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Assessing the welfare effects of congestion charges in a real world setting

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ABSTRACT

The standard textbook analysis shows that drivers as a group lose from congestion charges. However, it omits taste heterogeneity, shorter travel times far out in the larger network arising from less blocking back of upstream links and the possibility for drivers to reschedule. Taking account of these factors, using a dynamic scheduling model with heterogeneous users we find that all three add significantly to the benefit of the Stockholm congestion charges and that drivers as a group benefit from these charges even without recycling of revenues. This paper also provides an update on the consumer benefits of the Stockholm charges.

1. Introduction

It is generally known that congestion charging can be an effective measure to combat pollution and congestion in urban areas, but there is still low political and public acceptability in many places. One possible reason for low acceptability is the notion that drivers are worse off if not compensated by the revenues. In fact, the standard textbook analysis of congestion charging (Walters, 1961), using a static model of one origin–destination pair connected by one link and homogeneous users, shows that drivers are worse off with congestion charges if not compensated by return of revenues. This result is confirmed by an analysis of the Stockholm congestion charging scheme using the static state-of-the-art national traffic model Sampers (Engelson and van Amelsfort, 2011).

Both Sampers and the standard textbook analysis disregard three important factors increasing the benefits of congestion charges: network effects, the possibility for drivers to adapt by switching departure time and heterogeneity in the value of travel time (VTT).[1] In this paper network effects refer to possible benefits accruing to drivers not paying the charge (without recycling of money). First, network effects of this type are disregarded in the standard textbook analysis and greatly underestimated in static network assignment models that do not model blocking back of upstream links as queues build up.[2] Second, in a one-link dynamic bottleneck setting with homogeneous users, Arnott et al. (1994) show that an optimal time-varying

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[1] Sampers has one single VTT for each trip purpose and travel mode. For drivers the value of time is 6.7 €/h for work trips and 4.4 €/h for other trips.
[2] Network effects will in general increase the benefit of charging if the uncharged links are operating in series with the charged links, which is what we consider in this paper. If, however, uncharged links operate in parallel with the charged links this is not necessarily true.

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congestion charge is welfare-neutral for drivers if not compensated by return of revenues, since the reduction in queuing costs exactly compensates the charge. Third, ignoring heterogeneity in VTT in a system with a free parallel road leads to great underestimation of benefits because efficiency gains due to separation of traffic are ignored (Verhoef and Small, 2004).

It is well known that the above discussed effects are omitted in the textbook analysis. No previous research, however, has shown how important these factors are in a real-word setting. The purpose of this paper is therefore to estimate to what extent the three factors add to the social benefit of the Stockholm congestion charging scheme, and to a slightly modified scheme that will eventually be introduced, using the Silvester model, which links a dynamic network assignment model with a mode and departure time choice model assuming heterogeneous users (Börjesson, 2008; Kristoffersson and Engelson, 2009). We find that each factor adds significantly to the benefit of the charging scheme. In fact, the Silvester analysis indicates that drivers as a group benefit directly from the congestion charging scheme, without compensation. Direct benefits for many drivers could be one of several contributing factors to the high and even increasing public support[3] for the congestion charges in Stockholm, which is one of the most interesting and encouraging results of introducing them (Börjesson et al., 2011). Indeed, a majority voted in favour of the charges in the referendum held after the seven month trial.

The Silvester model is estimated for Stockholm and calibrated using actual traffic flows before and after the introduction of congestion charges, ensuring a large degree of behavioural realism. This paper, therefore, also provides an update on the benefits of the Stockholm congestion charges.

There is a large literature studying welfare effects of congestion charges. Most of it is theoretical (Verhoef and Small, 2004; Arnott et al., 1994; Glazer and Niskanen, 2000; Evans, 1992). There are also a few studies on real-world congestion charging schemes, most of them based either on observed travel times or on travel times from static assignment models. Eliasson (2009) provides an a posteriori cost-benefit analysis of the Stockholm congestion charging trial, based on observed travel times. Eliasson's study results in a net benefit of about 80 M€/year and as much as 40% of the time gains arise on links outside the cordon. Santos and Shaffer (2004) present and discuss a cost benefit analysis of the London congestion charging scheme undertaken by Transport for London (TfL), which is also based on observed travel data. Prud'homme and Bocarejo (2005) have undertaken another cost-benefit analysis of the London congestion charging scheme based on observed data. The results of the two analyses for London are very different: TfL finds a net benefit of the charging system of about 70 M€/year (similar to the result for Stockholm given above), whereas Prud'homme and Bocarejo find a net *loss* of about the same size. The main difference in the two studies lies, according to Mackie (2005) and Raux (2005), in the calculated travel time savings and the VTT. Prud'homme and Bocarejo (2005) do not consider travel time savings outside of the charging zone and apply a lower VTT.

Three independent cost benefit analyses have been made of a proposed marginal social cost pricing scheme in the Oslo-Akershus metropolitan region, which has a population of about one million. Grue et al. (1997) find a social benefit of 49 €/capita/year.[4] for the Oslo-Akershus area. The benefit is somewhat higher, 75 €/capita/year, in Fridström et al. (2000) The higher benefit in Fridström et al. (2000) is due, according to Vold et al. (2001), to the fact that the transport models differ and because the cost-benefit analysis is somewhat simpler in Grue et al. (1997). The difference in the transport models is not in the assignment; both use the static Emme/2 model. Rather, the two models differ on the demand side, where the model used in Fridström et al. (2000) includes trip frequency, destination and mode choice, whereas the model used in Grue et al. (1997) includes on the demand side route and departure time choice. Vold (2006) estimates the welfare gain of a link-based charging scheme (system optimum) in the Greater Oslo area to €295 per capita, using the transport and land use model RETRO. This is a much higher benefit than is found in the other two studies although this model uses static assignment, which could be due to the fact that the system is optimized on a link basis.

Rich and Nielsen (2007) provide social benefit calculations of four proposed charging schemes in Copenhagen using advanced route choice models but not dynamic assignment. Maruyama and Sumalee (2007) compare social benefit of different charging schemes in Utsunomiya in Japan using volume-delay functions to calculate link travel times, i.e. static assignment. The conclusion in Maruyama and Sumalee (2007) is that area-based schemes are in general socially more beneficial, but also more inequitable, than cordon-based schemes. Kickhöfer et al. (2010) provide social benefit calculations of several proposed distance-based charging schemes in Zürich using the activity-based model Matsim.

There are also a number of more advanced model studies. METROPOLIS has been implemented for Greater Paris and the simulated period is the extended morning peak (05:30–11:30). METROPOLIS integrates departure time and route choice, which has the advantage that the origin–destination matrix does not have to be divided into time slices (de Palma and Marchal, 2002). De Palma et al. (2005) analyse different road pricing schemes in a stylized urban road network using METROPOLIS. The yearly welfare gain is in the range $47.22–204.84, depending on whether the charge is flat or time-dependent (the latter generates greater benefits), and depending on whether the toll is link-based (system optimum), cordon-based or area-based. The scheduling benefits represent about one quarter of the total benefit. Engelson et al. (2012) compare METROPOLIS and SILVESTER, finding that the more appropriate integration of scheduling and routing decisions in the former model is an advantage over the latter. However, Silvester has a more advanced demand model and a more detailed supply model (spillback and intersection interactions).

[3] In Stockholm County, the public support has gradually risen from less than 30% in favour of the charges before the six-month trial in 2006 to more than 50% at the end of the trial, and to almost 70% at the end of 2007.

[4] 380 NOK converted to € with the conversion rate 1 NOK = €0.13.