8
2	2.544	320	76%	0.95	25%	35%	40%	6.7	29.7
3	3.501	378	89%	1.12	22%	31%	47%	6.8	31.0
4	4.769	464	94%	1.32	19%	30%	51%	7.1	29.3
5	7.765	85	96%	1.64	16%	17%	67%	6.9	25.8

We assume that commuters who use slow mode are concerned in no way through the introduction of road pricing. Neither they have to pay a charge nor they get the benefits of reduced travel times. All calculations have been done again for the five scenarios (Table 3).

The results are presented in Table 8

**Table 8: Welfare losses without consideration of mode substitution - extended sample (in DM per work trip)**

	Income group					
	all	1	2	3	4	5
<b>Scenario I</b>						
Welfare loss through the charge	0.76	0.66	0.65	0.78	0.80	1.04
Welfare loss through the time gain	-0.22	-0.07	-0.13	-0.21	-0.30	-0.60
<b>Total welfare loss</b>	<b>0.53</b>	<b>0.59</b>	<b>0.53</b>	<b>0.57</b>	<b>0.50</b>	<b>0.44</b>
<b>Scenario II</b>						
Welfare loss through the charge	0.76	0.66	0.65	0.78	0.80	1.04
Welfare loss through the time gain	-0.44	-0.14	-0.25	-0.42	-0.59	-1.21
<b>Total welfare loss</b>	<b>0.32</b>	<b>0.52</b>	<b>0.40</b>	<b>0.36</b>	<b>0.21</b>	<b>0.17</b>
<b>Scenario III</b>						
Welfare loss through the charge	0.38	0.33	0.32	0.39	0.40	0.52
Welfare loss through the time gain	-0.22	-0.07	-0.13	-0.21	-0.30	-0.60
<b>Total welfare loss</b>	<b>0.16</b>	<b>0.26</b>	<b>0.19</b>	<b>0.18</b>	<b>0.10</b>	<b>-0.08</b>
<b>Scenario IV</b>						
Welfare loss through the charge	1.52	1.32	1.31	1.56	1.60	2.08
Welfare loss through the time gain	-0.22	-0.07	-0.13	-0.21	-0.30	-0.60
<b>Total welfare loss</b>	<b>1.30</b>	<b>1.25</b>	<b>1.18</b>	<b>1.35</b>	<b>1.30</b>	<b>1.48</b>
<b>Scenario V</b>						
Welfare loss through the charge	0.76	0.66	0.65	0.78	0.80	1.04
Welfare loss through the time gain	-0.43	-0.17	-0.29	-0.43	-0.57	-0.83
<b>Total welfare loss</b>	<b>0.33</b>	<b>0.49</b>	<b>0.36</b>	<b>0.35</b>	<b>0.23</b>	<b>0.21</b>

First we look at some results for scenario I. The both groups with the largest monetary welfare losses are group 1 (lowest income) and group 3 (medium income). Commuters in group 5 (highest income) suffer the lowest loss. The average total loss lies in the range between 0.44 DM/trip and 0.59 DM/trip. The absolute welfare loss caused by the payment of the toll raises with increasing income. The main reason for this result: a growing share of commuters who use the car for their daily work trip. The benefits of reduced travel times increase as well with raising income. This is caused by the high positive correlation between income and the valuation of (saved) travel time.

If we compare these results with the first analysis (Table 4) we notice that the average welfare loss is considerable lower now. This is true regarding to the total average (0.53 DM/trip compared with 0.86 DM/trip) as well as regarding to the average in each income group. But this result is not surprising because the sample was extended by commuters who are not concerned by the charge.

In scenario III a relative low charge leads both to a considerable reduction of the traffic-volume and to a noticeable increase of the average speed within the urban area. In this

special case the welfare gains through travel time reductions may overcompensate the losses caused by the charge itself. Then the upper income groups (high values of time) will profit first and more.

The results of scenario V show that the average money metric welfare losses are lower if the implementation of a road pricing system reduces both the travel times by car and the travel times by public transport. Again higher income groups are favoured much more than groups with a lower income.

An analysis of the *relative* monetary welfare loss is also interesting. “Relative“ in this context means relative to the household income. Table 9 shows for scenario I the average absolute and relative monetary costs for work trips before road pricing (in DM per month), the absolute and relative welfare losses caused only by the charge (without time gains) and the absolute and relative total welfare losses. If we consider only the welfare loss caused by the toll we notice that the absolute burden raises with the height of income. But in relation to their income the commuters with lower income are charged much more than the ones with higher income. This is in so far important as many people are inclined to look rather at the direct monetary burden of road pricing and not or not to the same extent the compensating effect of reduced travel times.

**Table 9: Relative welfare loss caused by road pricing (scenario I, in DM per month)**

	Income group					
	all	1	2	3	4	5
(Monetary) trip costs without charge	35.60	32.40	32.--	36.40	37.20	44.40
Share of average household income	0.97%	2.34%	1.26%	1.04%	0.78%	0.57%
<b>Scenario I</b>						
Welfare loss through the charge	30.40	26.40	26.--	31.20	32.--	41.60
Share of average household income	0.83%	1.90%	1.02%	0.89%	0.67%	0.53%
Total welfare loss	21.20	23.60	21.20	22.80	20.--	17.60
Share of average household income	0.58%	1.70%	0.83%	0.65%	0.42%	0.23%

### 4.3 Measures of Inequality

After calculating the absolute and relative welfare losses or gains of the commuter caused by an introduction of road pricing we now analyse in short how the distribution of welfare has changed.

As a measure of the welfare of the commuters before the introduction of road user charges serves their income. We measure their welfare after the introduction as their income

plus the welfare changes in money-metric terms. To calculate the difference in the distribution of welfare before and after the imposition of the charge we use measures of inequality. The measures of inequality fall into two categories: positive and normative measures. Positive or statistical measures make no explicit use of any concept of social welfare. They try to catch the extent of inequality of a given income distribution. As positive measures we used the GINI-Coefficient (for a definition see SEN, 1997). In contrast to positive measures normative ones refer explicitly to a social welfare function. i.e. they are explicitly based on a judgement about social justice. Our normative measure is the one proposed by ATKINSON (ATKINSON, 1970). The parameter  $\varpi$  may be chosen deliberately in the ATKINSON-measure. It expresses the inequality-aversion of the society. If  $\varpi$  tends towards zero the society does not consider the welfare distribution as important since it values the welfare of every individual equally. If  $\varpi$  tends towards infinite the society is only interested in the position of the worst-off.

**Table 10 : Measures of inequality (scenario I)**

	GINI-Coeff.	ATKINSON-Measure		
		$\varpi = 0.5$	$\varpi = 1$	$\varpi = 2$
without charging	0.23601	0.04849	0.10043	0.22213
with charge; only consideration of welfare loss through the charge	0.23749	0.04921	0.10207	0.22688
with charge; consideration of total welfare loss (through charge and time gain)	0.23763	0.04925	0.10215	0.22704

The measures of inequality are calculated for scenario I (see Table 10). All measures indicate that the welfare is distributed more unequally after the introduction of road pricing than before. Both components of the welfare changes analysed before contribute to this effect. The toll itself as well as the travel time gains separately enlarge inequality.

But the impact of reduced travel times on the welfare distribution crucially depends on how people value their time. In our investigation we assume that the value of time corresponds positively and closely to income (section 3). There are other empirical studies which indicate that this relation is less strong than we find and assume here (see e.g. MVA, 1995). If we consider this correspondence less strong we may find that the reduction of time costs per work trip counteracts the increase in equality cause by the charge alone so that the welfare distribution altogether tends to become more equal (TEUBEL, 1997).

## **5 Using the revenues from road pricing**

We have already mentioned that a final statement about the distributional impacts of road pricing is only possible if we consider the use of the revenues as well. It is easy to show that optimal congestion pricing leads to a welfare gain for the society as a whole (see e.g. HAU, 1992). It is also true that we do not get a PARETO-improvement in a narrower sense - some road users will always lose. But we obtain a potential PARETO-improvement as defined by KALDOR and HICKS. The winners (in any case the state as the recipient of the revenues) may compensate the losers in such a way that a PARETO-improvement will be reached after the compensation. Whether such a compensation should actually take place and how to design a suitable compensation scheme is a question which in the end politicians have to answer.

There exist a number of proposals how to use the revenues in order to influence the distributional impacts in a desired manner and in order to enhance public acceptance. SMALL (1992b), for example, have suggested the following division of the net revenues (revenues less cost of charging): one third of the revenues should be used for each of the following tasks:

- improvement of transportation infrastructure (extension of the road network as well as improvement of public transport).
- reduction of taxes which have been used to finance the transportation infrastructure so far.
- direct monetary transfer to the affected road users as a group.

Other proposals have come from JONES (1991) and GOODWIN (1989). The latter has proposed to spend one third of the revenues on the improvement of the road infrastructure and one third on the improvement of the public transport system. The last third should be used to lower other taxes and to raise special social transfers.

The distributional impacts of an improvement of the transportation infrastructure are difficult to quantify. But especially the reduction of taxes and the monetary refund of the revenues to the affected road users are suitable to influence the distributional impacts directly. There exist various possibilities to return the proceeds on a direct way to the road users: reduction of other traffic-related taxes (fuel taxes, motor-vehicle tax), refund depending on the income (e.g. in the course of the income tax submission) or as a direct monetary lump-sum transfer to every commuter.

Based on the results of our analysis (extended sample, scenario I) we get a gross revenue of about 0.65 DM per commuter and trip after introducing road pricing. However, operating and maintenance costs of the (electronic) charging system have to be deduced from this gross revenues. The estimation of the share of operating costs in gross revenues vary

extremely. While SMALL (1992b) has assumed the share near to 5% the authors of an extensive study of road pricing in London (see RICHARDSON et. al., 1996) have estimated the share between 10% and 50% depending on the design of the road pricing system. Now we are able to compare the gross revenues of 0.65 DM/trip (minus operating costs of e.g. 10%) with the average welfare losses per trip caused by road pricing (0.59 DM to 0.44 DM. over all average 0.53 DM, see Table 8). We notice that it is possible to enhance the welfare of almost all groups of commuters through a suited compensation scheme even if a simple and not (welfare) optimal toll is levied. Then, depending on the distributional policy different groups may be favoured through various compensation schemes. Note: An improvement of the welfare of a group after a compensation means not necessarily that every commuter within this group is better off.

A counterargument often heard against a return of revenues to the affected road users is the following: the people have the same income after the compensation as before and have therefore no incentive to change behaviour. The charge have no allocation effect. However, even a complete retransfer of the revenues may eliminate the income effect of a rise in cost for travelling by car but not the substitution effect since the relative prices have changed and induced the desired allocation effect partially.

## **6 Final Comments and Conclusions**

This investigation was carried out to estimate the impact of introducing a road pricing system in big cities on the welfare of commuters. A microeconomic decision model for commuters served as the basis for a binary logit model. We have used disaggregated data on the behaviour of commuters in the city of Dresden to estimate this econometric model. Then we have applied Hicksian welfare measures to the estimated model and calculated the welfare losses per work trip caused by a road user charge for commuters in different income groups.

The results show that the absolute welfare loss decrease with increasing income. This effect is induced only to a small extent by the direct monetary burden of the toll. Instead the welfare gains through reduced travel times influence this effect. The reason for this influence is that the value of time raises with increasing income. We could confirm for our sample the claim that road pricing - without considering the use of the revenues - puts a lower burden on the better off than on the badly off road users. But the quantitative difference of the absolute burden is in all our scenarios small.



From an economic point of view this regressive effect is no argument against the introduction of road user charges as a means of congestion pricing. Congestion pricing improves the efficiency of the allocation of the scarce resource “road use“ and this allocative aspect should be considered independently from the distributional aspects of road pricing. Theoretically, a welfare optimal congestion toll entails revenues the redistribution of which may improve the position of all road users. But in practice the revenues may not suffice after subtracting the costs of charging for an improvement of everybody’s position since the height of the toll and the way of charging is determined in practice more by feasibility than by efficiency. Nevertheless it is even in practice possible to correct the undesired distributional effects partially.

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