Acknowledgements
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Abstract
This paper performs an ex-post cost-benefit and equity analysis of the Gothenburg congestion charges introduced in 2013, based on observed effects and an accurate transport model. We find that the net social benefit of the charge is positive. However, we also show that low income citizens pay a larger share of their income for three reasons. First, all income classes are highly car dependent in Gothenburg. Second, workers in the highest income class have considerably higher access to company cars.

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1 INTRODUCTION

Congestion pricing has proven to be an effective policy for reducing congestion and increasing welfare, but is still only implemented in a few cities: Singapore (Olszewski & Xie, 2005; Phang & Toh, 1997), London (Santos, 2005; Santos and Shaffer, 2004), Stockholm (Börjesson et al., 2012; Eliasson, 2009) and Milan (Carnovale & Gibson, 2013). Gothenburg, located on the Swedish west coast, introduced a time-of-day dependent cordon-based congestion charging scheme in January 2013. This paper presents an ex-post welfare and equity analysis of the Gothenburg system, and adds to the literature because it is by far the smallest city (half a million citizens) for which such effects have been evaluated. However, some small cities have implemented some form of congestion pricing: Durham (Santos 2004) and Minneapolis (Xie, 2013).

A number of theoretical studies examine welfare and distribution effects of congestion charges (Arnott, De Palma, & Lindsey, 1994; Evans, 1992; Glazer & Niskanen, 2000; Verhoef & Small, 2004). They find that although congestion charges increases welfare, they are likely regressive in cities where driving patterns among low-income and high-income groups are more similar. A few studies also explore the welfare of real-world examples. Daniéis et al. (2012) find a welfare effect of Milan’s Ecopass system of €7–12 million per year. Gibson & Carnovale (2015) show that the welfare benefits from reduced air pollution adds nearly another €2.7 billion per year. Eliasson (2009) finds a net benefit of €70 million per year for the Stockholm charges, but the consumer surplus for drivers is still negative. Börjesson and Kristoffersson (2014), however, show that when including network effects (travel time savings further out in the network), intra-individual variation in the value of travel time (VTT), and reduced scheduling disutility, the consumer surplus of the Stockholm charges is in fact positive. Transport for London (Santos & Shaffer, 2004) and Prud’homme and Bocarejo (2005) present different cost-benefit analyses of the London congestion charges based on observed traffic effects. The former study finds a net benefit of the charging system of approximately €70 million per year, whereas the latter finds a net loss of the same magnitude. The main difference between the two studies is, according to Mackie (2005), the method of calculating travel time savings and the VTT; Prud’homme and Bocarejo do not consider travel time savings outside of the charging zone and apply a lower VTT.

There are also a few equity studies on real congestion charging systems: San Francisco (Schiller, 1998), Oslo (Fridstrøm, 2000), Gothenburg (Transek, 2002), Stockholm (Eliasson and Mattsson; 2006) and Cambridge, Northampton and Bedford (Santos and Rojey, 2004). These studies indicate that high income groups are affected the most since they drive more. However, analysing payments in four European cities, (Eliasson, 2016) concludes that total congestion charge relative to income decreases with increasing income. Moreover, Levinson (2010) concludes that high income groups in general benefit the most from HOT lanes. Ison and Rye (2005) and Rye at al. (2008) note that if not considering the use of the revenues, the (proposed) congestion charging systems in the UK (the London system and other suggested systems) and Singapore are not equitable.

In this paper we explore how the costs and benefits of the Gothenburg charges are distributed across different segments of the population distinguished by income, gender, age group, and place of residence. Virtually all previous studies on distribution effects have applied different values of time for different groups of travellers (see for instance Eliasson

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1 Suits (1977) uses this definition of a regressive/progressive instrument,
and Mattsson (2006) and Verhoef and Small (2004)). This presents a particular problem when exploring how travel time benefits are distributed in the population. To some extent the variation in the value of time arises from income differences, because high income travellers have on average lower marginal utility of income. Hence, applying the true values of time in a welfare analysis puts a higher weight on the travel time gains of high income travellers. This is the main argument of Gálvez and Jara-Díaz (1998).

To avoid putting higher weights on high income travellers in cost-benefit analysis an often used solution is to apply the same average value of time for all income groups (Mackie, et al., 2001). However, plenty of studies show that income differences explain a limited part of the variation in the values of time in the population (Börjesson & Eliasson, 2012; Fosgerau, 2007; Ramjerdi, Flügel, Samstad, & Killi, 2010), presumably because the marginal utility of time varies in the population. In this study we therefore assume I) that that the marginal utility of time varies in the population, but is independent of income, and II) that the marginal utility of money depends on income but not on any other variable. In the distribution analysis we then keep the marginal utility of money constant across income groups but the marginal utility of time is still assumed to vary in the population. Moreover, assuming that all individuals with the same income have the same marginal utility of money also underestimate the benefits of sorting (Verhoef and Small 2004; Börjesson and Kristoffersson, 2014). Therefore, also do the distribution analysis with true values of time, to explore the sensitivity of our assumptions.

In Gothenburg the congestion is limited to a few highway junctions and the share of public transport trips is comparatively low: 26% for commuting trips in the OD (origin - destination) pairs where the charges apply (Björklind et al., 2014). The corresponding market share in Stockholm was 77% in 2006 before the charges were implemented (SL, 2013). Although the average charge per trip in Gothenburg is approximately half of what it is in Stockholm, the system generates approximately the same revenue. Hence, a substantially larger share of the population regularly pays the charge, indicating that the system is more regressive than the Stockholm system.

Several authors have emphasized that the use of revenue should be taken into account to get a complete picture of equity effects of a congestion charging system (de Palma & Lindsey, 2004; Eliasson & Mattsson, 2006; Santos & Rojey, 2004; Small, 1983). Ison and Rye (2005) argue that the preferred use of revenues is local public transport for equity reasons. This is also the case in London, where the revenues from the charging system are spent on local public transport. In Gothenburg the revenues co-finance a package of investments (West Swedish Agreement, October 28, 2009). The largest investment in the package is the West Link (€2.0 billion), which is an 8-km-long rail link including a 6-km-long tunnel under central Gothenburg. Most of the benefits of the West Link will accrue to individuals residing close to train stations far out in the larger Gothenburg region, and not primarily to the travellers affected by the charging system.

Levinson (2010) and Ison and Rye (2005) underscore that the distribution of costs and benefits of a charging system depends on the design of the system, including for instance exemptions and discounts. This is demonstrated by the Swedish congestion charging systems, where the congestion charge is included in the “taxable benefit value” of company cars. Hence, company car users are either exempt from paying the charge, or can deduct the charge from their gross income (which implies a discount of approximately seventy per cent). This implies negative effects on equity, since almost all company car users belong to the highest income segment.

Levinson argues that public opinion depends on the distribution (and the public’s perception of the distribution) of gains and losses of a (proposed) charging system. The Gothenburg system has indeed low public support: A consultative referendum was held in
September 2014, where fifty-seven per cent voted against the charges, although the support had increased since introduction of the charges in January 2013. Some authors (Eliasson and Mattsson, 2006; Levinson, 2010) have also argued that equity concerns coupled with low public acceptability is one of the main reasons why congestion charges are implemented in so few cities.

The paper is organized as follows. Section 2 describes the charging system, Section 3 the CBA methodology, and Section 4 the CBA results. The method and results of the equity analysis is included in Section 5 and Section 6 concludes.

2 THE GOTHENBURG CONGESTION CHARGES

Gothenburg (Göteborg in Swedish) is the second largest city in Sweden with half a million inhabitants within the city and nearly a million in the larger metropolitan area. The city is traditionally a seaport and manufacturing city dominated by blue-collar jobs, the car manufacturing industry being one of the dominant sectors. The blue-collar jobs are mainly located north of the Göta river, while the central business district is located south of it. Gothenburg is a sparsely populated metropolitan area. Its planning does not support an efficient public transport system, implying a considerably lower share of public transport than in Stockholm. For commuting trips in the OD-pairs where the charges apply, the public transport market share was 26% in Gothenburg in 2012 (Björklind et al., 2014), while in Stockholm the corresponding market share was 77% before the congestion charges were introduced in 2006 (SL, 2013).

Gothenburg has begun its shift towards a more high-tech and service-oriented economy. The population was relatively stable during the second half of the 20th century, but since the beginning of the 21st century it has increased, prompting a denser and more transit-oriented society.

A cordon-based congestion charging scheme was introduced in Gothenburg in January 2013 (see Figure 1). The charge is time-of-day dependent, ranging from €0.82 to €1.8 during weekdays 6.00 – 18:30, while other time periods are free of charge. A multi-passage rule applies which states that drivers only have to pay once when passing the cordon more than once during 60 minutes. The maximum daily charge is €6. Vehicles are charged when passing the cordon in either direction using automatic number plate recognition. The main objective of introducing congestion charges was to raise a yearly revenue of €100 million to co-finance a large infrastructure package, mainly a rail tunnel. Other objectives were to reduce congestion and improve the local environment. Congestion in Gothenburg was however mainly concentrated to the highway hub depicted in Figure 1.

The average charge is approximately €0.5 per passage, compared to €1 for the Stockholm system. In 2013 the number of passages was 132 million and the total revenue €71 million in Gothenburg to be compared with 77.6 million passages and the total revenue of €75.6 million in Stockholm. Since Gothenburg is less than half the size of Stockholm, each citizen thus pays on average twice as much as in Stockholm.

Public resistance against the congestion charges resulted in a consultative referendum in conjunction with the regularly-scheduled general election to the national parliament and to the city council, held on 14 September 2014. The referendum question was formulated as: “Do you think that the congestion tax should continue after the 2014 election?”. Fifty-seven per cent of the voters in the municipality voted “No”.

\(^2\) Here and in the rest of this paper we use the conversion rate 10SEK=€1.
Now, the key factor for receiving political support for charges was an agreement with the national government that Gothenburg would receive a major infrastructure package, funded by the congestion charging revenue, leveraged with an equally large national grant. Since a large share of the revenue from the charges is collected from citizens in surrounding municipalities, the agreement is a favourable deal for the city of Gothenburg, with all established political parties supporting the agreement. Since no alternative sources of funding could be found the congestion charges were kept.

![Gothenburg with the toll cordon depicted in red, main roads in black and highway hub in blue](image)

**Fig. 1** Gothenburg with the toll cordon depicted in red, main roads in black and highway hub in blue

### 3 COST BENEFIT ANALYSIS

In the design phase, the traffic effects of the Gothenburg charges were forecast using the Swedish national transport model system Samper (Beser and Algers, 2002). The traffic volume across the cordon and other larger links in Gothenburg was observed before and after the introduction of congestion charges. Travel times were measured by cameras before and after the introduction of congestion charges (City of Gothenburg, 2013b) in all major links in Gothenburg.
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The effects in terms of traffic volumes and travel times simulated by the model correspond well to the observed effects (West et al., 2016). The observed reduction in traffic volume across the cordon was on average ten per cent while the model predicted nine per cent. On the links where the charges reduced travel times the most, (the arterials leading into and from the bottlenecks on the highway hub depicted in Figure 1) the observed average travel time reduction was nine per cent while the predicted was eleven per cent.

The static assignment model predicted travel time effects of the congestion charges in Gothenburg with high accuracy because in Gothenburg spill-back queues are not a dominant problem. Welfare effects should be computed at the OD-pair level rather than on link level to include secondary effects on competing routes (Neuburger, 1971) so therefore we base our welfare analysis on model simulated effects.

In Stockholm on the other hand, where much of the congestion is dynamic, including spill-back queues and blocking of upstream intersections, travel time reductions on links outside the cordon were substantially underestimated by the transport model (Börjesson & Kristoffersson, 2014; Eliasson, et al., 2013). The CBA for the Stockholm system was therefore based on observed travel times on relevant links (Eliasson, 2009), which presented a problem requiring some method development for the welfare calculations.

3.1 Model description

The national transport forecasting model Sampers consists of five regional models, where Gothenburg is covered by the western Sweden sub-model. The demand model consists of nested logit models for six trip purposes (work, school, business, recreation, social and others) covering trip generation, destination choice and mode choice, and are estimated on national travel survey data 1994-2001. The demand models are linked to the software package Emme/3, assigning demand by mode to the transport network. For cars, travel times and cost from the assignment are fed back to the demand level in an iterative loop until convergence is reached, usually after the fourth iteration. Travel time and cost for public transport, walking and biking are assumed to be independent of transport volumes.

The OD matrices for freight and professional traffic are generated by a separate model, under the assumption that trip frequency, mode and destination choice of this traffic is insensitive to the charges. The route choice of the freight and professional traffic is however modelled in the assignment.

Since the transport model is static the departure time choice is not modelled. Instead, the mode-specific OD matrices produced by the demand models are split into three time periods (morning peak, afternoon peak and off-peak) according to purpose-specific fixed factors. The OD matrices for each time period are then assigned to the network. The time-of-day dependent charge is approximated by a constant charge within each time period. The constant charge is computed as a weighted average across each 15-minute interval within the given time period, the weights being the observed traffic volume. The approximation errors are highest for the off-peak period (e.g., midday when the charge ranges from €0.8 to €1.3 and night time which is free of charge).

These figures are for the whole day – 24 hours – including non-charged hours.

The model simulated travel time reduction on the links crossing the cordon was, however, close to the observed.
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EMME/3 distributes drivers by routes according to Wardrop user equilibrium. Path disutility $U$ is assumed to be a linear function of travel time ($T$), travel distance ($D$) and congestion charge ($C$)

$$U = \alpha T + \beta D + C,$$  

with $\alpha$ being the VTT and $\beta$ the distance cost. The VTT $\alpha$ (of the drivers in each OD pair) is taken to be a random variable $X$ following the log-normal distribution $\mathcal{N}(\mu, \sigma^2)$. The parameter $\beta$ is assumed to be equal across the population. In a standard network assignment, the path disutility (such as (1)) is assumed to be the sum of the disutilities of all links within the route. This assumption is valid for most transport networks. It is, however, not valid for the Gothenburg network where a multi-passage rule applies: A driver only has to pay one charge even if he or she uses a charged link more than once within one hour.

To implement the multi-passage rule, a hierarchical route choice algorithm with two levels is applied in the assignment (West et al, 2016). In the upper level, the drivers are split into two classes, paying and non-paying drivers. In the lower level, the drivers are assigned to the network; the paying drivers have access to the complete road network while the non-paying drivers can use only the uncharged links.

The assignment is run iteratively. In the first step (the lower level of the route choice algorithm), the travel time $T$ and travel distance $D$ of each OD pair, for the paying and non-paying drivers, respectively, are calculated under the assumption that the drivers minimize the path disutility defined by

$$U = \tilde{\alpha} T + \beta D,$$  

where $\tilde{\alpha}$ is the median VTT and $\beta$ the average driving cost per kilometre. The route choice differs between paying and non-paying drivers because the former may use the complete road network while the latter may use uncharged links only. The charge $C$ is set to zero in the lower level since the upper level of the route algorithm determines the share of drivers that pay the charge. Hence, only the relative weights of $T$ and $D$, that is the ratio $\tilde{\alpha}/\beta$, determines the route choice. We use the median VTT $\tilde{\alpha}$, and not the VTT distribution, in this step in order to produce a unique travel time and travel distance for each OD pair. Unique travel times and travel distances are required in the upper level of the route choice. The travel time and travel distance matrices for the paying drivers obtained by network skimming after the assignment are denoted $T^p$ and $D^p$. For non-paying drivers, the corresponding matrices are denoted $T^n$ and $D^n$.

The second step (the upper level of the route choice) determines the share of paying drivers in each OD-pair. The random distribution of $\alpha$ implies that some drivers in the OD-pair are better off paying a charge to save time, while others are not. A driver in OD-pair $(o, d)$ with VTT $\alpha^*$ is better off paying the charge $C$ and choose the faster route if $\alpha^* T^p_{o,d} + \beta D^p_{o,d} + C < \alpha^* T^n_{o,d} + \beta D^n_{o,d}$. The driver with the trade-off value of time, $k_{o,d}$, will be indifferent to paying the charge or to choose a detour. This trade-off value is computed as

$$k_{o,d} = \frac{C + \beta D^p_{o,d} - \beta D^n_{o,d}}{T^n_{o,d} - T^p_{o,d}}.$$  

The share of paying drivers in each OD pair is

$$q_{o,d} = P(X > k_{o,d}) = \int_{k_{o,d}}^{\infty} \ln \mathcal{N}(\xi; \mu, \sigma) d\xi.$$  

In the third step the paying and non-paying drivers are assigned to the network simultaneously. The iteration is then repeated from the first step until convergence is reached. Since different trip purposes have different VTT distributions, the calculations (3) and (4) are done by trip purpose, but this is left out to simplify the notation.
The parameters $\mu$ and $\sigma$ of the VTT distributions are taken from the Swedish VTT study (Börjesson & Eliasson, 2014). For commuting trips the median value of time, $\bar{\alpha}$, is 5.1 €/h and the mean value of time, $\bar{\alpha}$, is 10.8 €/h. For business and freight trips the median VTT is 27.3 €/h and the mean VTT 29.1 €/h, and for other private trips the median VTT is 2.5 €/h and the mean VTT 4.9 €/h. However, the VTT distributions applied in the route choice are stretched to the right (i.e., $\mu$ is increased) compared to the distributions from the national VTT study (for instance the stretched VTT for commuting trips has median 10.2 €/h). Otherwise the observed route choices (traffic volumes) are not reproduced by the model; more drivers than observed are then forecast to take a detour to avoid paying the charge.

We underscore that there is no strong reason to believe that the stretched VTT distribution represents the drivers’ true VTT. One possibility is that the stretching of the VTT distribution controls for deficiencies in the coding of the network (such that the travel times on small roads and streets are underestimated in the model). Another possibility is that the route choice is influenced by attributes not represented in the network model that are correlating with travel time, such as the preference for larger arterials rather than smaller streets due to for instance comfort. For this reason, we apply the original, not stretched, value of time distribution by trip purpose in the welfare calculation in Section 3.2.

### 3.2 The consumer surplus

In this section the consumer surplus is derived. The consumer surplus depends on the paid charges, the travel time gains, the changes in driving costs, and the adaptation cost for drivers priced off the road. Benefits from reduced travel time variability are not included in the transport model but are assessed separately from camera data measuring travel times (see Section 3.3). Welfare losses for public transport users due to more crowding are approximated to zero for the reasons stated in Section 3.4.

For drivers in OD-pairs without the choice between an uncharged and a charged route alternative, the value of the changes in travel time is computed as

$$\Delta v_{o,d} = \bar{\alpha}(T_{o,d}^0 - T_{o,d}^1),$$

where $\bar{\alpha}$ is the average VTT, and $T_{o,d}^1$ and $T_{o,d}^0$ are the travel times in the situation with and without congestion charges, respectively. The average VTT is assumed to be constant across OD-pairs.

For OD-pairs where there is a choice between a charged and an uncharged route, the value of the travel time gain is calculated as

$$\Delta v_{o,d} = \bar{\alpha}T_{o,d}^0 - \left((1 - q_{o,d})\alpha_{o,d}^nT_{o,d}^{1n} + q_{o,d}\alpha_{o,d}^pT_{o,d}^{1p}\right),$$

where $\alpha_{o,d}^n$ is the average VTT for the non-paying drivers, $\alpha_{o,d}^p$ is the average VTT for the paying drivers, and $T_{o,d}^{1n}$ and $T_{o,d}^{1p}$ are the travel times for non-paying and paying drivers in the situation with charges.

The average VTT for paying drivers is

$$\alpha_{o,d}^p = \mathbb{E}[X|X > k_{o,d}] = \frac{g_{o,d}}{q_{o,d}},$$

where $g_{o,d}$ is the partial expectation with respect to $k_{o,d}$ for the log-normal random variable, defined as

$$g_{o,d} = \alpha_{o,d}^p q_{o,d}$$

$$= \mathbb{E}[X|X > k_{o,d}] P(X > k_{o,d})$$

$$= \int_{k_{o,d}}^{\infty} \xi \ln \mathcal{N}(\xi; \mu, \sigma^2) d\xi$$
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\[
\hat{\alpha} \Phi \left( \frac{\mu + \sigma^2 \ln k_{o,d}}{\sigma} \right).
\]

Here \( \Phi \) is the standard normal cumulative distribution function. The derivation of the VTT expectation for non-paying drivers is straightforward since \( \hat{\alpha} = (1 - q_{o,d})\alpha_{o,d}^n + q_{o,d}\alpha_{o,d}^p \):

\[
a_{o,d}^n = \frac{\hat{\alpha} - q_{o,d}\alpha_{o,d}^p}{1 - q_{o,d}} = \frac{\hat{\alpha} - g_{o,d}}{1 - q_{o,d}}.
\] \(9\)

Combining (7) and (9) with (6) we have

\[
\Delta v_{o,d} = \hat{\alpha} T_{o,d}^0 - \left( (\hat{\alpha} - g_{o,d}) T_{o,d}^1 + g_{o,d} T_{o,d}^{1,p} \right).
\] \(10\)

Note that for OD-pairs where there is no choice between charged and non-charged routes, \( g_{o,d} = 0 \) and (10) collapses to (5).

The consumer surplus is

\[
\Delta W = \frac{1}{2} \sum_{o \in O} \sum_{d \in D} \left( s_{o,d}^0 + s_{o,d}^1 \right) \left( \Delta v_{o,d} + \Delta b_{o,d} - c_{o,d} \right),
\] \(11\)

where \( s_{o,d}^0 \) and \( s_{o,d}^1 \) are the OD-pair specific demand before and after the introduction of congestion charges, \( \Delta v_{o,d} \) is the value of the change in travel time, \( \Delta b_{o,d} = \beta \left( D_{o,d}^0 - \left( (1 - q_{o,d}) D_{o,d}^{1n} + q_{o,d} D_{o,d}^{1p} \right) \right) \) is the change in driving cost, and \( c_{o,d} = q_{o,d} C \) is the paid congestion charge per trip. If the average value of time \( \alpha_{o,d}^p \) and \( \alpha_{o,d}^n \) differs due to differences in the marginal utility of money arising from income differences, the welfare measure (11) implies that we put a higher weight on the travel time saving for high income travellers; this is formally explained in Section 5.

For private drivers using a company car, the employer pays the congestion charge; it is an employee benefit exempt from fringe benefits tax. It is unclear to what extent the employers deduct this benefit from the gross income, but even if it is the benefit implies a seventy per cent discount in the charge. This discount probably has a minor impact on the consumer surplus of the congestion charges: the (affluent) company car drivers would most likely not have been priced off the road even if they had paid the full charge. In this section we hence ignore this effect, but we will return to it in Section 5, analysing the distribution of gains and losses.

The consumer surplus (11) can be rewritten as

\[
\Delta W = \sum_{o \in O} \sum_{d \in D} s_{o,d}^1 \left( \Delta v_{o,d} + \Delta b_{o,d} - c_{o,d} \right) - \frac{1}{2} \sum_{o \in O} \sum_{d \in D} \left( s_{o,d}^1 - s_{o,d}^0 \right) \left( \Delta v_{o,d} + \Delta b_{o,d} - c_{o,d} \right),
\] \(12\)

where the first term is the consumer surplus for the remaining drivers and the second term is the consumer surplus (which must be negative) for drivers priced off the road. The valuations are taken from the Swedish appraisal guidelines (Börjesson, 2012; Börjesson & Eliasson, 2014).

3.3 Travel Time Variability

We measure travel time variability as the standard deviation of the travel time on the inner arterial links. Since travel time variability is not modelled in the transport model we cannot calculate the benefit of reduced travel time variability at the OD-pair level. However, we can
get a rough approximation of the magnitude of the effect of improved travel time variability relative to other effects using a simple link based analysis. Since the travel times on other links than the inner arterials in the direction toward the highway hub (depicted in Figure 1) stay largely unaffected by the charges, the standard deviation of the travel times on the arterial links corresponds well to the standard deviation of the travel times at the OD-pair level. Hence, in our rough approximation we assume that that the reduction in standard deviation of the travel time on the OD-level equals reduction in standard deviation on the inner arterial belonging to this OD-pair. There are four inter arterials, denoted \( l \), and we have then \( \sigma_{o,d} = \sigma_l \) if link \( l \) (\( l = 1, 2, 3, 4 \)) belongs to OD pair \( o,d \).

None of the OD-pairs includes more than one of the four links \( l \).

The ratio between the valuation of standard deviation and the valuation of mean travel time, usually denoted the reliability ratio, is estimated to be close to 1 for drivers in Sweden (Börjesson, 2008, 2009), which corresponds well to what is found for other countries (Bates et al., 2001). We therefore apply the reliability ratio 1 in this paper.

The travel times by day and 10-minute interval are available for 2012 and 2013 for the morning peak 7.00 – 9.00 (City of Gothenburg, 2013b). Table 1 shows the standard deviation averaged over the twelve 10-minute intervals in the peak, over six weeks in September and October for 2012 and 2013.

Table 1 The standard deviation of the travel time on the four inner arterial links, and the calculated benefit from the reduction

<table>
<thead>
<tr>
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<th>Number trips 7-9 am 2013</th>
<th>Std.dev. (min) 2012</th>
<th>Std.dev. (min) 2013</th>
<th>VTT (£/h)</th>
<th>Benefit (£)</th>
</tr>
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<tbody>
<tr>
<td>Bäckebol – Tingstad</td>
<td>11 100 000</td>
<td>2.3</td>
<td>2.2</td>
<td>0.1</td>
<td>8.7</td>
</tr>
<tr>
<td>Ullevi – Tingstad</td>
<td>5 600 000</td>
<td>1.2</td>
<td>1.0</td>
<td>0.1</td>
<td>8.7</td>
</tr>
<tr>
<td>Munkebäck – Tingstad</td>
<td>3 700 000</td>
<td>1.3</td>
<td>1.0</td>
<td>0.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Kallebäck – Tingstad</td>
<td>2 200 000</td>
<td>2.6</td>
<td>1.6</td>
<td>1.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Sum</td>
<td>22 600 000</td>
<td></td>
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</table>

The total yearly traffic volume in the morning peak 7.00 – 9.00 on the four inner arterial links is 22 600 000 vehicles. The total daily traffic volume on these links is roughly five times the volume in the morning peak: 100 million. We assume that standard deviation in the travel times for all traffic outside the morning peak 7.00 – 9.00, is on average 25% of the reduction in the morning peak. This means that the benefit from the improved travel time variability is approximately twice that of the morning peak or €1 500 000 per year. The results show (Section 4) that this benefit is small in relation to the benefit of shorter travel time. Hence, the approximation error we make from assessing the reduced travel time variability on a link basis is small.

3.4 Public transport

The producer surplus for the transit operator is obtained by subtracting the costs for providing additional capacity to the passengers diverted from driving from the additional fare revenues. Compared to 2012, transit ridership and sales of monthly and yearly tickets increased by seven per cent, but approximately two per cent is due to factors other than the congestion charges (Börjesson & Kristoffersson, 2015). The sales of monthly and annual travel cards had increased on average two per cent yearly over several years prior to 2012, due to population growth and various marketing campaigns continuing during 2013. The number of public transport trips also increased by five per cent in the charged OD-pairs according to the travel survey conducted before and after the introduction of the charges (City of Gothenburg,
2013a). The five per cent increase in sales of monthly and annual travel cards corresponds to a €8 million increase in yearly revenue for the public transport operator.

The operating cost for the public transport in the entire county (larger than the metropolitan area) increased by five per cent corresponding to €32 million/year. However, the operating costs increased even more the previous years (yearly increases of 5-11%), suggesting that it was not directly the increased public transport demand due to congestion charges that increased the operating costs (Västrafik, 2013). Moreover, in Gothenburg crowding in the public transport system is a minor problem, so one could also argue that additional public transport supply to reduce crowding were not required (the share of buses and commuting trains where anyone had to stand up was less than three per cent in 2013 (Björklind et al., 2014)). For this reason we assume that the operating cost of public transport producer stays unaffected by the congestion charges. We also assume that the value of time for public transport users does not increase due to increased crowding. The additional fare revenues are left out of the CBA since this is only a transfer from travellers to the operator.

3.5 External costs

The external costs of car use are taken from the Swedish CBA guidelines (ASEK, 2014). It is in total €0.073 per vehicle kilometre, the components being traffic safety (€0.022 per vehicle kilometre), noise (€0.019 per vehicle kilometre), emissions other than CO2 (€0.009 per vehicle kilometre) and CO2 emissions (€0.023 per vehicle kilometre). All these components depend on the local environment, and we use the costs for city environments, where the external cost per vehicle kilometre is assumed to be higher than the national averages.

3.6 Government cost and revenue

The government’s costs and revenues come from the paid charges, changes in fuel tax, and operating and maintenance costs of the charging system. The revenue from the paid charge is only a transfer from the drivers. The fuel tax corresponds to approximately €0.059 per vehicle kilometre, which is slightly less than the external cost.

According to the Swedish Transport Agency, the cost of the Gothenburg extension was €76 million, but only approximately half of that was a direct cost for the Gothenburg system (infrastructure, roadside, project management, testing of the system, information and education). The other half (€35 million) of the total budget was a cost for developing a new national central system for Swedish congestion charges. The central system of the original Stockholm system was developed and managed by IBM up until 2012. When introducing congestion charging in Gothenburg, this had to be replaced by a national central system. A new central system was necessary also to impose taxes on new bridges in some smaller cities, and not only for the Gothenburg system. The operation cost of the Stockholm and the Gothenburg system was in 2013 24 MEUR in total. Since the revenue is similar in the two systems, we assume that the operating and maintenance cost of the charging system was €12 million in 2013. This is substantially lower than operation cost of the Stockholm system the first year and is substantially lower than the operation cost of the London system.6

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5 https://www.transportstyrelsen.se/sv/Press/Kommentarer-och-fortyldiganden/Vad-kostar-det-att-ta-ut-trangselskattinfrastrukturavgift/
6 The latest estimate for London is a yearly (April 2015 - March 2016) operation cost of 90.1 M£ (compared to the revenue of 258.4 M£, 35%) (Transport for London, 2016), which is still a large
3.7 Marginal cost of public funds

According to the Swedish CBA guidelines net public expenditure should be multiplied by the marginal cost of public funds (MCPF). The underlying assumption is that an infrastructure investment requires a marginal increase in the tax revenue (assuming that total public expenditure on other measures remains constant). Sørensen (2010) estimates MCPF to 1.3 in Sweden.

In the case of revenue generated from congestion charges, the analogous argument can be made; if the revenue from congestion charges allows a marginal reduction in tax revenue (assuming that total public expenditure on other measures remains constant) the revenue should be multiplied by the MCPF. However, since the Gothenburg congestion charges were introduced to finance an infrastructure investment package that would not have been realized had the congestion charges not been implemented, this assumption may be contested. The political agreement (West Swedish Agreement, October 28, 2009) explicitly required partial funding from congestion charges of an investment package. For this reason we do not include MCPF in the net social benefit of the congestion charges. On the other hand, the share of the investment cost of the package that is covered by the revenue from the congestion charges should not be multiplied by the MCPF in the CBA of the investment package.

4 CBA RESULTS

Table 2 summarizes the result of the cost-benefit analysis. The figures in the left column are computed under the assumption that the value of time is constant in the population and hence that $\Delta v_{o,d} = \bar{\alpha}(T^0_{o,d} - (1 - q_{o,d})T^{1n}_{o,d} - q_{o,d}T^{1p}_{o,d})$. The figures in the right column are computed according to equation (10), assuming that the value of time is distributed in the population, and that drivers in OD-pairs where there is a choice between charged and uncharged routes are sorted between the routes with respect to their value of time.

Verhoef and Small (2004) and Börjesson and Kristoffersson (2014) show that ignoring heterogeneity in VTT in a system with uncharged routes leads to underestimation of social benefits, by disregarding the efficiency gains due to sorting of the drivers with respect to VTT. This sorting increases the value of the travel time savings by 43%.

Table 2 shows that the Gothenburg congestion charging system is beneficial for society even if not taking into account the benefit of the sorting of drivers between route with respect to their value of time. Table 2, however, does not take the investment cost into account. The investment cost of the system was €76 million. Assuming the yearly social benefit from the right hand column, €20 million, the system will have recovered the investment cost in terms of social benefits in a little less than four years. In financial terms, investment cost is recovered after just over one year, the yearly revenue being €59 million.
Table 2 Cost benefit analysis of the Gothenburg congestion charges

<table>
<thead>
<tr>
<th>Loss/gain M€/year</th>
<th>Constant VTT</th>
<th>VTT distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paid charge</strong></td>
<td>-77</td>
<td>-77</td>
</tr>
<tr>
<td>Travel time saving</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>Travel time variability saving</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Driving cost increase</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Loss for evicted drivers</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td><strong>Consumer surplus</strong></td>
<td>-56</td>
<td>-46</td>
</tr>
<tr>
<td>Traffic safety effects</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Noise reduction</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pollution reduction</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Reduction of CO2 emissions</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>External effects</strong></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Paid charge</td>
<td>77</td>
<td>77</td>
</tr>
<tr>
<td>Fuel tax decrease</td>
<td>-6</td>
<td>-6</td>
</tr>
<tr>
<td>Operating cost</td>
<td>-12</td>
<td>-12</td>
</tr>
<tr>
<td>Government</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td><strong>Net social benefit, excl. investment cost</strong></td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

The relative efficiency of the pricing scheme can be calculated as a ratio of the total net social benefits and the total revenue collected from the congestion charges. In this case, the relative efficiency is 20/77 = 0.26 (the right column in Table 2). This can be compared to the Stockholm system, where the relative efficiency was 65/80 = 0.81 (Eliasson, 2009). Hence, the sum of money that is redistributed in the population compared to the social benefit is substantially larger in the Gothenburg case than in the Stockholm case.

The consumer surplus can be split up on trip purpose according to Figure 2. A majority of the travel time savings accrue to business and freight trips due to their high value of time, even though private car drivers (work trips and other) pay a large part of the revenue.

![Fig. 2 Consumer surplus by trip purpose](image)

The large redistributions of money compared to the social surplus is one argument for carefully considering the redistribution effects, which is the topic of the next section.

## 5 DISTRIBUTION OF THE BENEFITS AND LOSSES

In this section we explore how the costs and benefits are distributed across segments of the population. In Section 5.1 we describe the method of computing the distribution effect with
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respect to income. In Section 5.2 we describe the data that is input to the analysis and in Section 5.3 the result. In section 5.4 we summarize the distributional effect with respect to age, gender and residential area.

5.1 Method

We assume that the costs and benefits of the reform for a given inhabitant depend on i) the travel time reduction per trip and the value of time, ii) the frequency of charged trips, iii) access to company car (implying that the driver does not personally pay the charge upfront). These factors are all functions of income (but depend on other factors too), and costs and benefits and depend therefore on the income level. The frequency of charged trips varies across income groups, not only because high income commuter in general have higher car use, but also because income groups are not are not evenly distributed across residential areas (and the driving patterns depend on geographical location).

First we explore distribution across income groups. In section 5.4 we will also explore the distribution effects with respect to age groups and gender. In section 5.5 we compare explicitly how the costs and benefits differ across residential location, and compare it to voting patterns.

The transport model operates at a zonal level. The zones are 0.1-1 km² in built-up areas. The population of residents in each zone \( o \) is divided into 12 different income classes \( i \). The number of individuals in each income class \( i \) in zone \( o \) is \( n_{oi} \). To compute the cost and benefits for drivers by residential area and income class, we need i)-iii) by residential area and income class. Since only trips originating from the resident zone can be linked to the residents of each zone we restrict the distribution analysis to commuting trips. Other trips do not always start in the zone where the driver resides.

Distribution analyses of the costs and benefits normally focus on the how the costs and benefits, converted to money units, are distributed in the population. However, one could argue that is more relevant to study how the distribution of the welfare (utility) varies across the population. We will describe the differences here. Assume I) that that the marginal utility of time varies in the population, but is independent of income, and II) that the marginal utility of money depends on income but not on any other variable. Admittedly these assumptions need a certain leap of faith, but are at least consistent with the marginal utility for money being the Lagrange multiplier relating to the income constraint and marginal utility for time being the Lagrange multiplier relating to the time constraint (DeSerpa, 1971; Jara-Díaz & Guevara, 2003).

Assume that the average value of time for travellers in income group \( i \) is \( \bar{\alpha}_i \) and let \( \Omega_i \) be the social weight of individuals in income group \( i \). For simplicity we here leave out drivers priced off the road, and the drivers choosing to take a detour to avoid paying the congestion charge. The welfare change for a representative traveller \( j \) in income group \( i \) and OD-pair \((o,d)\), is then

\[
\Delta V_{ij} = \Omega_{ij}(\nu_j(T^0_{o,d} - T^1_{o,d}) + \tau_i \Delta b_{o,d} - \tau_i c_{o,d})
\]  

where \( \nu_j \) is the marginal utility of time for individual \( j \) and \( \tau_i \) is the marginal utility of money for income group \( i \). This can be compared to the change in consumer surplus \( W_{ij} \) for a representative traveller \( j \) in income group \( i \) and OD-pair \((o,d)\),
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\[
\Delta W_{ij} = \left( \frac{v_j}{\tau_i} \left( T_{0,d}^0 - T_{0,d}^1 \right) + \Delta b_{o,d} - c_{o,d} \right)
\]  

Comparing (13) and (14), it is clear that using (14) as a welfare measure is equivalent to setting the social weights inversely proportional to marginal utilities of money, i.e. \( \Omega_{ij} = \frac{1}{\tau_i} \). This is one of Gálvez and Jara-Díaz (1998) main points. Since we assume that the marginal utility of money increases with decreasing income, welfare measure (14) means that we put a higher weight on the time gains of higher income people.

To avoid putting higher weights on high income travellers an often used solution is to apply the same value of time for travellers (Mackie et al, 2001). However, many studies show that income differences explain a limited part of the variation in the values of time in the population (Börjesson & Eliasson, 2012; Fosgerau, 2007; Ramjerdi, Flügel, Samstad, & Kili, 2010), presumably because the marginal utility of time varies in the population.

An argument for still using the Kaldor-Hicks criterion of efficiency (Kaldor 1939) in our CBA (and project evaluation in general) is that the Swedish government, and many other governments, are in fact both willing and able to undertake substantial monetary redistributions. This is disregarded by Gálvez and Jara-Díaz (1998). However, when specifically analysing distribution effects of a specific policy, it makes little sense to put a higher weight on the time gains of high income drivers.

Therefore, when we do the welfare analysis we use the welfare measure:

\[
\Delta W_i = \left( \frac{v_j}{\bar{\tau}} \left( T_{0,d}^0 - T_{0,d}^1 \right) + \frac{\tau_i}{\bar{\tau}} \Delta b_{o,d} - \frac{\tau_i}{\bar{\tau}} c_{o,d} \right)
\]

where \( \bar{\tau} \) the mean marginal utility of money for all income groups. If our assumptions I) and II) above do not hold we might over- or under estimate the distribution effects. For instance if the marginal utility of time increases with income, we will underestimate the benefit of the charges for high income people. Moreover, assuming that all individuals within the income group have the same marginal utility of money underestimate the benefits of sorting (Verhoef and Small 2004; Börjesson and Kristoffersson, 2014).

The variables i)-iii) by income class and zone are derived as follows:

i) Travel time gains

The value of time for income class \( i \) is assumed to be lognormally distributed \( \ln N(\mu_i, \sigma^2) \). This distribution is consistent with our assumptions I) and II) if the marginal utility of time is distributed as \( \ln N(\ln(c), \sigma^2) \), where \( c \) is the median marginal utility of time, independent from income, and \( \tau_i \) is the marginal utility of money for income group \( i \). The VTT for income group \( i \) is then \( \frac{\ln N(\ln(c), \sigma^2)}{\tau_i} = \ln N(\ln(c) - \ln(\tau_i), \sigma^2) \).

Our assumptions imply \( \mu_i = \ln(c/\tau_i) \). The parameters \( \mu_i \) and \( \bar{\tau}/\tau_i \) of the other income classes are derived assuming that the median value of time, \( \bar{\tau} \), equals \( c/\bar{\tau} \). and the income elasticity on \( 1/\tau \) is 0.5 (the income elasticity of the value of time was estimated to 0.5 in the Swedish 2008 value of time study (Börjesson & Eliasson, 2014)). Hence, \( \mu_i = \ln(\bar{\tau}/\tau_i) \). The average VTT differs by zone because the income distribution differs by zone.
ii) Frequency of charged trips

For each zone \( o \) the transport model generates the total number of charged trips \( s^1_o \). The model does not generate the number of charged trips by income class. However, the distribution of charged trips by income class can be derived from the two-wave survey described in Section 5.2, but only on the aggregate level for the urban area and not by zone. To approximate the number of charged trips per inhabitant aged over 16 by zone and income class, let \( \delta_i \) be the number of charged trips per inhabitant in income class \( i \) at the aggregate level for the urban area. Let \( n^1_o \) be the total number of individuals in income class \( i \) in zone \( o \). Then we assume that the share of all trips \( s^1_o \) starting in zone \( o \) that are made by the individuals in income class \( i \) is

\[
r^i_o = \frac{\delta_i n^1_o}{\sum_{i \in I} \delta_i n^1_o}.
\]

The number of trips per individual in income class \( i \) residing in zone \( o \) is then \( r^i_o \sum_{d \in D} s^1_{o,d} / n^1_o \).

iii) Access to company car

From aggregate data we know the average number of company cars per inhabitant by income class. We assume that this distribution is constant across all zones. From this we calculate the share of the drivers with access to a company car in each income class, \( \gamma_i \), who do not pay the congestion charge.

Welfare effect

To compute the social benefit by income group and zone of residence, we compute the share of paying and non-paying drivers by zone and income class, \( q^i_{o,d} \). In the cost-benefit analysis in 3.2, \( k_{o,d} \) is the threshold VTT between paying and non-paying drivers in each OD-pair. Based on the value of time distribution for income class \( i \) and \( k_{o,d} \) for each OD pair we compute the share of paying drivers by income class and OD pair

\[
q^i_{o,d} = \int_{k_{o,d}}^\infty \ln \mathcal{N}(\xi; \mu_i, \sigma^2) \, d\xi
\]

\[
= \Phi \left( \frac{\ln k_{o,d} - \mu_i}{\sigma} \right)
\]

\[
= \Phi \left( \frac{\ln k_{o,d} - \ln \left( \tilde{\alpha} \frac{\bar{T}}{\bar{T}_i} \right)}{\sigma} \right)
\]

\[
= \Phi \left( \frac{\ln \left( k_{o,d} \frac{\bar{T}_i}{\bar{T}} \right) - \ln(\tilde{\alpha})}{\sigma} \right)
\]

\[
= \Phi \left( \frac{\ln k^i_{o,d} - \mu}{\sigma} \right)
\]

\[
= \int_{k^i_{o,d}}^\infty \ln \mathcal{N}(\xi; \mu, \sigma^2) \, d\xi
\]

(17)
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where \( k_{o,d}^i = k_{o,d} \tau_i / \bar{\tau} \). Following the derivation of (9) in Section 3.2 we find that the value of travel time savings for all drivers (paying and non-paying) is

\[
\Delta v^i_{o,d} = \bar{a} T_{o,d}^0 - \left( (\bar{a} - g^i_{o,d}) T_{o,d}^{1n} + g^i_{o,d} T_{o,d}^{1p} \right),
\]

where \( g^i_{o,d} = \int_{k_{o,d}^i}^{\infty} x \ln \mathcal{N}(\xi; \mu, \sigma) \, d\xi. \)

We will perform the distribution analysis applying (18) and (15), to explore the importance of the differences of the marginal utility on money. Note that we still take into account that the marginal utility of time is distributed, and thereby keep the benefit of sorting between routes into account in the analysis.

The aggregate welfare effect for the remaining drivers in income class \( i \) is

\[
\Delta W_i = \sum_{o \in O} r_o^i \sum_{d \in D} s_{o,d}^i \left( \Delta v^i_{o,d} + \tau_i / \bar{\tau} \Delta b^i_{o,d} - \tau_i / \bar{\tau} c^i_{o,d} \right),
\]

where \( \Delta b^i_{o,d} = \beta \left( D_{o,d}^0 - \left( 1 - q^i_{o,d} \right) D_{o,d}^{1n} + q^i_{o,d} D_{o,d}^{1p} \right) \) and \( c^i_{o,d} = q^i_{o,d} C \). Here we do not calculate the number of drivers priced off the road for each income class separately. As shown in Table 2, their loss is relatively small compared to the loss for the remaining drivers.

5.2 Data

The frequency of trips to be charged in different segments of the population is derived from a two wave travel survey conducted in Gothenburg in November 2012 and November 2013 (Börjesson et al., 2016). The surveys were sent to random samples of adult residents in relatively central parts of the Gothenburg region (the municipalities of Göteborg, Mölndal, Partille and Öckerö, and the postal areas Mölnlycke and Landvetter in Härryda municipality), resulting in 1582 (2012) and 1426 (2013) useable responses, with response rates of 40% and 38%, respectively.

The survey included questions on travel behaviour, socio-economic questions and questions relating to congestion charging and parking. The survey included a broad set of questions on various topics to avoid policy bias. The respondents were reminded of the design of the charging system by showing a map and times when the charge applies. The respondents were asked how often they paid the congestion charge (or would pay it in the 2012 wave).

Table 3 reports the frequency of charged trips by income class in the situation without the charges according to the survey. The income classes in the survey do not match the income classes in the transport model. The values in Table 3 were therefore interpolated to the income classes in the model, shown in Table 4.

<table>
<thead>
<tr>
<th>Income €/month</th>
<th>( \delta_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1 500</td>
<td>0.16</td>
</tr>
<tr>
<td>1 501 – 2 500</td>
<td>0.29</td>
</tr>
<tr>
<td>2 501 – 3 500</td>
<td>0.40</td>
</tr>
<tr>
<td>3 501 – 4 500</td>
<td>0.49</td>
</tr>
<tr>
<td>4 501 –</td>
<td>0.56</td>
</tr>
<tr>
<td>Average all individuals in the survey</td>
<td>0.35</td>
</tr>
</tbody>
</table>

The share of the drivers with access to a company car, \( \gamma_i \), is taken from the report (Ynnor, 2014). This distribution corresponds well to the result from the survey in the Gothenburg region. Table 4 summarizes all data needed to compute i) – iii) by income class and zone.
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Table 4 Median VTT ($\tilde{a}_i$), mean VTT ($\bar{a}_i$), paying trips per day ($\delta_i$) and share of the drivers with access to company car ($\gamma_i$) by income class.

<table>
<thead>
<tr>
<th>$i$</th>
<th>Income (k€/year)</th>
<th>$\tilde{a}_i$ (€/h)</th>
<th>$\bar{a}_i$ (€/h)</th>
<th>$\delta_i$</th>
<th>$\gamma_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>1</td>
<td>0.1 – 3.9</td>
<td>1.7</td>
<td>3.6</td>
<td>0.04</td>
<td>55.1%</td>
</tr>
<tr>
<td>2</td>
<td>4 – 7.9</td>
<td>3.0</td>
<td>6.2</td>
<td>0.11</td>
<td>26.0%</td>
</tr>
<tr>
<td>3</td>
<td>8 – 11.9</td>
<td>3.8</td>
<td>8.0</td>
<td>0.17</td>
<td>10.3%</td>
</tr>
<tr>
<td>4</td>
<td>12 – 15.9</td>
<td>4.5</td>
<td>9.5</td>
<td>0.23</td>
<td>7.1%</td>
</tr>
<tr>
<td>5</td>
<td>16 – 19.9</td>
<td>5.1</td>
<td>10.8</td>
<td>0.28</td>
<td>6.1%</td>
</tr>
<tr>
<td>6</td>
<td>20 – 23.9</td>
<td>5.7</td>
<td>11.9</td>
<td>0.33</td>
<td>5.9%</td>
</tr>
<tr>
<td>7</td>
<td>24 – 27.9</td>
<td>6.2</td>
<td>13.0</td>
<td>0.38</td>
<td>8.4%</td>
</tr>
<tr>
<td>8</td>
<td>28 – 39.0</td>
<td>6.6</td>
<td>13.9</td>
<td>0.42</td>
<td>15.1%</td>
</tr>
<tr>
<td>9</td>
<td>32 – 35.9</td>
<td>7.1</td>
<td>14.8</td>
<td>0.46</td>
<td>22.9%</td>
</tr>
<tr>
<td>10</td>
<td>36 – 39.9</td>
<td>7.5</td>
<td>15.7</td>
<td>0.49</td>
<td>33.1%</td>
</tr>
<tr>
<td>11</td>
<td>40.0 –</td>
<td>7.8</td>
<td>16.5</td>
<td>0.53</td>
<td>64.9%</td>
</tr>
</tbody>
</table>

5.3 Income distribution effects

Figure 3 shows the benefit per car commuting trip by income group.

\[
W_i = \frac{\sum_{o \in O} r_o^i \sum_{d \in D} s_{o,d}^1 \left( \Delta v_{o,d}^i + \tau_i / \bar{\tau} \Delta b_{o,d}^i - \tau_i / \bar{\tau} c_{o,d}^i \right)}{\sum_{o \in O} r_o^i \sum_{d \in D} s_{o,d}^1} \tag{20}
\]

Figure 3 shows that drivers in almost all income segments are worse off with the charges; the gains offset the losses only for the highest income segment. In general, the income has a larger impact on the losses than on the gains. The income effect on the loss side is driven by the income effect on the cost sensitivity. The income effect on the gain side is smaller because all drivers experience similar travel times, even though drivers in higher income segments to some extent do fewer detours to avoid the congestion charge.

\[
\text{When computing the value of time for income class } i \text{ applying the elasticity 0.5, we assume the income in each class is the mid-point in the interval.}
\]
To analyse the distribution effects of the congestion charge, it is more relevant to consider the full population and not only the drivers. Such analysis takes into account that high income individuals undertake charged trips more frequently than low income individuals. Figure 4 shows the welfare effect per inhabitant by income group

\[
W_i = \frac{\sum_{o \in O} r^{i}_o \sum_{d \in D} s^{1}_{o,d} (\Delta v^{i}_{o,d} + \frac{\tau_i}{\bar{\tau}} \Delta b^{i}_{o,d} - \frac{\tau_i}{\bar{\tau}} c^{i}_{o,d})}{\sum_{o \in O} n^{i}_o}.
\] (21)

All income groups are on average worse off with the charges, except the highest income group. Except for the highest income classes, the losses increase with income, because individuals with higher incomes undertake charged trips more frequently. For the highest income class, however, the losses are offset by the gains due to the considerably higher access to company cars. The richest third pays three times more than the poorest third. Eliasson and Mattsson (2006) found that in Stockholm the richest third pays four times more than the poorest third. 

Hence, the congestion charge is a regressive tax instrument. Moreover, in Gothenburg the revenue are not spent to improve the local public transport system to benefit local low income groups. It is rather spent on a rail tunnel that will mainly benefit commuters further out in the region as explained in Section 2. As long as a congestion charge is justified from the perspective of economic efficiency and to price externalities, negative distribution effects may be less controversial. But since the congestion charge in Gothenburg is mainly implemented for fiscal reasons, to finance the rail tunnel and other infrastructure projects, the equity concern may be more problematic.
We continue by analysing the gains and losses by gender and age group. According to the survey, men and women undertake on average the same number of charged trips per day. According to the value of time study, the average value of time does not differ between men and women. However, twenty-eight per cent of the men, but only six per cent of the women, have access to a company car (Ynnor, 2014). This means that men and women benefit from the charges to the same extent, but women on average suffer larger losses than men.

According to the survey, the average frequency of charged trips differs by age group. Also the access to company car differs by age group, see Table 5. The value of time study, however, does not reveal any age differences. Taking account of the age effect on the frequency of charged trips and the access to company cars, the distribution of gains and losses are distributed between age groups according to Figure 6. The age group 56-64 years suffers the largest losses, and the group 36-55 benefit the most. The net loss is fairly constant across all groups except for the oldest.

**Table 5** Paying trips per day and share of drivers with access to company car for each age group

<table>
<thead>
<tr>
<th>Age group</th>
<th>𝛿ᵢ</th>
<th>𝛾ᵢ</th>
</tr>
</thead>
<tbody>
<tr>
<td>18–25</td>
<td>0.26</td>
<td>0.05</td>
</tr>
<tr>
<td>26–35</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>36–55</td>
<td>0.45</td>
<td>0.14</td>
</tr>
<tr>
<td>56–65</td>
<td>0.41</td>
<td>0.10</td>
</tr>
<tr>
<td>65–75</td>
<td>0.26</td>
<td>0.04</td>
</tr>
<tr>
<td>over 75</td>
<td>0.12</td>
<td>0.01</td>
</tr>
</tbody>
</table>
The Gothenburg Congestion charges: welfare and distribution effects

Fig. 5 Gains and losses of the charge by age group for all individuals in the Gothenburg Labour Market

5.5 Geographical distribution effects

Finally, we analyse the geographic distribution of gains and losses. We also compare them to the outcome of the referendum held in September 2014, to explore to what extent the outcome of the referendum is driven by self-interest. We make the assumption that the charges do not have any impact on the geographical location of the inhabitants (i.e. that they do not induce spatial sorting).

Figure 7 shows the loss per inhabitant by zone of residence. Residents of the neighbourhood just outside the toll cordon pay the most, because of their high frequency of charged trips. Figure 8 shows that the largest travel time gains are concentrated along the largest arterials, especially along the north-south link, E6, where the travel times reduced the most. Figures 7 and 8 combined show that residents of neighbourhoods north and west of the toll cordon, where the average income is low, suffer the largest net losses. They have low values of time and low access to company cars. The residents of the inner city both gain and lose less than the residents just outside the cordon, because they undertake fewer charged trips.
Fig. 6 Geographical distribution of loss

Fig. 7 Geographical distribution of time gain
The Gothenburg Congestion charges: welfare and distribution effects

Figure 8 shows the referendum results. The referendum was only held in the municipality of Gothenburg. It demonstrates that residents of central Gothenburg are more positive to the charges, whereas residents of further out in the region are more negative. This pattern is consistent with the pattern of losers of the charges in Figure 7; residents further out in the municipality lose more. However, the darkest areas on the map, east and south-west of the charging zone, where the residents are most positive, also lose a lot from the charges. Therefore, no correlation was found between voting pattern and gains, losses or net benefit. As found by Börjesson et al. (2016), the attitudes to congestion charges is not only formed by self-interest, but also by more stable attitudes such as environmental attitudes and general attitudes to taxation.

![Geographical distribution of referendum results](image)

Fig. 8 Geographical distribution of referendum results

The investment cost was from a financial perspective repaid in slightly more than a year and is from a social surplus perspective repaid in less than four years.

6 CONCLUSIONS

Although Gothenburg is a small city with congestion limited to the highway junctions, the congestion charge scheme is socially beneficial, generating a net surplus of €20 million per year. The social benefit of €20 million per year is similar to Milan, but substantially lower
than the social benefit of the Stockholm and London systems. The operation cost of the Gothenburg system is substantially lower than it was in Stockholm, because it could be set up as extensions of the Stockholm system. Still, the sums that are redistributed are substantially larger than the net benefit. The low relative efficiency of the policy stems from the lower congestion levels, implying smaller travel time benefits. Since many small cities have low congestion levels low relative efficiency is likely to be general problems for small cities.

Due to the relatively large sums that are redistributed an analysis of the distribution effects are central. The distribution analysis shows that the congestion charge is regressive, for several reasons. First, even low income individuals are highly car dependent in Gothenburg, due to the relatively low population density and public transport share (26% in the charged OD-pairs). Second, workers in the highest income class have considerably higher access to company cars, and thereby the employer pays the congestion charge on behalf of the employee as a tax-free benefit. The negative distribution effects due to the company car legislation might not be transferable to small cities in other countries. However, the high car dependence for commuting also for low income people, is probably a general problem also for other small cities. As a comparison, Eliasson et al. (2016) show that fuel taxes and purchase taxes on new cars are progressive over most of the income distribution.

Men and women benefit from the charges to the same extent because they make the same number of charged trips. This is not the case in Stockholm, where women commute relatively more by public transport. This difference is likely an effect of higher car dependence, and a less attractive public transport system. However fewer women on average have access to a company car for commuting trips and suffer larger losses than men. The net loss is fairly constant across age groups, except for the oldest (over 75) who drive less.

Except for the highest income class the average consumer surplus is clearly negative. Since most residents of Gothenburg suffer a net loss from the charges, and because of the distribution of the direct effects of the charges are regressive, the spending of the revenue is decisive for the total effect on equity. However, the revenue is spent mainly on a rail tunnel which primarily gives benefits to commuters from surrounding municipalities in the regions. This could be one important reason behind the low public support of the charges.

7 REFERENCES


The Gothenburg Congestion charges: welfare and distribution effects


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