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Equity effects of congestion pricing
Quantitative methodology and a case study for Stockholm

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Abstract

It is widely recognised that congestion pricing could be an effective measure to solve environmental and congestion problems in urban areas—a reform that normally also would generate a net welfare surplus. Despite this the implementation of congestion pricing has been very slow. One reason for a low public and political acceptance could be that equity impacts have not been given enough concern. In studies of distributional impacts of congestion pricing it has often been claimed that the reform is regressive rather than progressive even if there are studies claiming the opposite. We develop a method for detailed, quantitative assessment of equity effects of road pricing and apply it to a real-world example, namely a proposed congestion-charging scheme for Stockholm. The method simultaneously takes into account differences in travel behaviour, in preferences (such as values of time) and in supply of travel possibilities (car ownership, public transport level-of-service etc.). We conclude that the two most important factors for the net impact of congestion pricing are the initial travel patterns and how revenues are used. Differences in these respects dwarf differences in other factors such as values of time. This is accentuated by the fact that the total collected charges are more than three times as large as the net benefits. With respect to different groups, we find that men, high-income groups and residents in the central parts of the city will be affected the most. If revenues are used for improving public transport, this will benefit women and low-income groups the most. If revenues are used for tax cuts, the net benefits will be about equal for men and women on the average, while it naturally will benefit high-income groups. Given that it is likely that the revenues will be used to some extent to improve the public transport system, we conclude that the proposed congestion-charging scheme for Stockholm is progressive rather than regressive.

Keywords: Congestion pricing; Equity; Distributional impacts; Case study

1. Introduction

Congestion pricing has been suggested for a long time as a means to solve environmental and congestion problems in urban regions. The standard argument is that congestion pricing induces a more efficient use of existing infrastructure, while also generating revenues that may, for example, be used for investments in the

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road and public transport systems. Among transport economists, this is far from controversial; indeed, the research literature often cites the Smeed report (HMSO, 1964), which claimed that "the case for road [congestion, our insertion] pricing is irrefutable". On the other hand, enthusiasm among politicians and the public has not exactly been overwhelming. Oberholzer-Gee and Weck-Hannemann (2002) discuss this lack of political and public support and suggest ways of overcoming the resistance by considering the fairness of the system and by integrating the idea in a policy of environmental quality. Viegas (2001) also stresses the importance of equity for making congestion pricing politically and publicly acceptable.

In fact, there are only a few cases in the world where congestion pricing has actually been implemented, the most recent example being London from 2003. The city of Stockholm will carry out a "full-scale trial" of congestion charging for nearly seven months in the beginning of 2006, to be followed by a referendum among the citizens in the city in connection with the general elections in September the same year.

It is well known that congestion pricing normally will generate a net welfare surplus. But although this is true,[1] this argument alone may not be particularly convincing in a real-world situation, since it neglects equity effects, i.e. the questions about how costs and benefits are distributed across socioeconomic groups.

Equity effects are important for at least two reasons. First, the magnitude of the redistribution between different groups can be so large that it dwarfs the net benefit of the reform. In some real-world applications, the distributional effects may be so much larger than the efficiency gains that congestion charging may not be seen as "worthwhile". This is especially likely to happen if initial congestion levels are low, or demand for road travel is relatively inelastic. Second, congestion pricing may be regressive, or have other adverse equity effects. Whether this is the case will often depend on the quality of other available modes and on the design of the congestion charges.

From this we can conclude that in order to evaluate any proposed, real-world congestion-charging scheme, it is crucial to

- investigate distributional effects,
- consider the impact of different use of revenues, and include this in the calculation of the distributional effects, and
- compare the magnitude of the net welfare surplus with the total distributional effects.

There is a fairly large number of theoretical studies regarding these issues, for example Arnott et al. (1994), Glazer and Niskanen (2000), Richardson (1974) and Small (1983). From them one can conclude that the equity effects will in general depend on the design of the charging system (when and where the charges are levied) and socioeconomic differences in travel pattern (for example, how mode choice and destination choice differ across income groups). However, there are significantly fewer studies on detailed, quantitative assessments of the questions indicated above. Moreover, the large-scale traffic models used to evaluate the traffic consequences of the charges are not suitable for evaluating socioeconomic impacts (for reasons to be explained further below). Finally, most present studies deal exclusively with how costs and benefits are distributed among income groups, and do not consider other dimensions, such as distribution of costs and benefits across gender, residential areas or household types.

The aim of the present paper is to present a method for detailed, quantitative assessment of equity effects of road pricing and to apply it to a real-world example, namely a proposed congestion-charging scheme for Stockholm. The method simultaneously takes into account differences in travel behaviour, differences in preferences (such as values of time) and differences in supply of travel possibilities (car ownership, public transport level-of-service etc.). The study is based on an extensive modelling effort, using a full-scale, state-of-the-art transport model together with a sample enumeration-based model, developed specifically to take socioeconomic differences in valuations and travel behaviour into account. The method can be applied to study equity effects of any transport-related investment or policy measure.

[1] To be specific, this is true for any "well-designed" congestion pricing system, provided for example that the charge levels are close to optimal and that the system is not so ill-made that it increases total congestion by for example creating congestion outside a certain tolled area or not so expensive to run that it will consume the welfare gains.

2. Previous research

There is a considerable body of literature on road pricing and also specifically on congestion pricing. Recently a special issue of this journal was devoted to the theory and practice of congestion charging (Wong et al., 2005). The articles in this issue cover a number of aspects of congestion charging and we will come back to some of them later on in this paper. Rather surprisingly, though, none of them deals explicitly with distributional or equity effects. There is, however, an older literature on welfare and distributional effects of congestion pricing. This literature is mainly theoretical, studying the effects analytically or by numerical simulations with a well-specified but highly simplified model of a real transport system. We have no intention to cover this research. We will rather give some examples of the mixed kind of arguments that have been put forward and what conclusions we draw for the direction of the present study of the proposed congestion pricing system for Stockholm.

The most studied question has been whether congestion charges will benefit the poor or the rich. Different studies have come to different conclusions. This is largely dependent on what assumptions are made about the preferences and travel behaviour of different groups, and what effects are taken into account in the study or the model.

Several scholars have argued that congestion charges will be regressive, since people with high income have a higher value of time, and hence more often feel that the time gain is worth the charge (Richardson, 1974; Evans, 1992; Arnott et al., 1994; Small, 1983). Moreover, people with small economic margins will suffer more from congestion charges (Richardson, 1974). In addition, they generally have inferior possibilities to decide their time for work, and thus cannot avoid charges levied during peak hours (Arnott et al., 1994). They are more likely to live far from the city core, and their destination is more often located outside the inner city in areas where public transport is poor (Transek, 2002). Moreover, if road investments are not financed by charges they have to be financed by income taxes, and since those with high incomes pay more tax they would suffer more from that alternative (Arnott et al., 1994).

However, other scholars have argued that those with low incomes would gain the most from congestion pricing. Many of the previous arguments have typically come up in an American context where car is the dominant mode of transport. The situation may be different in typical European cities, where citizens have access to and actually patronise public transport and also "slow modes" in particular during peak hours (Armelius, 2004). When there is a choice between a fast (car) and a slow (public transport) mode, a toll that increases welfare is likely to be on the fast mode. Since those using the fast mode usually are the more affluent travellers, such tolls will be progressive (Glazer and Niskanen, 2000). Since low-income groups more often use public transport, not only will they be less affected by the charges, but they will also profit more from the revenues if they are spent on improving public transport (as is generally proposed for at least part of the revenues) (Evans, 1992). Several studies (in particular European ones) argue that people with high incomes drive more frequently, and more often have their destination in the inner city where congestion is highest (Foster, 1974). They are also more likely to live within or close to the inner city and therefore cannot avoid the charges or choose alternative routes. Again, this argument presupposes a "European" geographical distribution of income groups, with the rich closer to the city centre. Some argue that congestion pricing also slows down the development towards a more car-dependent society, which favours those with low incomes who are less likely to have a car (Swedish Society for Nature Conservation, 1998).

These disparate views indicate that it is difficult to come to clear-cut conclusions about the distributional effects of congestion pricing. Rather we have to carry out equity analyses for specific congestion pricing schemes and specific cities.

Such quantitative studies have been carried out for some cities, e.g., San Francisco (Schiller, 1998), Oslo (Fridstrøm, 2000), Gothenburg (Transek, 2002), Stockholm (Swedish Environmental Protection Agency, 2001) and Cambridge, Northampton and Bedford (Santos and Rojey, 2004). These studies indicate that those with high incomes are affected the most since they more often drive a car, and in addition are more likely to live in areas with poor access to public transport. The net effect if all were to equally share the revenues would then be that those with low incomes would gain the most. These calculations are still uncertain, e.g., since the models used do not fully consider differences in time values and effects on departure time for travel. There are in fact theoretical studies focussing solely on departure time that indicate that those with high incomes will gain more than those with low incomes, given that they share the revenues equally (Arnott et al., 1994).

Common for all studies is that the differences in the direct benefits and costs between income groups are fairly small. It may therefore be more important for the issue of equity how different groups benefit from the use of the revenues. We will quantify these differences in the following analysis for Stockholm. In a partially parallel study on the same data, Franklin (2004) expands on the present equity analysis by the use of more sophisticated equity measures that allow for a very detailed representation of the distributional impacts for different groups by means of relative distribution functions and polarisation indices. The conclusions from that study concerning the proposed congestion-charging scheme for Stockholm are very similar to the ones we draw in the present study, however.

In many theoretical studies treating the case when revenues are channelled back in some way, it is often assumed that *all* trips are subject to congestion charging. This stands in contrast to most real cases, where charges are only implemented in the city centre, and where a large share of the trips is by public transport (especially in the city centre). This is for example the case in London, where only car trips in the city centre are charged, and a large majority of the trips are already made by public transport. It also applies to Stockholm, where the proposed system only affects the city centre (although the tolled area in relative terms is a bit larger than in London), and a majority travel by public transport or slow modes. For Stockholm, it could be estimated that only 5–10% of all trips in the region (10–20% of all car trips) will be affected, depending on whether the north–south arterial road (Essingeleden) is charged or not. In the following analysis for Stockholm we will therefore stress how the proposed system will affect different groups.

Further, these theoretical studies (and some empirical ones as well) often assume that the revenues are refunded through lump-sum redistribution. It is then not unlikely that congestion pricing will be regressive. But most often, a more realistic assumption would be that the revenues would be used to increase public spending (perhaps in the form of road investments or improved public transport), to decrease taxes, or both. Clearly, different use of revenues will imply different net effects, and consequently will determine whether the charging system, viewed as a whole, will be progressive or regressive (Small, 1992). Accordingly, we will investigate the distributional effects of different use of the revenues for the proposed system for Stockholm.

3. Methodology

In our evaluation of the proposed congestion-pricing scheme, we want to predict as precisely as possible the distributional effects for different groups of individuals, where we take their individual characteristics such as income, gender, family situation, occupational status, location, car ownership etc. into account. Standard state-of-the-art transport models usually do consider such variables. However, they, generally speaking, lack in two respects when it comes to evaluating distributional effects.

First, and perhaps most important, it is virtually impossible in a large-scale model to account for all cross-correlations between variables such as income, gender, car ownership, occupational status, family situation etc. Usually, each of these variables is specified for each geographic zone, but it would be unfeasible to specify the *simultaneous* distribution of all variables for each geographic zone. Thus, it is necessary to choose between good geographic resolution and a good representation of the simultaneous distribution of socioeconomic variables. For most applications, good geographic resolution is a more important consideration, as it will otherwise be difficult to calculate, for example, link flows with any accuracy. But when the main focus is to study distributional effects, this is no longer true: it is then more important to account for socioeconomic cross-correlations, such as high-income households having greater car ownership than other households.

Second, even while the more advanced transport models take some cross-correlations, such as car ownership and household type, into account when calculating modal split, destination choices, etc., they will seldom or never fully reflect, for example, cross-correlations with income. More generally, they lack a detailed representation of the behaviour of *different* groups of individuals—groups that may be important for the evaluation of distributional impacts of congestion pricing.

SAMPERS is the most recent large-scale transport model that has been developed for Stockholm (Beser and Algers, 2001). This model is also subject to the limitations discussed above. We therefore need a model that would reflect the behaviour of different groups more closely. To this end a system of logit models is estimated that could be applied on a sample enumeration basis (the SE model for short). SAMPERS will still be needed to provide certain input data to the SE model, e.g., the effects of congestion charges on car travel times and costs between different zones. This will be described in more detail below.

The SE model consists of four separately estimated nested logit models for the combined choice of travel mode and destination zone for work trips and for other trips, for men and for women, respectively (see Algers, 2002, for further details). In these models the travel time and travel cost parameters have been estimated as functions of income. This will give rise to travel time values that will be increasing with income in a characteristic way for each sub-model. The SE model thus allows us to represent the behaviour of men and women separately, and in a way that accounts for their individual incomes, car availability, family situation, occupational status etc.

When the SE model is used for evaluating a transport policy, it should be applied to a representative sample of individuals. In the present case we apply the model to the same sample as the one on which it has been estimated. It consists of 4085 individuals from 18 years of age and older taken from travel surveys carried out in the County of Stockholm during the years 1994–2000. These individuals are characterised not only by variables such as gender and income, but also by variables correlated with these variables such as location, car ownership, family situation and occupational status. The survey contains all journeys that these individuals have made during the surveyed day.

The distributional effects of a congestion-pricing scheme will then be evaluated by simply applying the sub-models of the SE model to each individual in the sample in a before-and-after fashion. We then need as input data travel times and costs (including possible congestion charges) between the zones for the different available modes before and after the congestion-pricing scheme has been implemented. Since the car travel times between different zones depend on the congestion levels on the links connecting the zones, we need a full-scale transport model to calculate how these values are affected by the congestion-pricing scheme. This is where we need the SAMPERS model.

When we are calculating times and costs between OD pairs, we should note a practical difficulty. Considering an OD pair of zones, there is usually no unique route that will minimise the generalised costs for all individuals. Rather two individuals with different time values will choose different routes. An individual with a low time value will prefer a cheap but slow route, whereas an individual with a high time value will prefer an expensive but fast route. The travel time and cost parameters that are needed for the SE model have been estimated as functions of income. This means that we in principle have as many time values as individuals in the sample. In the network assignment module of SAMPERS,[2] on the other hand, there are only five classes of car trips with time values ranging from 19 SEK/h to 200 SEK/h. The best we can do is therefore to choose car travel times and costs for an individual trip according to the equilibrium routes for the class of trips in SAMPERS that has a time value that is as close as possible. This incongruence between the models will of course create some inconsistencies between how the behaviour is modelled in the SE model and how the destination alternatives are described in terms of their car travel times and costs. Our judgement is that these inconsistencies will be of minor importance for our results and conclusions.

The present evaluation methodology handles effects of congestion pricing on mode choice and destination. One important behavioural response is not captured, however, namely the change of departure time for the trip.[3] At an aggregate level the reduction of car traffic in total may therefore be overestimated, while the reduction during charged hours may be underestimated. To what extent the effects will be erroneous for different groups is difficult to predict. It is likely, however, that individuals with high time values in reality rather will change departure time than, as predicted by the present methodology, change mode or destination. It should also be noted that the present methodology only considers first order and essentially short-term effects. While

[2] SAMPERS uses the well known user equilibrium network model EMME/2 for the assignment of car travel demand to the network.

[3] Olszewski and Xie (2005) estimate higher demand elasticity values with respect to charge levels for the afternoon peak than for the morning peak using data from the Singapore Electronic Road Pricing system. This indicates that drivers have more flexibility in retiming their trips in the afternoon than in the morning period. Saleh and Farrell (2005) examine the implications of work schedule flexibility and other personal constraints on departure time choices in a stated choice study. Their results indicate that the peak spreading effects of congestion pricing will depend not only on scheduling flexibility of work trips but also on the flexibility of non-work commitments related to child care provision, openings hours of shops and leisure activities.

effects on the choice of workplace are considered through the work trip destination model, no secondary effects on wages, housing rents, land-use, productivity and economic growth etc. are included.

3.1. Separating the impacts of congestion pricing

The effects of congestion pricing can be separated into four parts:

- *Higher travel costs* for those who travel by car in the charged areas during charged hours.
- *Changed travel behaviour* to avoid the charges—for example by switching mode and destination.
- *Shorter travel times* for those who travel by car in the charged areas during charged hours (in some relations, travel time may increase due to route choice effects).
- *Revenue generation*, which can be spent on e.g. new roads, improved public transport, lower taxes or increased public sector expenditure in general. The revenue generation should be calculated net of the costs of operating the charging system. In the present study we have ignored these operating costs, however.

It is the net effect of these four components that decides whether a given individual will lose or benefit from the congestion charges.[4] In this study, we will investigate four examples of revenue use to illustrate how different the net impact may be:

- Revenues are split evenly to all adults in the region (labelled *lump-sum redistribution* below).
- Revenues are used to improve the public transport system; we assume that the value of this for a given individual is proportional to the number of public transport trips he or she makes. This could also be interpreted as if the revenues are used for lowering public transport fares. Irrespective of interpretation, we neglect any second-order effects on public transport demand due to improved service levels or lower fares (labelled *public transport refund scheme*).
- Revenues are used to reduce the cost of car travel; we assume that the value of this for a given individual is proportional to the number of car trips he or she makes (labelled *car refund scheme*).[5]
- Revenues are used to decrease income tax; we assume that each adult individual gets a refund proportional to his or her income. This is equivalent to assuming a decrease in the regional income tax (which at the regional level in Sweden is a constant percentage of income—i.e. no progressivity) (labelled *tax cut refund scheme*).

Compared to the way impacts on travel costs, times and behaviour are calculated, the calculation of the perceived utility from these different uses of revenue is a bit sketchy. Our methodology could, however, be used to evaluate distributional effects of more detailed revenue use, such as specific infrastructure investments etc. This is beyond the scope of the present study, however.

3.2. Computation of the impacts

Consider a particular individual in the sample who is to make a work trip or another trip. Let P_{jm} be the probability for a trip to destination j with mode m, c_{jm} and t_{jm} travel cost and travel time for that trip, and θ the value of travel time. The value for θ is chosen specifically for each individual and trip type according to the estimated sub-model in the SE model. Moreover, let 0 and 1 denote "before" and "after" the congestion-pricing scheme has been implemented. We will calculate the total welfare change ΔW for the individual through the "rule of a half":

[4] This calculation of the net effect ignores the costs of collecting the charges. Should we know these costs, the calculation could easily be modified.

[5] Kockelman and Kalmanje (2005) propose a similar rebate policy dubbed "credit-based congestion pricing (CBCP)". The difference is that the revenues are returned back with the same amount to each licensed driver.

$$\Delta W = \frac{1}{2}\sum_{jm}(P^0_{jm} + P^1_{jm})(c^0_{jm} - c^1_{jm}) + \theta\frac{1}{2}\sum_{jm}(P^0_{jm} + P^1_{jm})(t^0_{jm} - t^1_{jm}).$$

Since only car travel times and costs change, the formula simplifies to

$$\Delta W = \frac{1}{2}\sum_{j}(P^0_{ja} + P^1_{ja})(c^0_{ja} - c^1_{ja}) + \theta\frac{1}{2}\sum_{j}(P^0_{ja} + P^1_{ja})(t^0_{ja} - t^1_{ja}),$$

where the car mode is denoted by a (auto).

Assuming, as we do, that the only change in car travel costs between the before and after situation is the congestion charge d_{ja} (which may or may not be a reasonable assumption depending on the design of the system), we get

$$\Delta W = -\sum_{j}P^1_{ja}d_{ja} - \frac{1}{2}\sum_{j}(P^0_{ja} - P^1_{ja})d_{ja} + \theta\frac{1}{2}\sum_{j}(P^0_{ja} + P^1_{ja})(t^0_{ja} - t^1_{ja}).$$

This means that the net welfare effect can be separated into three parts:

$\sum_{j}P^1_{ja}d_{ja}$ Total paid charges,

$-\frac{1}{2}\sum_{j}(P^0_{ja} - P^1_{ja})d_{ja}$ Value of changes in travel pattern,

$\theta\frac{1}{2}\sum_{j}(P^0_{ja} + P^1_{ja})(t^0_{ja} - t^1_{ja})$ Value of time savings.

4. Case study

As mentioned above, a full-scale trial of congestion pricing will be carried out in the city centre of Stockholm for a period of nearly seven months from January 3 to July 31, 2006. Shortly after the end of the experiment a referendum will be held in the City of Stockholm. Depending on the outcome of the referendum the congestion-charging system will be made permanent or not. The system that will be implemented is a modified version of the one analysed in this paper. We perform our evaluation for the year 2005.

4.1. Charging system analysed

The charging system[6] to be analysed is defined by two cordon lines: the first encircles the inner city of Stockholm, the second divides the encircled area in a northern and a southern part along the water connection between lake Mälaren and the sea (see Fig. 1). All cars passing any of these cordon lines in any direction are charged. The charges are only imposed during daytime on weekdays and are higher during peak hours:

- 15 SEK during peak hours (7–9 am and 4–7 pm),
- 10 SEK in mid-day hours (9 am to 4 pm).

The main north–south arterial road, Essingeleden, which actually crosses the western part of the charged area (see Fig. 1), is treated in a separate way. This road is charged at only one point (in both directions), however only during peak hours. The charge level is then 15 SEK.[7] This means that during peak hours it will cost in total 45 SEK to go by car through city centre and 15 SEK via Essingleden, and during mid-day hours 30

[6] The charged area of inner city of Stockholm has a diameter of approximately 5–6 km. In addition, the municipality of Lidingö—located on an island east of inner city (see Fig. 1)—is also included in the northern half of the charged area.
[7] A scenario without charges on Essingeleden was also studied. It yielded similar results.

Fig. 1. Cordon lines of the analysed congestion-charging system for Stockholm.

SEK and 0 SEK, respectively. Since the charge levels vary during the day, different travel times have been calculated by the SAMPERS system for the different time periods.

4.2. Overall effects on traffic

According to the SAMPERS model the congestion-charging system is predicted to reduce the number of car journeys by almost 5% for the county as a whole. The number of journeys made by public transport is estimated to increase by 3%, while walking and cycling increase by slightly more than 1%. The total number of trips at the county level is hardly affected at all by the charges, while they are reduced by 3% in the inner city. The number of vehicle kilometres travelled by car during charged hours is reduced by 3% in the county as a whole and by 20% in the inner city.

The charging system is estimated to yield revenues close to 1300 million SEK per year. If Essingeleden is excluded, the revenues go down to around 1000 million SEK, partly because the revenues from Essingeleden itself disappear, and partly because a greater number of cars then choose to take this bypass if it is free of charge.

4.3. Effects for different groups

In the following, we describe the effects of congestion charging for different groups of travellers by applying the methodology described in the previous section.[8] All effects are calculated per individual in each group. The welfare effects are separated into three parts: *paid charges*, *value of changes in travel pattern* and *value of time*

[8] Due to a mistake in the coding of the methodology, the choice probabilities in the SE model have been calculated based on travel times and costs between zones produced by SAMPERS for a common time value of 43 SEK/h for all individuals. When calculating how much each individual is travelling, the correct travel times and costs have been used, however. We believe that this mistake has had only a minor impact on the results.

savings. The sum of the latter two minus paid charges is the *net effect* displayed. The generated revenues (the sum of charges paid) can be spent in different ways. Four alternative refund schemes explained in Section 3.1 are considered: *lump-sum redistribution, public transport refund scheme, car refund scheme* and *tax cut refund scheme*. The sum of the *net effect* and the *value of refund scheme* is the *net effect including refunding*. This is our main measure of how congestion pricing will affect each group. In addition, we present some other indicators that can be useful for understanding how congestion pricing will affect different groups.

It is worth mentioning that every group is considered on average.[9] The congestion charges are assumed to be equally high for everybody. The average effects can therefore be interpreted as describing how many in a certain group who are affected on a given day—most people also vary their travel behaviour from day to day. One should hence keep in mind that there can be considerable variation within a group.

4.4. Men and women

Men and women make just about the same total number of trips, but men travel more by car and also make longer journeys (Table 1). This means that congestion charges to a greater extent affect men's travel behaviour and travel costs than women's. Men make almost 70% of inner city trips by car during peak hours. It is estimated that the total number of trips to the inner city (charged area) across all modes will decrease by more than 3% for men and a little over 2% for women.

About two thirds of the charges are paid by men. Compared to women, close to double the share of men pay charges for their trip to work—8% compared to just over 4% for women. Men already have greater travel costs on average initially, and then their travel costs increase the most in relative terms as well: 19% compared to 15% for women. There are of course great differences within each group. One way to illustrate this is to pick out the one fifth within each group that pay the most charges, and compare them. The women who are "worst off" pay about 1800 SEK per year, while the corresponding one fifth of the men pay about 6500 SEK per year—close to four times as much.

Fig. 2 presents the total annual value of men's and women's charges, adjustment costs and travel time savings. The last bar shows the resulting net effect of the charges (before redistribution of revenues), which is negative. In other words and as expected, the value of reduced travel time is lower than the charges plus the value of the adjustment cost, on average. Men "lose" on average a total of about 600 SEK per year (all effects combined) when charges are introduced, while the corresponding cost for women is about 400 SEK per year. Note that the benefits from the revenues are not displayed in the figure and that the variation within groups can be large.

The crucial factor for the net effects is how the revenues are channelled back to the travellers. In Fig. 3 the net effects for men and women are shown for three of the hypothetical uses of revenues described previously. The net effect including refunding is hence the combined effect of charges paid, changes in travel behaviour, reduced travel times and share of the revenues. Fig. 3 implies that women are favoured if the revenues are shared equally, and even more so if the revenues are used for public transport (since women use public transport more than men). If the revenues are used to lower taxes, both groups receive just about equal benefit on average at the total level—men a little more than women.

4.5. Income

The residents in the region have been divided into three groups according to their individual income so that there are equally many in each group. This means that the definitions of "high" and "low" income are rather broad. There is then a clear connection between income level and car use, as well as with travel distance (see Table 2). The higher the income, the greater the share of the journeys is made by car and the longer are the journeys (especially trips to work). This means that people with high incomes are more affected by the charges than people in low-income groups. The richest third undertakes about three times as many trips by car to the inner city, compared to the poorest third.

[9] The methodology employed by Franklin (2004) allows a more detailed equity analysis in this respect.

Table 1
Effects of charges for men and women (all effects per individual in each group)

Category	Indicator	Men	Women
General	Trips affected by charges (before)	16%	9%
	No. of car trips/year (before)	310	242
Travel costs	Avg. travel cost/day [SEK] (before)	18.5	13.1
	Avg. charging cost/day [SEK]	3.5	1.9
	Increase in travel cost	19%	15%
	Paid charges/year [SEK]	921	496
Travel changes	Avg. trip length	−1.7%	−1.5%
	No. trips to inner city	−3.4%	−2.3%
	No. trips south ↔ north (excl. charged area)	−7.0%	−4.8%
	No. car trips	−2.7%	−2.6%
	Value of changes in travel pattern/year [SEK]	−155	−93
Travel time	Avg. travel time/day [min] (before)	64	62
	Value of time savings/year [SEK]	491	206
Net effect	Net effect/year [SEK]	−585	−382
Value of refund scheme	Lump sum redistribution per year [SEK]	704	704
	Public transport refund scheme per year [SEK]	597	808
	Car refund scheme per year [SEK]	780	631
	Tax cut refund scheme per year [SEK]	825	588
Net effect incl. refunding	Lump sum redistribution per year [SEK]	119	322
	Public transport refund scheme per year [SEK]	11	426
	Car refund scheme per year [SEK]	195	249
	Tax cut refund scheme per year [SEK]	240	206

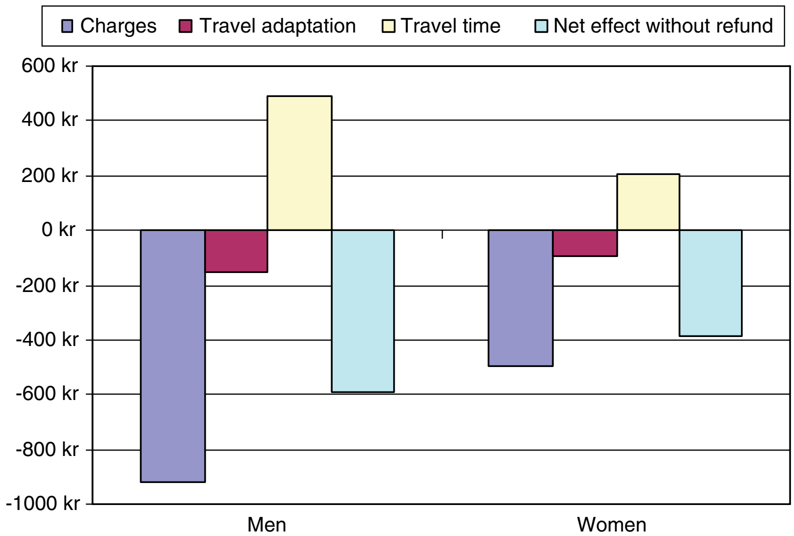

Fig. 2. Effects of charges for men and women (SEK per individual and year).

Regarding the total number of trips to the inner city (all modes), people with middle or high incomes are estimated to reduce their travel the most (more than 3% compared to not even 2% for the low-income group). The richest third of the residents in the county each pays more than four times as much in congestion charges than does each of the poorest third. Also, over four times as many of the high-income residents pay charges for their trip to work on a given day (10% of the high-income residents as compared to 2.5% of the low-income

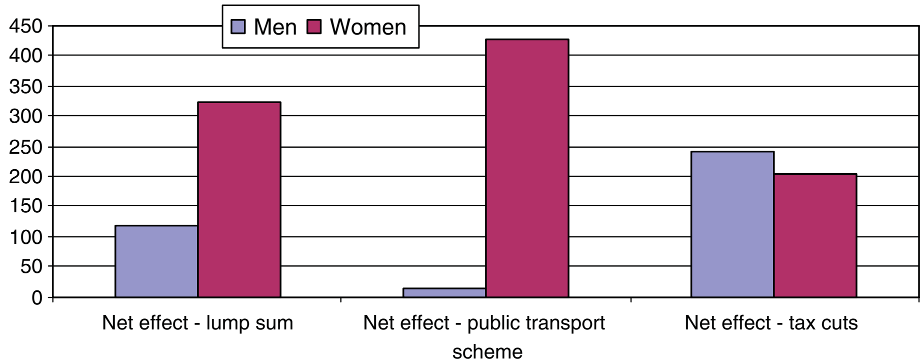

Fig. 3. Net effects including refunding for men and women for three hypothetical uses of revenues (SEK per individual and year).

Table 2
Effects of charges for equal-sized income groups (all effects per individual in each group)

Category	Effect	Low	Medium	High
General	Trips affected by charges (before)	6%	12%	21%
	No. of car trips/year (before)	193	292	379
Travel costs	Avg. travel cost/day [SEK] (before)	9.9	18.4	21.5
	Avg. charging cost/day [SEK]	1.2	2.5	5.2
	Increase in travel cost	12%	13%	24%
	Paid charges/year [SEK]	302	644	1344
Travel changes	Avg. trip length	−1.5%	−1.6%	−1.8%
	No. trips to inner city	−1.9%	−3.6%	−3.3%
	No. trips south ↔ north (excl. charged area)	−5.0%	−5.6%	−7.4%
	No. car trips	−2.7%	−2.8%	−2.5%
	Value of changes in travel pattern/year [SEK]	−72	−135	−186
Travel time	Avg. travel time/day [min] (before)	61	64	65
	Value of time savings/year [SEK]	87	255	808
Net effect	Net effect/year [SEK]	−288	−523	−722
Value of refund scheme	Lump sum redistribution per year [SEK]	704	704	704
	Public transport refund scheme per year [SEK]	797	721	555
	Car refund scheme per year [SEK]	504	741	959
	Tax cut refund scheme per year [SEK]	237	729	1355
Net effect incl. refunding	Lump sum redistribution per year [SEK]	417	181	−17
	Public transport refund scheme per year [SEK]	509	197	−167
	Car refund scheme per year [SEK]	216	217	237
	Tax cut refund scheme per year [SEK]	−51	206	634

residents). Travel costs are strongly correlated with income even without congestion charges. High-income residents have more than double the total travel costs compared to low-income residents (much depending on them using the car more). As a consequence of the charges, these costs increase by 24% for high-income residents, while low-income residents increase their travel costs by half of that. The one fifth of high-income residents who pay the most charges pay just under 8000 SEK per year, which is almost six times as much as the corresponding fifth of the low-income residents who pay about 1400 SEK per year.

If charges, adjustment costs and travel time savings are summed up (see also Fig. 4), it is revealed that the low-income group "loses" less than 300 SEK per year, the middle income group slightly over 500 SEK per year and the high-income group some 700 SEK per year (generalised costs). Note that the benefits of the revenues are not included in these values.

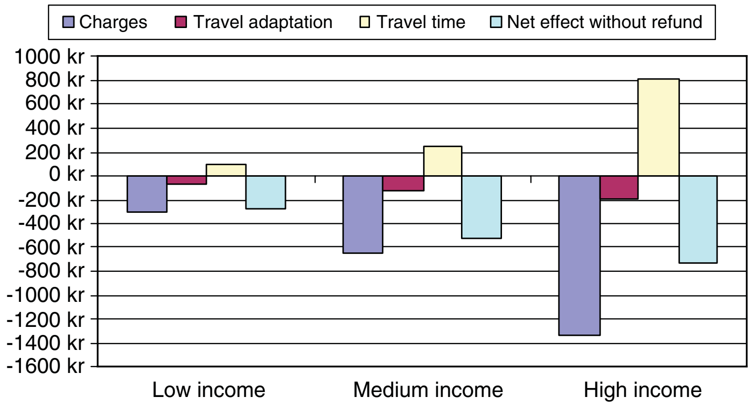

Fig. 4. Effects of charges for equal-sized income groups (SEK per individual and year).

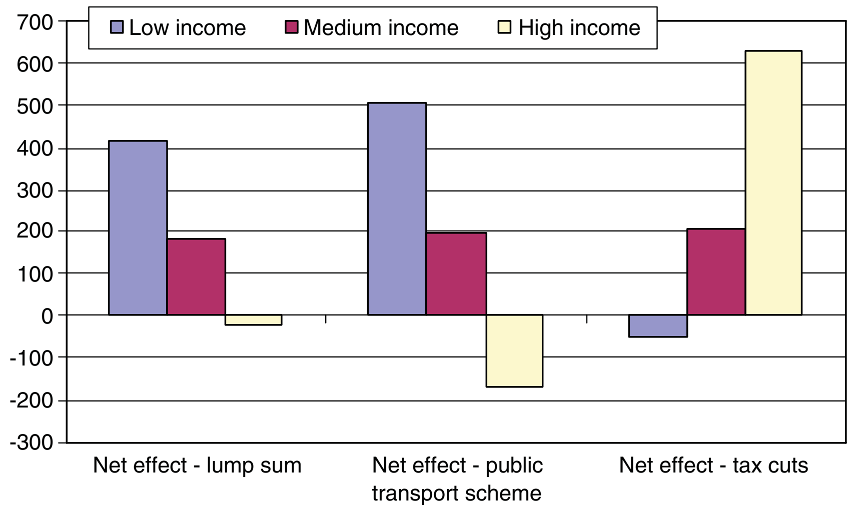

Fig. 5. Net effects including refunding for equal-sized income groups for three hypothetical uses of revenues (SEK per individual and year).

Again, it is the way chosen for the use of revenues that determines the net effect for different groups. In Fig. 5 the net effects for three hypothetical refund schemes (described earlier) are presented. The figure implies that if the revenues are divided equally between the inhabitants in the county, low-income residents receive the greatest net benefits. Middle-income residents are also net winners, while high-income residents suffer a slight loss on the whole. If the revenues are used for public transport, the net effects favour low-income residents even more, while using them to lower income tax favours the high-income group.

4.6. Household type

Single parents drive a car to a considerably greater extent than single households do (see Table 3). Households with two adults with and without children also drive more than single households. Households with two adults without children would be the ones who would be most affected by the charges. For single parents, 6% would be affected, while the percentage for households with two adults without children is more than doubled.

A comparison of how much the charging system would change the total amount of travel (for all modes) in relative terms yields rather small differences among the household types. Single parents reduce their trips the most (about 4–7% fewer trips) and single households the least (2–4% fewer trips).

Table 3
Effects of charges for different household types (all effects per adult in each group)

Category	Effect	Single	2 adults	2 ad + chi	1 ad + chi
General	Trips affected by charges (before)	11%	15%	11%	6%
	No. of car trips/year (before)	156	242	289	342
Travel costs	Avg. travel cost/day [SEK] (before)	12.9	15.6	18.0	14.7
	Avg. charging cost/day [SEK]	2.4	2.7	3.0	2.3
	Increase in travel cost	19%	17%	17%	15%
	Paid charges/year [SEK]	634	693	783	587
Travel changes	Avg. trip length	−1.3%	−1.2%	−1.7%	−1.7%
	No. trips to inner city	−1.6%	−2.9%	−3.0%	−4.0%
	No. trips south ↔ north (excl. charged area)	−4.0%	−4.9%	−5.9%	−7.0%
	No. car trips	−3.7%	−2.6%	−2.8%	−2.2%
	Value of changes in travel pattern/year [SEK]	−111	−127	−131	−106
Travel time	Avg. travel time/day [min] (before)	59	61	68	69
	Value of time savings/year [SEK]	230	339	451	229
Net effect	Net effect/year [SEK]	−515	−480	−463	−464
Value of refund scheme	Lump sum redistribution per year [SEK]	704	704	704	704
	Public transport refund scheme per year [SEK]	811	640	665	966
	Car refund scheme per year [SEK]	444	710	890	592
	Tax cut refund scheme per year [SEK]	617	695	801	550
Net effect incl. refunding	Lump sum redistribution per year [SEK]	189	224	242	240
	Public transport refund scheme per year [SEK]	295	160	202	502
	Car refund scheme per year [SEK]	−71	230	428	128
	Tax cut refund scheme per year [SEK]	102	214	338	86

The differences between household types in the amount of charges paid are rather small. Households with two adults with and without children pay the most (per adult), single households a little less and single parents the least.

In Fig. 6 the net effects including refunding for the three hypothetical revenue uses are presented. Again it is shown that the use of revenues is crucial for the resulting distributional effects. Fig. 6 indicates that if the rev-

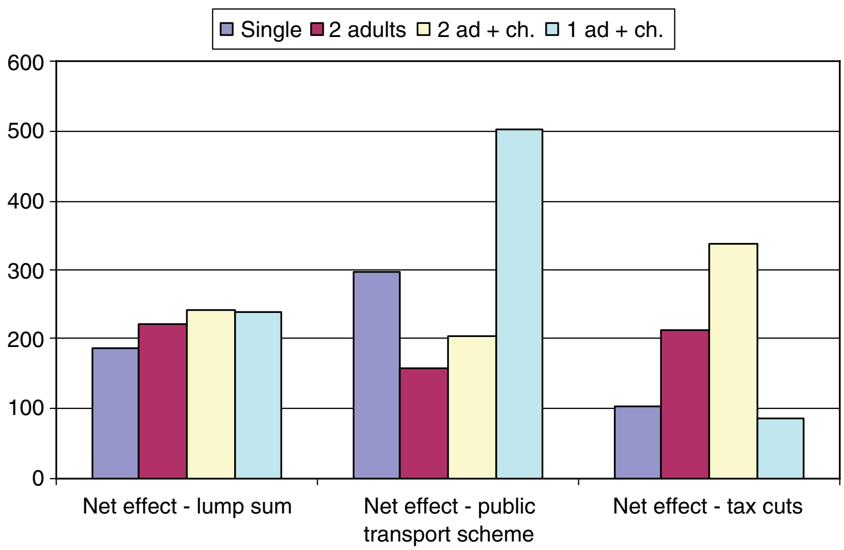

Fig. 6. Net effects including refunding for different household types for three hypothetical uses of revenues (SEK per adult and year).

enues were divided equally among the residents in the county, the differences between household types would be small. All households gain about 200 SEK per adult and year, if the combined effect of charges paid, changes in travel behaviour, reduced travel times and share of revenues is considered. If the revenues are used for public transport, the charges favour single parents more than other household types on the whole, while the alternative with lower taxes benefits households with two adults and children the most. This can be explained partly by differences in travel patterns (single parents' trips are less affected by the charges) and partly by differences in income (households with two adults and children have higher incomes than other groups). It is of course necessary to bear in mind that there may be considerable variations within the groups.

4.7. Occupation

We compare four occupational groups: employed (including self-employed), students (over 18 years of age), senior citizens and "non-workers". The last group includes unemployed, those on parental or sick leave and others who are not employed.

When comparing how much of the total travelling undertaken by each of these groups is affected by the charges, it is seen that the employed are by far most affected (see Table 4). Regarding total travelling, students would be the least affected by the charges. This is logical since this group travels much less by car than other groups. The changes are rather similar for the other groups, calculated as percentages. Employed travellers are estimated to pay three to four times as much in total charges per capita as others. The differences are small among the remaining groups.

In Fig. 7 the net effects including refunding for the three hypothetical refund schemes described earlier are presented. These calculations show again that the use of the revenues is crucial for the resulting distributional effects. The rough estimate in the figure implies that if revenues are divided equally between the regional residents, employed residents benefit the least or slightly more than 100 SEK per year on average, while the remaining groups gain threefold that, about 400 SEK per capita and year (combined average effect of charges paid, changes in travel behaviour, reduced travel times and share of revenues). If revenues are used for public

Table 4
Effects of charges for different occupation groups (all effects per individual in each group)

Category	Effect	Employed	Retired	Students	Unempl
General	Trips affected by charges (before)	15%	13%	3%	8%
	No. of car trips/year (before)	342	197	134	163
Travel costs	Avg. travel cost/day [SEK] (before)	21.4	6.9	7.0	5.2
	Avg. charging cost/day [SEK]	3.7	1.2	1.0	0.9
	Increase in travel cost	17%	18%	15%	18%
	Paid charges/year [SEK]	964	321	267	240
Travel changes	Avg. trip length	−1.6%	−2.2%	−1.4%	−1.9%
	No. trips to inner city	−3.2%	−3.3%	−1.2%	−4.3%
	No. trips south ↔ north (excl. charged area)	−6.4%	−5.0%	−4.2%	−6.0%
	No. car trips	−2.7%	−1.7%	−3.6%	−1.7%
	Value of changes in travel pattern/year [SEK]	−165	−51	−66	−45
Travel time	Avg. travel time/day [min] (before)	64	64	64	64
	Value of time savings/year [SEK]	546	13	44	9
Net effect	Net effect/year [SEK]	−583	−359	−289	−275
Value of refund scheme	Lump sum redistribution per year [SEK]	704	704	704	704
	Public transport refund scheme per year [SEK]	752	263	1153	340
	Car refund scheme per year [SEK]	853	488	433	487
	Tax cut refund scheme per year [SEK]	1007	319	48	380
Net effect incl. refunding	Lump sum redistribution per year [SEK]	121	346	415	429
	Public transport refund scheme per year [SEK]	168	−96	864	64
	Car refund scheme per year [SEK]	270	130	144	212
	Tax cut refund scheme per year [SEK]	424	−40	−241	105

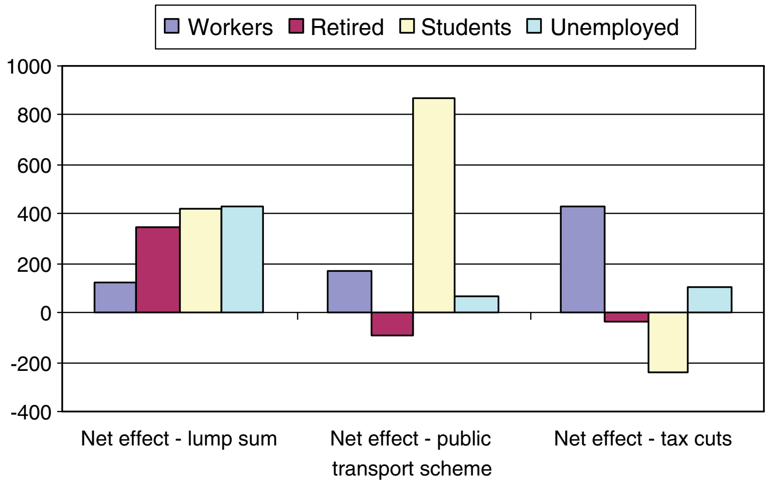

Fig. 7. Net effects including refunding for different occupational groups for three hypothetical uses of revenues (SEK per adult and year).

transport, students are on the whole favoured by the charges more than other groups, while using them to lower taxes would benefit the employed residents the most.

4.8. Geographical differences

About 35% of regional trips have the inner city as their origin and/or destination. Just below 10% of all trips in the county are made by car to/from the inner city and will therefore be affected by the charges. Travel

Table 5
Effects of charges for different geographical areas (all effects per individual in each area)

Category	Effect	Far north	Near north	North city	South city	Near south	Far south
General	Trips affected by charges (before)	7%	11%	22%	21%	16%	10%
	No. of car trips/year (before)	348	262	128	128	241	242
Travel costs	Avg. travel cost/day [SEK] (before)	20.8	12.7	8.2	9.0	12.9	19.8
	Avg. charging cost/day [SEK]	1.7	2.4	3.1	4.6	3.8	2.4
	Increase in travel cost	8%	19%	37%	51%	30%	12%
	Paid charges/year [SEK]	429	635	795	1184	998	619
Travel changes	Avg. trip length	−1.3%	−1.2%	−3.0%	−3.1%	−1.0%	−1.2%
	No. trips to inner city	−5.7%	−5.0%	0.0%	0.0%	−6.1%	−2.9%
	No. trips south ↔ north (excl. charged area)	−6.7%	−5.9%	–	–	−5.5%	−5.4%
	No. car trips	−1.0%	−2.5%	−7.5%	−10.2%	−4.6%	−2.6%
	Value of changes in travel pattern/year [SEK]	−69	−105	−143	−165	−189	−121
Travel time	Avg. travel time/day [min] (before)	68	59	50	52	62	69
	Value of time savings/year [SEK]	491	345	122	252	287	343
Net effect	Net effect/year [SEK]	−7	−395	−815	−1098	−899	−396
Value of refund scheme	Lump sum redistribution per year [SEK]	704	704	704	704	704	704
	Public transport refund scheme per year [SEK]	602	693	773	802	795	689
	Car refund scheme per year [SEK]	885	661	345	370	617	837
	Tax cut refund scheme per year [SEK]	688	687	764	710	718	700
Net effect incl. refunding	Lump sum redistribution per year [SEK]	698	310	−111	−393	−195	308
	Public transport refund scheme per year [SEK]	595	299	−42	−296	−104	293
	Car refund scheme per year [SEK]	878	266	−471	−728	−282	441
	Tax cut refund scheme per year [SEK]	681	293	−51	−387	−181	304

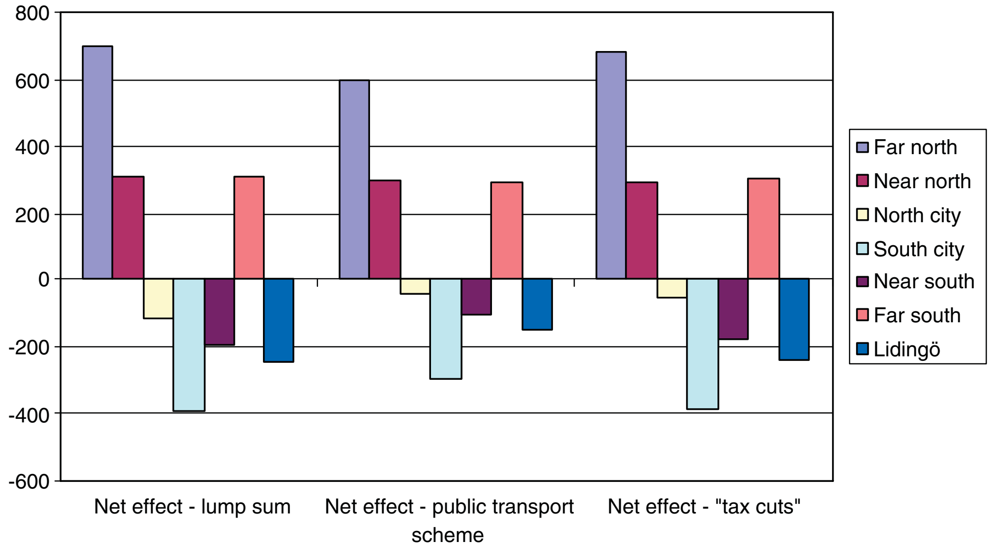

Fig. 8. Net effects including refunding for different geographical areas for three hypothetical uses of revenues (SEK per adult and year).

costs are considerably higher in the outer parts of the county initially (see Table 5). For natural reasons the charges affect travel costs more and more the closer one gets to the city centre. Travel costs for trips starting in the inner city increase by 40–50%.

Just as before, net effects including refunding depend on the way that revenues are channelled back to the residents (see Fig. 8). However, the geographical distribution is fairly similar among the different refund schemes except for the car scheme (see Table 5). This is in contrast to previous analyses where the outcome for different groups could vary a lot depending on the specific refund scheme. The central parts of the county lose on the whole for all of the alternative revenue uses analysed, while the outer parts benefit in all cases. Also, southern parts lose more than northern ones. This is because many more people live in the southern part of the region and work in the northern part than the other way round. These geographical differences are most accentuated for the car refund scheme.

It is of course possible, if one so wishes, to use the revenues so that the geographical net effects would be more evenly distributed. One could for instance choose to enhance public transport in the central parts of the county, or let the charges finance differentiated lowering of municipal taxes. The latter would, however, entail legal complications.

5. Conclusions

This study confirms the hypothesis often put forward in previous research and sometimes also in the public debate: the two most important factors for the net impact of congestion pricing (at a group level) are the initial travel patterns and how revenues are used. Differences in these respects between two groups dwarf differences in other factors such as values of time.

The former means that people driving frequently in the inner city are those who will be affected the most. At a group level it is hence less important that, for example, low-income residents are more cost sensitive and have lower values of time than high-income residents. Since high-income residents make more car trips (especially in the charged areas), it is still they who, on average, will reduce their car trips the most, pay most charges, and experience the largest net loss when charges, travel changes and time gains are added together. However, this should not conceal that a low-income resident who is going by car from a suburb to inner city will be more affected by the charges than a high-income resident in the same situation.

But the perhaps most important finding is that the net impact to a large extent will be decided by how the revenues are spent. This means that careful monitoring of distributional impacts from the revenue use is at least as important as monitoring the direct distributional impacts from the charges themselves.

As a measure of the "relative efficiency" (or "relative cost efficiency") of the pricing scheme, the total net welfare benefits (including refunding) can be compared to the total collected congestion charges. On average, the net benefits (including refunding) are 222 SEK per resident and year (under the assumption that the cost of operating the charging system can be ignored), while total charge revenues amount to 704 SEK per resident and year. Hence the revenues are more than three times as high as the net welfare benefits (including refunding). Expressed differently, the net total benefit (including refunding) to total revenue ratio is 0.32. Thus, while congestion charging is clearly a reform with a positive cost–benefit ratio, this result underscores that redistribution effects can be considerable, supporting our finding that the spending of the revenues is crucial for who will win and who will lose on this reform. Our result can be compared to those derived from the use of a dynamic network simulation model that also includes an endogenous handling of departure-time decisions (De Palma et al., 2005). In an application to a stylised urban network they attain a net total benefit (including refunding) to total revenue ratio of 0.72 and 0.28 for an optimised time-varying and a flat cordon charging scheme, respectively.

Turning to more specific results, we find that men, high-income groups and residents in the central parts of the city (including near south) will be affected the most: they will pay the most and often also reduce their car trips the most. Even after accounting for time gains and that these groups have relatively high values of time, their total generalised travel costs will increase the most (i.e., they have the highest negative net effect without refunding).

In this particular case, men will pay on average twice as much as women. Taking also time savings and changes in travel patterns into account, men will lose around 50% more than women from the direct effects of the charges. If revenues are used for improving public transport, this will benefit women most. If revenues are used for tax cuts, the net benefits will be about equal for men and women on average.

As to income effects, the richest third will pay four times more charges than the poorest third. Taking also time savings and changes in travel pattern into account, the richest third will lose around 2.5 times more than the poorest third from the direct effects of the charges. If revenues are spent on public transport, this will primarily benefit low-income groups, while proportional tax cuts will naturally benefit high-income groups. Given that it is likely that the revenues will be used to some extent to improve the public transport system we conclude that the proposed congestion-charging scheme for Stockholm is progressive rather than regressive.

Interestingly, our conclusions about the effects for men and women and for different income groups and about progressivity are consistent with the conclusions from the more detailed equity analysis by Franklin (2004).

Variables such as employment status and family situation matter less than gender and income, but the effects are still significant. Employed residents will be affected more than non-employed.

From a geographical point of view, inhabitants in the city centre and the innermost southern suburbs will be affected the most by the charges. This latter result stems from the geographical distribution of residents and employment in Stockholm: there is a considerable regional imbalance resulting in significantly more people commuting from the southern suburbs to jobs in the north than the other way round. As to the adverse effect on city centre inhabitants, it has in fact often been claimed in the Swedish debate that congestion charges will turn the city centre into a "reservation for the [rich] city centre inhabitants", and unjustly benefit those living there. Instead, our analysis shows that city centre inhabitants will, on average, lose more from the charges than residents in other parts of the county. The reason for this is that while it is seldom necessary to travel by car to the city centre, those living there will (at least sometimes) need to use their car for, for example, long-distance trips or some types of shopping. In those cases, they cannot avoid the charges (apart from travelling at other times), which results in them being more adversely affected.

It should be remembered that the differences in averages among different groups may conceal that there are also considerable variations within the groups.

The particular conclusions from our case study of course depend on the particular structure of the transport system, the geographic distribution of residents and employment and the congestion-charging scheme. Stockholm has a well-functioning public transport system and the proposed charges would be especially high during peak hours in the inner city, which is the time and place when and where the accessibility by public transport is at best. It is likely that similar results would be obtained for other cities with similar transport systems and travel patterns.

As a final conclusion, we agree with Santos and Rojey (2004) that the distributional impacts of congestion pricing have to be assessed on a city and scheme specific basis taking into account where different population groups live and work and what mode of transport they use for their travelling and how the revenues are allocated back to them.

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