Ex-post evaluation of national transport model Gothenburg congestion charges application

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Abstract
This paper evaluates the forecast effects of the Gothenburg congestion charges implemented in 2013. We find that the predicted traffic reductions and travel time gains were close to the observed in the peak. However, the traffic reduction was under-predicted in off-peak, because the model does not capture all of the various adaptation strategies applied to discretionary trips. The predicted route choice is highly sensitive to the VTT and distance cost implemented in the assignment model. To improve the route choice a continuous VTT distribution estimated from SC data was implemented but had to shifted upwards, adding to the evidence that VTT inferred from SC data might not reveal travellers long-term preferences.
Keywords: Congestion charges, Transport model, Validation, Value of time, Volume delay function, Decision support

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1 INTRODUCTION

Transport model predictions are a corner stone in project evaluation. For infrastructure investments these predictions form the fundament for welfare calculations and for congestion pricing it is crucial for the financial outcome. Still, there are few systematic ex-post evaluations of transport model predictions (see Hartgen (2013), Nicolaisen and Driscoll (2014) and van Wee (2007) for literature reviews on ex-post analysis). One reason for the lack of ex-post evaluations of transport model predictions is that the forecast is often conducted long before the implementation of the policy or project, implying that model inputs are inaccurate. In many cases even the design of the project or policy has changed since the forecast was made. Another reason is lack of data describing the traffic system before and after the implementation of the policy or project.

The Gothenburg congestion charges implemented January 1, 2013, however, provides an excellent opportunity for an ex-post evaluation. Travel times and traffic volumes were monitored 2012 and 2013 (Börjesson and Kristoffersson 2014), and the evaluated transport model scenario represents the transport system and land-use of the year it was implemented.[1] The present paper evaluates the forecasted effect of the Gothenburg congestion charges. The paper also demonstrates the specific problems arising when modelling the effect of congestion pricing in a road network where drivers have many possibilities to avoid paying the charge by changing route.

Detailed ex-post evaluations of transport model predictions, such as the present study, are important for understanding the strengths and limitations of transport models and for identifying needs for model development. We are also interested in similarities and differences regarding the accuracy of the prediction of the Stockholm charges, indicating to what extent the accuracy of model predictions can be generalized and transferred between the cities. There exist a large number of studies predicting the effects of suggested congestion charging schemes (e.g. Eliasson and Mattsson 2006, Fridstrøm et al. 2000, Kickhöfer et al. 2010, Rich and Nielsen 2007 and Santos 2002). By drawing more general conclusions regarding which effects that can be predicted with high accuracy and which effects that are more difficult to model in different types of road networks, other model studies can be interpreted in a more informed way.

Flyvbjerg (2005) finds that forecasts of large rail infrastructure project are significantly overpredicting demand, but that the main reason for this is strategic bias due to fiddling with the forecast assumptions. Pickrell (1989) finds the same for 10 urban transit projects in the United States. Flyvbjerg

[1] The model predictions evaluated in this paper are produced by an updated version of the model, where the land-use and transport network had been updated to the 2013 level. The volume delay functions have been replaced by new recently estimated volume delay functions for all regions in Sweden, increasing the prediction power of travel times.

(2005) finds further that predictions for the road projects he analyse are overestimated slightly. Welde (2011), Welde and Odeck (2011) and Goodwin (1996), however, find that the demand forecasts for (toll-free) road projects tend to be underestimated.

Næss et al. (2006) and Li and Hensher (2010) find that traffic volume on toll roads was generally overestimated (the former analysing European and American projects and the latter Australian). Also Bain (2009 and 2011) finds that forecasts tend to overpredict traffic volumes on toll-roads and suggest that this patter is due to optimism bias regarding revenues. Recent studies by Welde and Odeck (2011) and Welde (2011), using data on both tolled and toll-free roads, find that traffic volumes on tolled roads was fairly accurate, possibly because these forecasts have been scrutinized over the years, but that traffic volumes on toll-free roads were underpredicted. Leape (2006) shows that the effect of the London congestion charges was also fairly accurate, just a slight underprediction of the traffic reduction.

The effects of the Gothenburg charges were predicted by the Swedish national transport model system Sampers (Beser Hugosson and Algers, 2002). Sampers has been in use for 10-15 years and is carefully estimated, applying state-of-practice large scale modelling techniques, but lacking dynamic assignment, departure time choice or activity based modelling techniques. Sampers was also applied to forecast the effects of the Stockholm congestion charges. Eliasson et al. (2013) find that the model predictions were accurate enough to facilitate the design of an efficient system design, but that travel time gains on links outside the toll cordon was underpredicted substantially, due to the inability of the static model to capture dynamic congestion and spillback queues[2]. Consequently the model could not be applied to calculate the social benefit of the system.

The challenges facing the modellers forecasting the effect of the Gothenburg charges are slightly different from those that faced the modellers forecasting the effects of the Stockholm charge. On one hand dynamic congestion and spillback queues is a much smaller problem in Gothenburg. The topology of the transport network in Gothenburg, on the other hand, implies a large number of OD-relations where the driver has the choice between a faster charged route and an uncharged but slower route. In this respect, Gothenburg is more representative for other cities than Stockholm, where water acts like natural barriers effectively preventing most unwanted route choice effects.

Due to the many possible route choices, the predicted route choice proved to be highly sensitive to the value of travel time (VTT) assumed in traffic assignment. Moreover, a multi-passage rule was applied in Gothenburg (allowing multiple passages within an hour for the same fee), introducing a non-additive component into the route choice utility function. The Gothenburg toll system hence resembles a zone-based congestion charging system such as the one in

[2] And this problem could thus not be avoided by adjusting parameters in the volume delay functions (Engelson and van Amelsfort 2011).

London. We demonstrate how this problem was solved, requiring a continuous VTT distribution. Assumption of the VTT distribution in route choice has received surprisingly little attention in the literature. A likely reason is that very few congestion pricing systems inducing route choice effects have been designed and evaluated in the world. Evaluation of the predicted route choice in Gothenburg is therefore of general interest for the modelling of route choice effects in response to congestion charging in many cities.

We find high accuracy of the predicted reduction of traffic volume across the cordon in the peak, 11% compared to the observed 12%. The reduction in the off-peak, however, was under-predicted, as it was in the Stockholm case. The lower accuracy of the off-peak predictions seems to be driven by the different and possibly more diversified adaptation strategies applied to discretionary trips, whereas virtually all commuters priced off the road switched to public transport. Due to the lower and more local congestion and the lack of spill-back queues and blocking of upstream intersections in Gothenburg the travel times were predicted with high accuracy. The average travel time gains on selected links in the model were 11.1% compared to the observed 9.4%, implying high accuracy of a modelled-based cost-benefit calculation of the system (in contrast to the Stockholm case).

The paper is organized as follows. Section 2 describes the charging system and Section 3 the transport model. Section 4 describes the modifications that were done to the transport model to be able to predict effects of the congestion charge and the results are shown in section 5. Section 6 provides the conclusions of this study.

2 -THE GOTHENBURG CONGESTION CHARGES

Gothenburg (Göteborg in Swedish) is the second largest city in Sweden with half a million inhabitants within the city borders and nearly a million in the metropolitan area. The city is traditionally a harbour and manufacturing city dominated by blue collar jobs, the car manufacturing industry to name one of the dominant sectors. These work places are mainly located north of the Göta river, while the central business district is located south of it. The region is further relatively sparely populated and its planning does not support an efficient public transport system, implying a considerably lower share of public transport than Stockholm. For commuting trips in the relations where the charges apply, the public transport market share was 26% in Gothenburg in 2012, while in Stockholm the corresponding market share is 77% (Börjesson and Kristoffersson 2014).

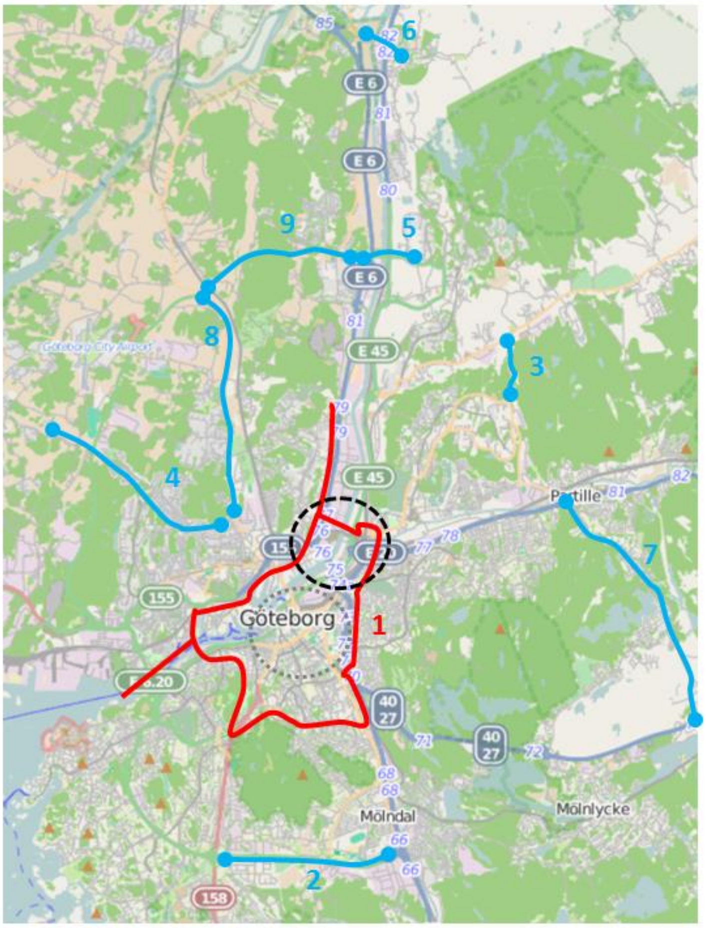
Gothenburg has begun its shift towards a more high-tech and service oriented economy. The population was relatively stable during the second half of the 20th century, but has in the beginning of the 21st century started to increase rapidly, prompting a denser and more transit oriented society.

A cordon-based congestion charging scheme was introduced in Gothenburg in January 2013. The toll is time-of-the-day dependent, ranging from 0.8 euros to 1.8 euros during weekdays 6.00 – 18:30, while other time periods are free of charge. The maximum daily charge is 6 euros[3]. Vehicles are charged when passing the cordon in either direction using automatic number plate recognition.

Congestion relief was not the only, not even the main, objective of the charging system. The main objective was to raise yearly revenue of €100 million, co-financing a large infrastructure package, mainly in public transport. A third objective was improved local environment.

The topology of Stockholm is ideal for congestion charges. The bottlenecks are located on the arterials leading into the city centre, which is surrounded by water acting as natural barrier, preventing rat-running. Gothenburg, however, has fewer natural barriers and the bottlenecks are mainly located on the highway hub northeast of the city centre, implying more rerouting in response to charges and more than twice as many checkpoints as the Stockholm system (38 compared to 18). The adopted design consists of a ring cordon with two antlers, see Figure 1.

[3] Here and in the rest of this paper we use the conversion rate 10SEK=€1.



1. Charging Cordon
2. Söderleden
3. Bergsjövägen
4. Björlandavägen
5. Angeredsbron
6. Jordfallsbron
7. Landvettervägen
8. Tuvevägen
9. Norrleden

Time (weekdays)	Charge
06:00–06:29	8 kr
06:30–06:59	13 kr
07:00–07:59	18 kr
08:00–08:29	13 kr
08:30–14:59	8 kr
15:00–15:29	13 kr
15:30–16:59	18 kr
17:00–17:59	13 kr
18:00–18:29	8 kr
18:30–05:59	0 kr

Fig. 1 The congestion charging scheme of Gothenburg. The red line depicts the ring and the antlers while the blue lines show alternative routes.

Since many workplaces are located outside the city centre, work trips may easily pass two or more checkpoints. To avoid penalizing these drivers more than others, a multi-passage rule was implemented. The rule states that if passing the cordon more than once within 60 minutes, only the highest charge has to be paid. Hence, the Gothenburg congestion charges are link-based, but not additive, posing an extra difficulty in modelling the route choice (see section X).

There were changes in the public transport network and lane priority introduced two weeks prior the introduction of the congestion charges. We cannot distinguish the effect of these measures from the impact of the congestion charges. But evidence from Stockholm, where a substantial improvement in the public transport system was implemented six months prior to the congestion charges, suggest that improvement in the public transport system have a negligible impact on the road traffic compared to the effect of congestion charges (Kottenhoff and Brundell-Freij 2009).

Travel time were observed for the arterial routes (depicted in Figure 2), relevant bypasses and for selected links inside the toll cordon in the morning peak (07:00 – 08:00). and averaged over all weekdays within five weeks in September and October for 2012 and 2013. Traffic counts were available for October and April for selected links and for December for the rest of the toll stations. A travel survey was undertaken in March – April 2012 and March –

April 2013 with 3,000 respondents, which provided information on mode choice effects (City of Gothenburg 2013).

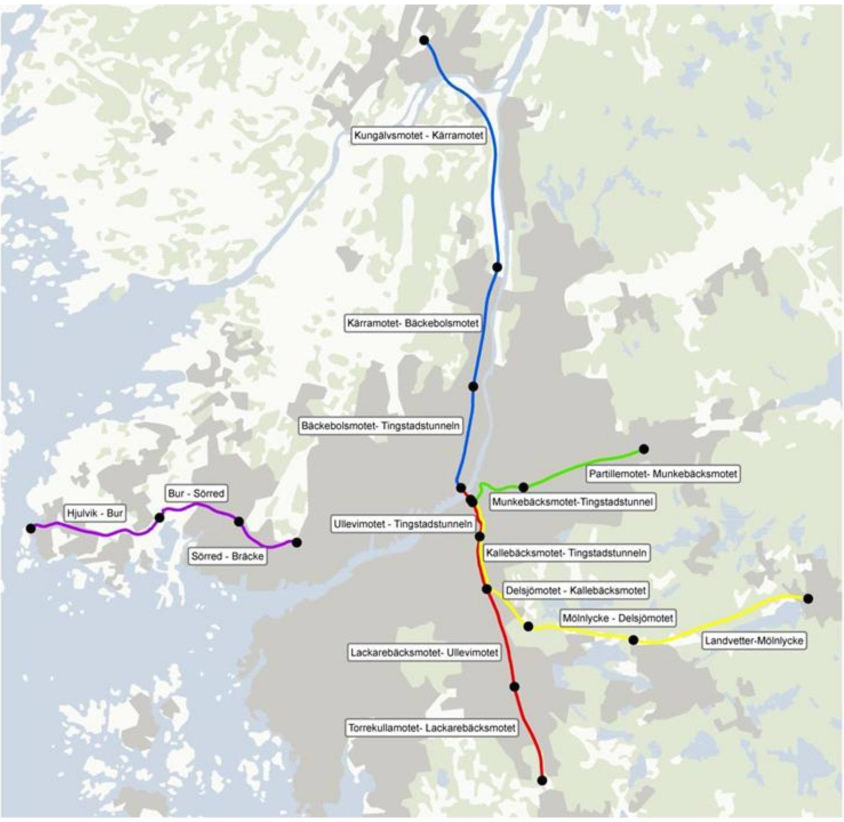


Fig. 2 Measured travel time sections for arterials

3 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 car, 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 travel times are assumed to be independent of the transport volumes.

OD-matrices for freight and professional traffic are generated by an external model and kept constant in the forecast. The route choice is still modelled in the assignment model, implying that this traffic affects the congestion level facing the private car traffic.

The transport model is static and departure time choice is not modelled. Instead the mode specific OD-matrixes produced by the demand models is split into three time periods (morning peak, afternoon peak and off-peak) according to fixed factors specific for each trip purpose. The OD-matrixes for each time period are then assigned to the network. The congestion charge must therefore be approximated by a constant charge within each time period, although it varies in reality. The changing level is approximated by a weighted average of the real congestion charge within the given time period. The weights are equal to the observed traffic volume by 15 minute interval. The approximation errors are highest for the off-peak period, including both midday where the charge ranges from 0.8 to 1.3 euros and night time which is free of charge.

Chain trips (especially those starting in one period and ending in another) are not likely to be accurately predicted and it was discovered that the number of drivers affected by the multi-passage rule was higher in reality (45%) than in the model (30%). Therefore the congestion charges were adjusted downwards to correct for the incomplete modelling of the multi-passage rule.

4 MODELING THE ROUTE CHOICE EFFECTS

The static and deterministic assignment model EMME/3 distributes drivers according to Wardrop user equilibrium. Path disutility is assumed to be a linear function of travel time (T), travel distance (D) and congestion charge (C). If there are no charges levied in a network, route choices are usually quite insensitive to the relative weights of these variables, due to high correlation between travel time and distance. When congestion charges are introduced, however, a travel cost, uncorrelated with travel time or distance, enters the path disutility. In this situation the predicted route choice becomes more sensitive to the relative weights.

There is not much evidence in earlier literature regarding the relative weights of travel time, travel distance and congestion charge in route choice models. Evidence from Stockholm provides some but not much evidence since there are only few OD pairs where route choices are influenced by these weights. In the process of designing and predicting the effects of the Gothenburg system, a study was undertaken to assign values to the parameters of T, D and C in the path disutility function. This work is described in 4.1. Section 4.2 describes the implementation of the multi-passage rule, demanding a continuous VTT distribution.

4.1 Weighs on travel time versus distance

In the situation without charges we assume the path disutility

$$U = \alpha T + \beta D, \tag{4.1}$$

where α and β is the marginal distutility of time and distance, respectively. The absolute values of α and β can be arbitrarily chosen and do not influence the choice of route, only their relative weight α/β.

In the initial situation without charges, the model-computed traffic volumes matched the observed traffic on the links across the on the cordon and on the surrounding highways fairly well when the ratio α/β was taken to be 100 km/h. This value was therefore assigned to α/β in all the future analyses. We assume that α and β are constant across the population.

In the situation with charges we assume the path disutility

$$U = \alpha T + \beta D + \gamma C, \tag{4.2}$$

where α/γ is the value of travel time (VTT) and β/γ is the distance cost. We assume that γ is distributed in the population implying that α/γ and β/γ are distributions as well.

A VTT distribution was estimated based on the Stated Choice (SC) data from the national VTT study, for commuters in Stockholm and Gothenburg only.[4] The hypothesis that this distribution is lognormal could not be rejected (using the test developed by Bierlaire and Fosgerau (2007)). The mean of this distribution is 11.3 €/h. However, since the distribution is highly skewed, with a few drivers having very high VTT, half of the drivers have a VTT below 5.0 €/h.

Assuming the median VTT 5.0 €/h and a ratio α/β of 100 km/h implies the marginal distance cost, β/γ, 0.05 €/km. In reality the marginal distance cost varies substantially between vehicles (depending on factors such as age and brand, etc.), and it is further uncertain what distance cost the drivers perceive and take into account when choosing route. However, 0.05 €/km barely covers the fuel cost for most vehicles, and was considered unreasonably low. Moreover, since a large share of drivers was assigned an ever lower VTT, most drivers in affected OD pairs were forecast to take a detour to avoid paying the charge. This was also considered unlikely, partially based on the experiences from Stockholm.

A remedy to both problems was to stretch the lognormal VTT distribution to the right (by translating the corresponding normal distribution to the right). The size of this stretch was guided by a route choice SC survey conducted in the spring of 2010. This survey was conducted from a random sample of 1,000 inhabitants of the municipality of Gothenburg aged 18-75 in 2010. The respondents were presented binary choices of routes for 13 well-known origin destination pairs (see Figure 3 for an example). No information regarding travel time or distance was presented. In the first five binary choices no congestion charge applied. In the following eight binary choices a congestion charge was levied one of the routes.

[4] Drivers residing in a city have significantly higher VTT than others.

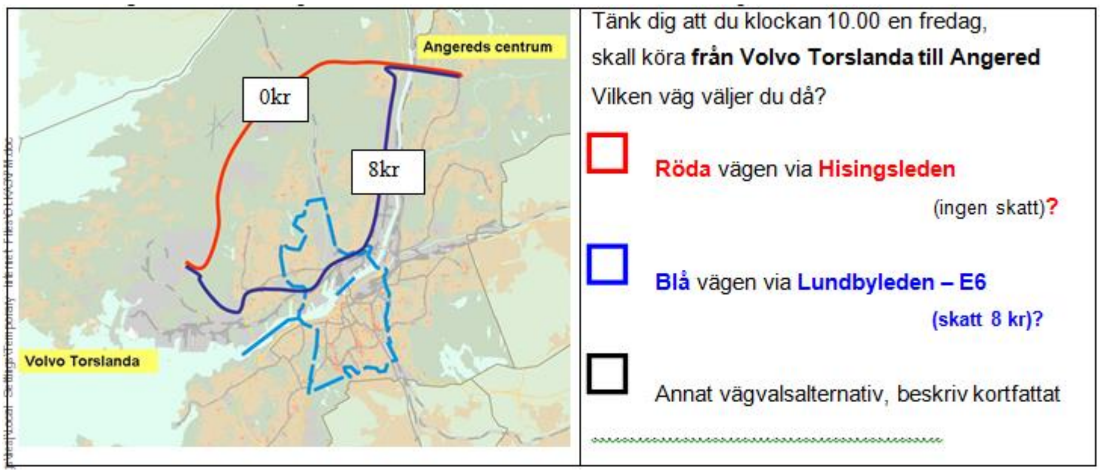


Fig. 3 Sample binary choice from the SC survey

The resulting choices from the survey were combined with data on travel time and distance for the routes to estimate VTT, α/γ, by applying a binary logit model with utility functions defined by (4.2) assigned to the two alternatives, while constraining the ratio α/β to 100 km/h. The resulting VTT was 10.8 €/h, which is close to the mean VTT estimated from the national VTT study. A ratio α/γ of 10.8 €/h and a ratio α/β of 100 km/h implies the distance cost β/γ of 0.11 €/km. This is still at the lower end of the distribution of driving cost including wear and tear but larger than the fuel cost for most cars.

The rather low distance cost might be explained by another finding in the route choice SC survey: The respondents tended to prefer the larger arterials to streets, even in cases when the arterial route has longer travel time and travel distance, and even is charged. This is not captured in the utility function 4.2, which may explain why the value of β/γ that we derive is lower than the actual distance cost for most vehicles.

4.2 Modelling the multi-passage rule

In assignment the path disutility (such as the one defined by 4.1) of a route is normally the sum of the path disutility of all links within the route. This is, however, not the case in the Gothenburg network when the multi-passage rule applies. Then a driver only has to pay one charge even if he or she uses more than one changed link.

To implement the multi-passage rule, a hierarchical route choice algorithm was applied in the assignment. The idea is to split the drivers in to two classes, paying and non-paying drivers. The choice set of alternative routes for the paying drivers is calculated under the assumption that the driver has access to all links in the network. The choice set of alternative routes for the non-paying drivers is calculated under the assumption that the driver only has access to the links that are uncharged.

The assignment is run iteratively in three steps. In the first step the route choice and resulting travel time and travel cost, for paying drivers and the non-paying drivers respectively, is calculated according to Wardrop user equilibrium, i.e. under the assumption that the drivers minimize the path disutility defined by 4.1. The resulting travel time, travel distance and paid charge for the paying drivers are denoted D_P, T_P and C. For non-paying drivers the resulting travel time and travel cost are denoted D_N and T_N. T and D differ between paying and non-paying drivers because the latter have access to uncharged links only. Non-paying drivers have equal or a higher path utility 4.1 than paying drivers.

In the second step the cumulative VTT distribution, Φ, calculated as described above is assigned to the population of drivers in each OD pair. Based on Φ, the drivers are split in two groups, paying and non-paying drivers. The share of drivers in the paying group equals 1- $\Phi(r)$, which is determined from the trade-off value r, defined as

$$r = \frac{C}{\left(T_N + \frac{\beta}{\alpha} D_N\right) - \left(T_P + \frac{\beta}{\alpha} D_P\right)}. \qquad (4.4)$$

The share of drivers in the non-paying groups equals $\Phi(r)$.

In the third step the drivers in the paying and in the non-paying group are assigned to the network simultaneously, assuming the path utility (4.1). And the procedure is repeated from the first step until convergence is reached.

It is essential to apply a continuous VTT distribution in the assignment, to avoid unrealistic thresholds effect on the share of drivers assigned to the paying and non-paying group.

The model predicts that approximately 30% of the traffic is free of charge due to the multi-passage rule, whereas it was on average 45% in 2013. This is higher than the model prediction because the route choice algorithm does not take into account that the round-trip with total duration less than one hour the return trip is free of charge. To account for this in the model that we analyse in the present paper, the charge assumed in the model is adjusted so that it matches the average charge per passage in 2013.

5 RESULTS

The model results were compared with traffic counts, observed travel time and travel survey results on modal split described in Section 2.

5.1 Traffic flow

Table 1 compares the observed and the predicted effect on the traffic volume across the cordon. For the morning and afternoon peak the model predictions are very close to the observed, while the predicted off-peak effect is slightly underestimated (predicted 7% compared to the measured 10%). This indicates that the effect of congestion charges on commuting trips is more accurately modelled than the effect on other trips.

Total traffic flow across the toll cordon was overestimated by 5% in the situation without charges and 7% in the situation with. On main arterials, the discrepancy between prediction and outcome is even larger (see Figure 4). This correlates with an underestimation of travel times on these links (see section 5.2). The discrepancy between predicted and observed traffic flow is larger in the morning and afternoon peak periods when there is congestion in the network and the bulk of trips are commuting trips. In the off-peak free flow speed prevails.

Table 1 Traffic flow across the toll cordon before and after introduction of congestion charges

	Before		After		Change	
	Observed	Model	Observed	Model	Observed	Model
Morning	62067	69112	54557	61 728	-12%	-11%
Afternoon	67594	74000	59819	65 745	-12%	-11%
Off-peak	53548	54790	48407	50 786	-10%	-7%
Day	794801	834119	712821	762 807	-10%	-9%

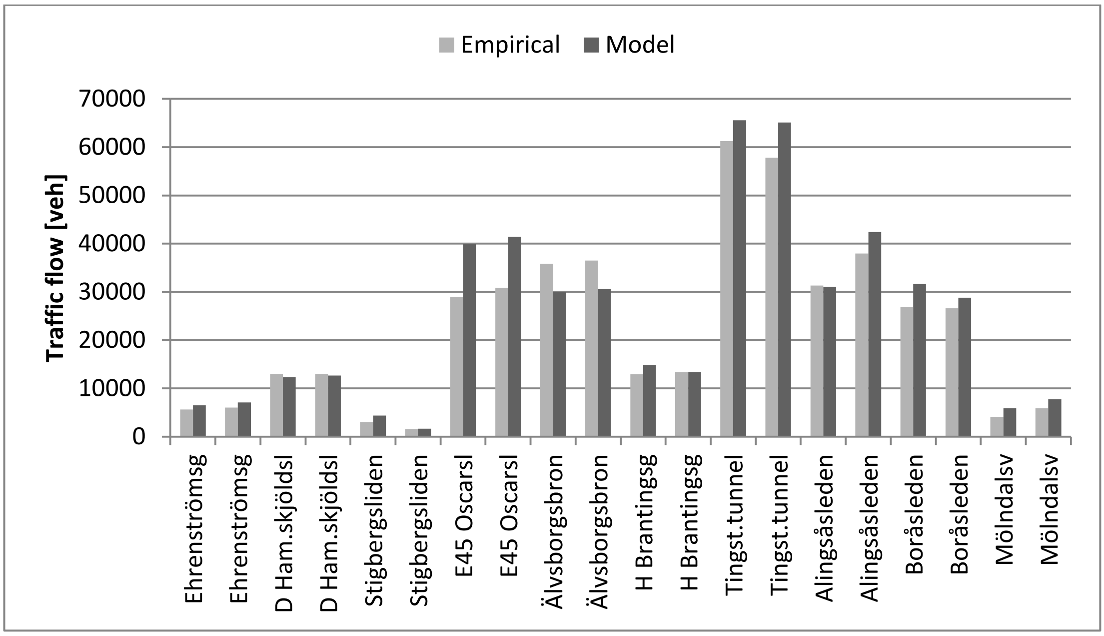


Fig. 4 Comparison between measured and modelled traffic flow for whole day on main arterials across the toll cordon 2012

On large arterials across the cordon, traffic flow decrease was overestimated. However, as showed earlier, the total decrease prediction is relatively accurate. This implies that traffic flow decrease was considerably underestimated on the local streets passing the cordon. The VDFs are very sensitive to the coding of junctions and will need thorough manual coding to work properly. Overestimation of travel time gains on the local streets passing the cordon would explain the underestimation of traffic flow decrease across the cordon. This in turn might explain why traffic flow decrease was overestimated on the large arterials.

5.2 Travel time

Figure 5 and Figure 6 compare predicted and observed travel times in the situations with and without the charges. The travel time was underpredicted by 33% on the northern inner arterial (Bäckebol – Tingstad) and overpredicted by 33% on the inner arterial (Munkebäck – Tingstad). However, the travel time *change* between before and after the introduction of congestion charges was generally neither underestimated nor overestimated (see Figure 4 and Figure 5).

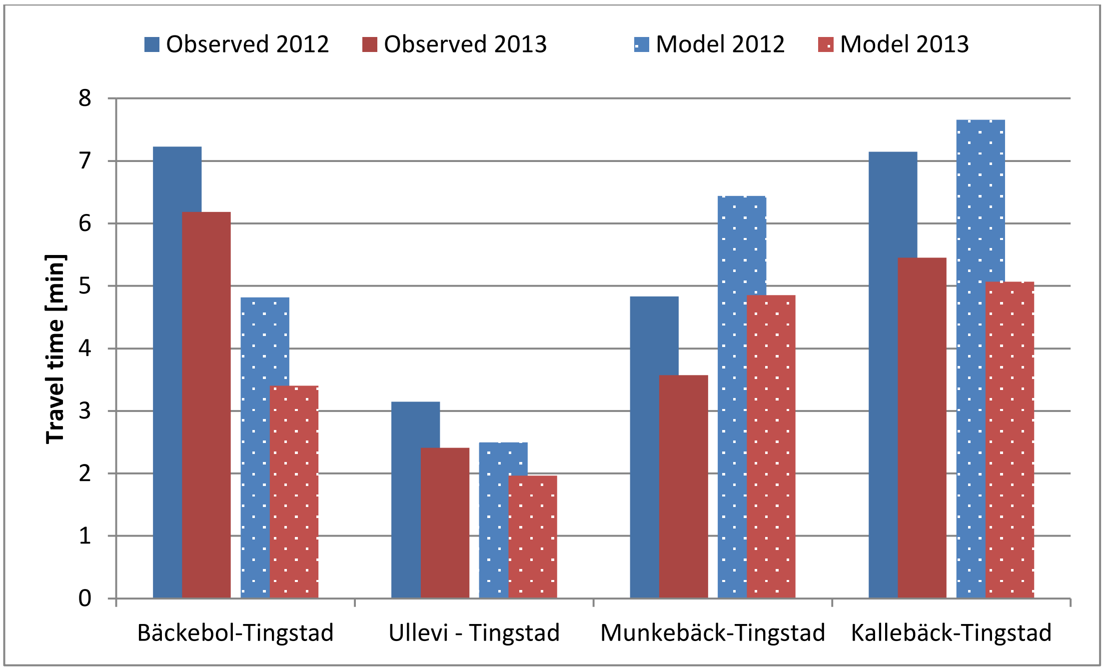


Fig. 5 Comparison between measured and modelled travel time on inner arterials during morning peak

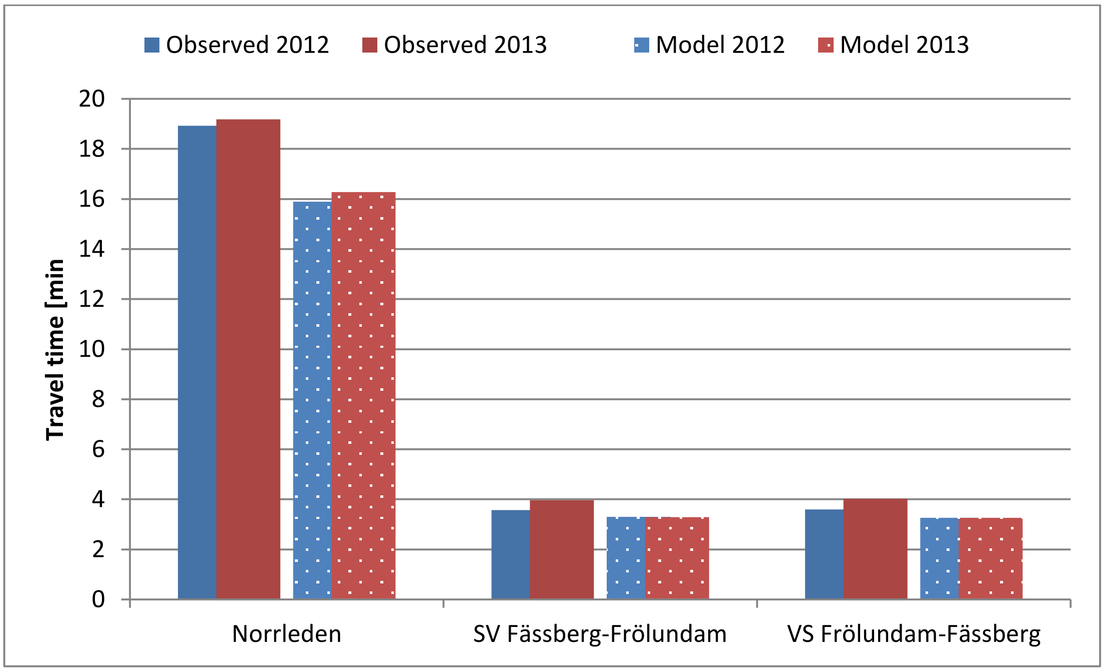


Fig. 6 Comparison between measured and modelled travel time on bypasses during morning peak

The deviation in travel time that occurs on some links indicates that the network needs to be adjusted to better represent reality and presumably that the model needs to be calibrated.

5.3 Modal split

The modelled change in total number of car trips and public transport trips can be compared with panel survey data projected on the entire population. The comparison can provide insights on mode choice accuracy in the model. Figure 7 illustrates how the effect on work trips is more accurately predicted than the effect on other trips by comparing the total number of trips generated per mode in the model with results from the travel survey.

The public transport results from the travel survey should be interpreted with precaution as changes in public transport supply (the first survey was undertaken already in March – April 2012) and weather conditions are likely to have affected public transport ridership during the time period. These are most likely the reasons why ridership increased more than car travel decreased in the survey data. The sales of monthly public transport cards increased by 15 000 from 2012 to 2013, but part of this can be explained by long-term trends in the region. According to the panel survey, the increase was around 12 000. If this is correct, it means that virtually the whole decrease in car travel to work switched to public transport. This is not captured by the model, which predicted that the total number of motorized work trips would decrease. However, the model is supposed to capture long term effects on travel demand which might not have been visible only one year after implementation.

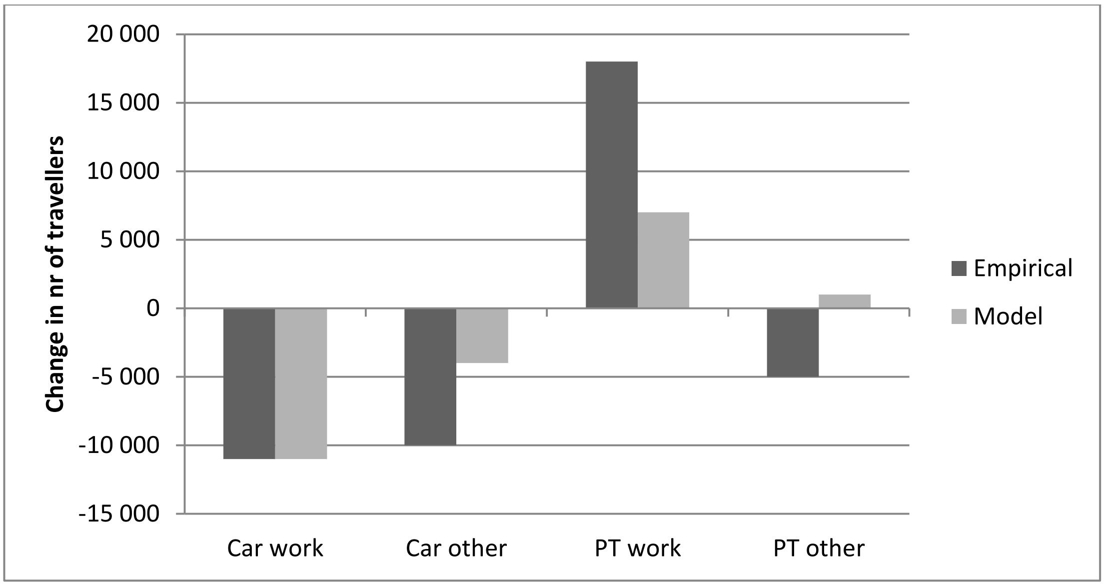


Fig. 7 Change in number of travellers between 2012 and 2013

5.4 Revenue

The multi-passage rule makes revenue predictions difficult. The average charge per passage that was adjusted in the model to correct for the incomplete modelling of the multi-passage rule led to a more realistic level of behaviour change (i.e., exaggeration of traffic flow decrease in the model was addressed) that was only possible to accomplish ex-post. This adjustment led to a realistic prediction of the revenue, when accounting for the error in total flows.

6 CONCLUSIONS

The aim of this study was to evaluate to what extent a state-of-practice transport model with static network assignment is able to accurately predict the effects of introducing congestion charging in Gothenburg, which would allow for using it in cost benefit analysis of the congestion charges. The effects on traffic flow and travel time were predicted with high accuracy in the peak. The

Stockholm case showed that in highly congested road networks a dynamic simulation model might be crucial for capturing the full benefit of congestion charges (Berglund et al. 2014). The result from this study however shows that in contrast to the findings of Engelson and van Amelsfort (2011), it is possible to capture the full congestion effects with a static assignment model if queue spillback is not a large problem.

A continuous VTT distribution was estimated from SC data from the Swedish value of time study (Börjesson et al. 2012). According to SC data, a substantial share of drivers has values of time below 1 €/h. The VTT distribution was, however, shifted to the right since this gave rise to large route choice effects inconsistent with results from Stockholm. Given the shifted distribution we find that the route choice in general was predicted with fairly high accuracy, indicating that SC data produced a VTT distribution cannot be applied in route choice modelling. This adds to the body of evidence showing that VTT inferred from SC data does not reveal travellers' long-term preferences (De Borger and Fosgerau 2008).

How drivers truly evaluate routes is not self-evident. There are strong indications that large arterials attract drivers even when they are neither the fastest nor the cheapest route. These particular route choices are impossible to model with the currently available variables. The high VTT and fixed ratio between VTT and distance cost applied in this study might then only serve as a proxy for some other underlying factors influencing the choice.

Using a continuous VTT distribution and hierarchical route choice was demonstrated as a successful method of modelling the multi-passage rule implemented in Gothenburg congestion charges and was shown to give realistic predictions of route choice effects. This method can be applied to other comparable congestion charging systems as well, which would improve realism in the distribution of choices, especially when there are similar discount structures (i.e., zone-based charges or similar). However, not all possible pricing systems can be modelled with this method, as the complexity of this approach explodes with the number of toll structures (e.g., rings or barriers) if the charge depends on the number of toll stations passed.

The difficulties in predicting off-peak traffic effects remain and is likely to remain as long as the overall model structure remains the same (i.e., with course time of the day representation and insufficient modelling of service traffic, shopping trips and trip chains). In the Gothenburg case, they result in an underestimation of traffic flow decrease during off-peak hours.

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