Congestion pricing

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The fundamental reason for the existence of cities is that they enable high accessibility. High accessibility is associated both with economic gains such as higher wages and productivity, and opportunities to satisfy specialized interests and lifestyles. The history of human civilization is a history of urbanization. Scientific and cultural progress rest on two cornerstones: one is the written language, enabling us to communicate innovations and experiences over distance and time; the other is cities, which have always been our engines of innovations and discovery. Since the demand for and the rewards of high accessibility have accelerated over the last two centuries, this has fuelled urbanization at an ever higher pace.

But when firms and individuals all strive to be close to each other, congestion is inevitable. Congestion is hence a fundamental characteristic of cities: it is not due to failures of transport planners, or something that can be eliminated by improved urban planning or transport systems with higher capacity. While both of them may help, they cannot eliminate the fact that urban space is an inevitable constraint. The fundamental tension of cities is that the better accessibility they provide, the more people and firms they will attract, and the higher will the demand for transportation become – but this increases congestion, which causes accessibility to deteriorate. Since most negative effects of transportation – congestion, crowding, emissions, noise – are external, transport consumption will be higher than what would be the efficient level, if left unchecked. Urban transport planning must therefore be characterized by two principles: first, space must be used efficiently (space-efficient transport modes, compact land use planning); second, policies must be introduced that strike a balance between positive and negative effects of mobility. This is where congestion pricing fits in.

The purpose of congestion pricing is to find a better balance between positive and negative effects of mobility. When designing congestion charges, the intuitive idea is that benefits must be balanced against losses – benefits in the form of time savings for remaining car trips, and losses in the form of adaptation costs for the disappearing car trips. In theory, the optimal congestion charge is to charge drivers exactly in proportion to the loss of time they cause other drivers, i.e., equal to the difference between marginal private cost and marginal social cost. However, this theoretical concept is infeasible to implement exactly, since it would vary by link and each minute. A more practical definition is that a congestion charge is a charge that makes driving costs better reflect the time loss a car trip causes other drivers. In practice, congestion charging design is about finding an implementable system where the time gains for the remaining traffic is higher than the loss for the "disappearing" ("tolled-off") trips, and high enough to cover investment and operating costs.

The aim of this chapter is to discuss how the theoretical idea can be applied in practice, and discuss how different cities have tackled this challenge. The first section gives a brief overview of the major operational urban congestion pricing schemes. The second section gives a summary of the theory of congestion pricing, stressing the points that are important for applications. The third section discusses benefits and costs in practice. The fourth section gives a summary of the vast literature of public and political opinions of congestion charges. Finally, the last section presents some speculations about the future of congestion pricing.

Operational congestion charging systems

Singapore

Singapore pioneered the idea of congestion charging in practice, first by its Area Licensing Scheme (ALS) introduced in 1975, and then by its Electronic Road Pricing system (ERP) replacing the ALS in 1998. The ALS required drivers of private cars and motorcycles to buy and display a paper license when entering the urban centre during peak hours. The ALS was replaced by the ERP in 1998, where payments are drawn from a prepaid cash card in the vehicle when it passes under a toll gantry. The number of gantries have increased over time; in 2013 there were 71 gantries (Agarwal, Koo, & Sing, 2015). Some of the gantries form a cordon around the urban centre, while some are placed on expressways. The rates are revised four times per year by the Singapore Land and Transport Authority (LTA), based on how measured speeds deviate from "ideal" speeds, which are set to 20–30 km/h on arterial roads and 45–65 km/h on expressways (Menon, 2000; Menon & Kian-Keong, 2004).

Since Singapore has had congestion charges in place for so long, it is rather pointless to compare the effect of the charges to a counterfactual situation without charges. However, it is clear that the charges are effective. Olszewski and Xie (2005) show that the regular revisions of the charges by the LTA have substantial effects on traffic levels and congestion. Menon (2000) showed that the change from ALS to ERP decreased traffic levels by 15%, since charges were then levied per trip rather than per day.

London

The London congestion charge was introduced in 2003. Vehicles were subject to a £5 charge per day if they drove in a centrally located area on weekdays between 07:00-18:00. The charged area was extended to the west in 2007-2011, but then returned to the original definition. The charge has been increased several times, and is now (2016) £11.50. Emergency vehicles, disabled blue badge holders, buses and “ultra-low emission vehicles” are exempt, while residents in the area get a discount (90%) and drivers signing up for automatic payment get a £1 discount.

Drivers are responsible for paying the charge (several payment channels are available), while automatic number plate recognition is used for identifying vehicles (although an automatic debit system has recently been introduced). This is different from the systems in for example Singapore, Sweden and Norway, where it is not the responsibility of drivers to calculate the charge or remember to pay (Singapore uses a cash card, while the Swedish and most Norwegian systems automatically send invoices to the vehicle owner). The main drawback of placing this responsibility on the driver is that it severely limits how charges can be designed: any differentiation in time or space has to be extremely coarse in order not to place an unreasonable cognitive burden on the driver. Moreover, the operating cost of the London system is very high compared to other systems – around £80M in 2014 (Transport for London, 2015), which is around eight times higher than for example the Swedish and Norwegian systems which have similar numbers of passages (the London system handles around 450 000 vehicle movements per day (Dix, 2006)).

The charge has had a persistent effect on traffic volumes, although establishing its exact effect against a counterfactual situation with no charge of course becomes more difficult over time. In 2007, four years after the introduction, the number of chargeable vehicles entering the zone had decreased by 30%, leading to an overall traffic decrease of 16% (Transport for London, 2007). The corresponding changes in vehicle kilometres (VKT) were a 25% reduction of potentially charged vehicle kilometres, and an overall VKT reduction of 12% (Givoni, 2012). These numbers had been broadly stable since the introduction. The immediate effect on congestion was a reduction of around 30%. Over time, road space has been reallocated from cars to other modes (buses, bicycles, pedestrians) and other uses, making direct comparisons difficult. In 2007, Transport for London (TfL) concluded that a direct comparison between 2002 and 2006 gave an 8% reduction of congestion, but if factors affecting the then-current road capacity was taken into account, TfL concluded that the charges were "continuing to deliver congestion relief that [was] broadly in line with the 30 percent reduction achieved in the first year of operation". In 2014, TfL concluded that congestion levels had remained stable since 2006 (Transport for London, 2014).

This highlights an interesting and non-trivial policy choice, which applies to any city introducing congestion pricing. The freed-up road capacity, which at first leads to travel time savings for drivers, does not necessarily have to be used for improving car travel times in the long run. Another option is to use it for other purposes: bus lanes, bike lanes, pedestrians or whatever is deemed to yield the best "value per square meter". The important thing is that choices of space allocation must be made consciously; the freed-up space must not be squandered, since it is a hard-earned, scarce and valuable resource.

Stockholm

Stockholm introduced its congestion pricing system in 2006, first as a 7-month trial followed by a referendum, and then permanently in 2007 (descriptions of the political story can be found in Gullberg and Isaksson (2009) and Eliasson (2014)). Vehicles crossing a cordon around the inner city (in any direction) were charged[1] 2€ in peak hours (7:30-8:30 and 16:00-17:30), 1.5€ in the 30-minute periods before and after the peaks, and 1€ the rest of the day (6:30-18:30). Nights and weekends are free. Charge levels have remained essentially unchanged until 2016, when a new charge was introduced on the western bypass (*Essingeleden*), and the original charges were increased to 3.5€ in peak hours and to 1.1€ during mid-day, gradually increasing and decreasing before and after the peak periods.

The charges decreased traffic volumes across the cordon by around 20% during charged hours, leading to reductions of queuing times of around 30-50% on the affected arterials and to emission reductions in the inner city of around 10-15% (depending on type of emissions) (Eliasson, 2008; Eliasson, Hultkrantz, Nerhagen, & Rosqvist, 2009). Traffic levels across the cordon have remained stable ever since the introduction, despite inflation, economic growth, increased population and increased car ownership all contributing to a general traffic increase in the rest of the region. This indicates that the relative effect of the charges, compared to the counterfactual, has increased over time, as people have got more time to adjust (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012).

[1] Costs are converted from Swedish kronor using a conversion rate of 10 kr = 1€.

Milan

Milan introduced an environmental charge called Ecopass in 2008. The charge was levied on vehicles entering an 8 km^2 zone in the urban centre weekdays 7:30-19:30 (only once per day). Vehicles were identified by cameras using automatic number plate recognition at 43 toll gantries at the perimeter of the zone, with drivers being responsible for paying the charge retroactively. The charge was designed primarily to curb emissions, so it was differentiated according to emission standards: Euro3-compliant vehicles and alternative-fuel cars were exempt, while more polluting vehicles paid a charge varying from 2€ to 10€ depending on emission standards. Originally, the idea was to tighten the rules for which vehicles were exempt over time, but this never happened due to political opposition (Croci & Douvan, 2015).

In the first year, the number of charged vehicles decrease 56%, leading to an overall traffic reduction of 21%. This reduced emissions by 14-23% (depending on type of emission) and decreased the number of days with pollutant levels over threshold levels (Danielis, Rotaris, Marcucci, & Massiani, 2012), which was the main purpose of the system. Congestion and accidents were also reduced substantially. Around three quarters of total time savings occurred outside the zone (Danielis et al., 2012). Gradually, however, the congestion reduction decreased because of car substitution: before the introduction, 42% of the traffic was made up of vehicles that would be subject to the charge, but by 2011 this share had decreased to around 10%, and the overall traffic reduction had been reduced to 11% in 2011 (compared to 2007) since exempt vehicles had to a large extent replaced the charged vehicles.

The Ecopass system was introduced as a one year trial, which was then extended a year at a time. In 2011, proponents of the original charge pushed through a referendum about extending the system to cover a larger area and all types of vehicles. 80% of the voters were in favour, and in 2012 a redesigned system, Area C, replaced the Ecopass system (Beria, 2015; Croci & Douvan, 2015). The system was first introduced as a trial, but made permanent in April 2013. The Area C charges were designed to have a stronger effect on congestion: the baseline charge is 5€ for all vehicles to enter the zone (per day), although commercial vehicles and cars parking in private parking areas pay 3€. Heavily polluting vehicles (Euro 0 petrol and Euro 0-2 diesel) are not allowed to enter at all. Residents get 40 free entries per year, after which they pay 2€. In all, this means that only 41% of vehicles pay the full charge. The Area C scheme decreased traffic further: traffic volumes in 2012-2013 were 38% lower than in 2007 (before Ecopass). Emissions (PM10) were estimated to have decreased by 18% compared to 2011 levels.

Gothenburg

Gothenburg introduced its congestion charging system in 2013. The scheme consists of a cordon with two additional tolling borders sprouting out from the cordon. Charges are levied 6:00-18:30 on weekdays, and range from 8 SEK to 18 SEK depending on the time of day. Vehicles are charged when they cross a toll border in any direction, but only have to pay one charge during any one-hour period. The Gothenburg system uses the same technology and invoicing system as Stockholm.

Traffic across the toll cordon was reduced by 12%, and average congestion indices on the relatively small number of congested links were reduced from 160% to 80% (Börjesson &

Kristoffersson, 2015). Most of the affected links were not congested even before the charges, however.

The Gothenburg congestion charges have two purposes: generate revenues for an infrastructure package and reduce road congestion. The background was that Stockholm had managed to use their toll revenues to strike a deal with the national government, where the revenues were leveraged with national funding to fund a large infrastructure package. Inspired by this, Gothenburg negotiated a similar deal. The deal prescribed that the system should generate around 1 billion SEK per year (a third more than the Stockholm revenues, despite Gothenburg being less than half the size of Stockholm), with the secondary objective to reduce congestion as efficiently as possible given the revenue constraint. However, Gothenburg did not have a lot of road congestion; it was limited to a few junctions and the morning rush hour. This led to a fierce political debate. Descriptions of the political story and the changes in public opinion can be found in Börjesson, Eliasson and Hamilton (2016) ad Börjesson and Kristoffersson (2015).

Other systems

Norway was the second pioneer of urban road pricing, after Singapore. Oslo, Bergen and Trondheim all introduced road pricing systems in the late 1980's or early 1990's, and several other cities have followed. However, most of the Norwegian systems are not intended to reduce congestion, but merely to generate revenues for infrastructure investments (although there are a few examples where there have been secondary objectives as well, such as congestion reduction or environmental improvements, for example the Trondheim system).

The Norwegian systems are still interesting from a technical point of view, but since most are designed *not* to affect traffic, they mostly fall outside the scope of the chapter.

A few comparatively small towns have introduced some form of congestion pricing; the most well-known are Durham (UK, 2002) and Valletta (Malta, 2007) (Attard & Ison, 2010; Santos, 2004). This context is obviously different, but experiences from these cities confirm many of the main conclusions from other cities, for example that drivers are indeed sensitive to pricing.

In the United States, the HOT lane concept (High-Occupancy vehicles and Toll) is relatively common. The idea is to charge one lane on a multi-lane expressway to provide a virtually congestion-free alternative. Several studies indicate that this can be a viable option to decrease average congestion levels, increase throughput and yield a net social benefit (Burris & Stockton, 2004; Janson & Levinson, 2014).

Costs and benefits of congestion pricing: Theory

This section gives a brief summary of congestion pricing theory. The purpose is not to attempt to summarize the large literature in this field, but to give a quick and accessible overview, and to point out some specific conclusions which are important from an applied point of view.

Consider a road[2] with a travel time t which depends on the traffic volume D, so we have $t = t(D)$. This is called a volume-delay function, and is normally characterized by $t'(D) \geq 0$ and $t''(D) \geq 0$. Assume that drivers' generalized travel cost c is the sum of the travel time[3] and a toll τ: $c = t(D) + \tau$. Let $p(D)$ be the inverse demand function, that is $p(D) = c$. The total social benefit B is the sum of the consumer surplus $\int_0^D p(x)dx - cD$ plus the toll revenues τD:

$$B = \int_0^D p(x)dx - cD + \tau D = \int_0^D p(x)dx - [t(D) + \tau]D + \tau D = \int_0^D p(x)dx - t(D)D$$

The optimal toll τ^* can be obtained by solving for the optimal volume D^* (by differentiating B with respect to D and setting equal to zero):

$$\frac{dB}{dD} = p(D^*) - t'(D^*)D^* - t(D^*) = 0$$

Using that $p(D) = t(D) + \tau$, we get the optimal toll τ^*:

$$\tau^* = t'(D)D$$

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[2] Instead of a single road, one can also think of an area with a dense road network, such as the downtown of a city; similar relationships hold between traffic volumes and travel times (Daganzo, 2007; Daganzo, Gayah, & Gonzales, 2011; Geroliminis & Daganzo, 2008).

[3] We assume that the travel time has been converted to an equivalent monetary cost. Hence, this exposition tacitly assumes that drivers have the same value of travel time.

To give this an interpretation, define the *social cost* SC as the sum of the aggregate generalized cost minus toll revenues: $SC = (t(D) + \tau)D - \tau D = t(D)D$. The derivative of the social cost is the *marginal social cost* $MSC = t(D) + t'(D)D$. The optimal toll τ^* is equal to the difference between the MSC and users' generalized travel cost (without toll).

The welfare gain B of a toll τ which changes demand from D_0 to D_1 is the change in consumer surplus plus the toll revenues, which gives

$$B(\tau) = \int_o^{D_1} p(x)dx - (t(D_1) + \tau)D_1 + \tau D_1 - \int_o^{D_0} p(x)dx + t(D_0)D_0 =$$

$$= t(D_0)D_0 - t(D_1)D_1 - \int_{D_1}^{D_0} p(x)dx$$

The first two terms is the change in total travel time, and the integral is the welfare loss of adaptation costs (the welfare loss for disappearing car trips). This shows the intuitive idea explained in the beginning: congestion pricing involves balancing total travel time gains (the first two terms) against the welfare losses of adapting to the charges (the integral). The toll revenues do not appear in the social benefits; they are just a transfer. In practice, of course, they are of enormous importance. The formula is true for *any* toll – not just an optimal toll. Hence, congestion charges do not have to be optimal to deliver social benefits; it is enough that they generate time gains larger than the adaptation costs. This is of great practical importance. Determining the optimal toll by calculating the marginal social cost is a very difficult task in practice, while measuring aggregate travel time gains and assessing adaptation costs (using e.g. the rule-of-a-half) is relatively straightforward. This is what makes it possible to design and evaluate practically implementable congestion charges.

The formula can be rewritten in a way that allows it to be drawn in a well-known and illuminating diagram. Rewriting $t(D_0)D_0 - t(D_1)D_1 = \int_{D_1}^{D_0} MSC(D)dD$, we get $B(\tau) = \int_{D_1}^{D_0} MSC(D)dD - \int_{D_1}^{D_0} p(x)dx$. The social benefit of a toll τ can then be drawn as the shaded triangle in Figure 1 (the figure shows the benefits of an optimal toll); it is the difference between the integral under the MSC curve and the integral under the inverse demand curve, from the initial demand D_0 to the resulting demand D_1.

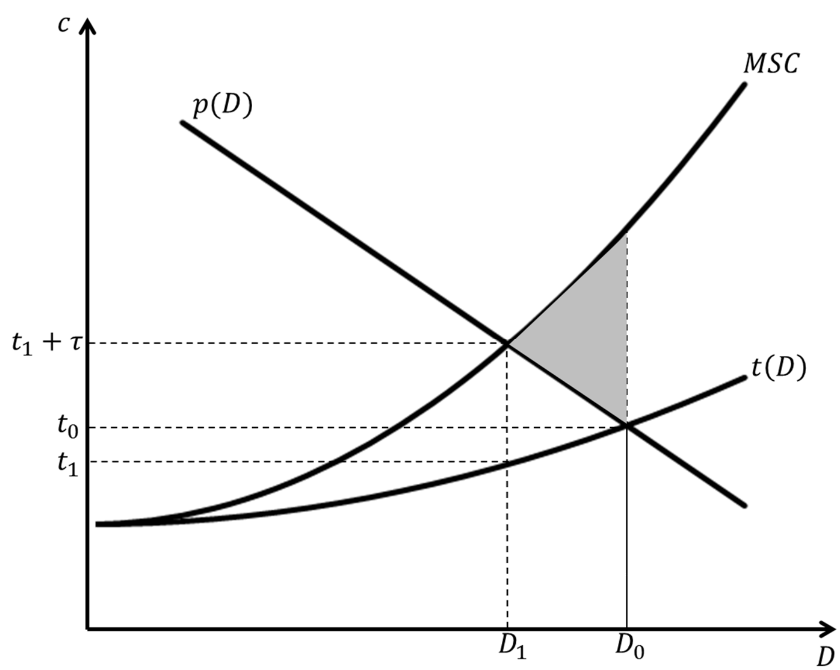

Figure 1. Net social benefits of an optimal congestion charge.

From this figure, a number of important conclusions can be drawn. First, the magnitude of the toll benefits depend on two things: the slope of the demand curve, and the difference between

MSC and $t(D)$.The slope of the demand curve is a measure of how easy it is for drivers to adapt to the charges, i.e to avoid them: the more difficult it is to adapt, the steeper is the slope, and the smaller will the toll benefits be. In order for a toll to deliver large benefits, it must be reasonably easy for drivers to find alternatives to paying the charge (other modes, destinations, routes, departure times) – at least for a subset of their trips. The difference between MSC and $t(D)$ is a measure of the congestion on the road – severe congestion means that the difference is big. Hence, tolls will only yield large benefits if congestion is severe. This is also intuitively obvious, but surprisingly enough, this point often needs to be emphasized in applied practice (see the Gothenburg case above).

Second, toll revenues (the rectangle with size $\tau * D_1$) are often large compared to the net social benefit (the shaded triangle). From a pure social cost-benefit point of view, the toll revenues are just a transfer; but in reality, it is a transfer between different groups of citizens. The use of the revenues, and the political power over the revenues, is hence crucial for the political economy of congestion charges. Moreover, it may be seen as unreasonable to redistribute large sums of money in order to generate a small net benefit. A judgment must be made whether the net social benefit is large enough to justify the redistribution of money.

Third, the marginal benefit of the toll decreases quickly as the toll increases from zero towards the theoretically optimal level. In other words, a relatively low toll will deliver a substantial share of the theoretically maximal benefits. Considering the argument above, that the net benefit needs to be large enough to warrant the redistribution of money, aiming for the optimal toll level may not necessarily be seen as worthwhile or even justified; a moderate toll may be sufficient. A related point is that, intuitively speaking, it is not so important to set precisely the optimal toll and achieve the optimal demand. To see this, imagine that demand is a little higher or lower than the optimal demand D_1. The welfare loss from this deviation will be the little triangle between the $p(D)$ and MSC curves with width equal to this deviation from the optimal demand. This loss of benefit will clearly be small compared to the benefit generated by the toll. This is important from a practical point of view, since the optimal toll cannot be determined (or charged) in practice – partly because demand curves cannot be measured exactly, partly because demand and travel times vary randomly across days.

Fourth, even the optimal toll will not reduce congestion to zero; at the optimal demand level, there will still be congestion. How much depends on the slope of the demand curve: the steeper the slope, the higher the congestion level will be at optimal demand (all else equal).

Alternative theoretical analyses

The theoretical model above is called a *static* model of congestion, because the congestion function (the volume-delay function) $t(D)$ does not take into account that congestion first builds up and then dissipates, and that drivers may change their departure times to avoid the worst queues. A theoretical model that takes this into account is called *dynamic*. The most common dynamic model in the theoretical literature is the so-called "bottleneck" model of congestion. Drivers are assumed to arrive at a bottleneck in a certain order, queue up and wait, and then pass through the bottleneck in first in-first out order. This causes queues to first build up and then dissipate. The optimal congestion charge in this model varies over time. S An analysis can be found in Arnott et al. 1993). The conclusions from the dynamic model are different from the static in two ways: the optimal toll will eliminate queues completely, and drivers will be just as well off as before the toll even before revenue recycling (not worse off, as in the static analysis). The latter is because drivers' welfare losses from paying the toll and rescheduling their trips are exactly offset by their reduced travel times. The net social benefit is the resulting toll revenues.

The conclusions from the bottleneck model depend crucially on the assumption that the capacity of the bottleneck is constant, in other words that the flow through the bottleneck does not decrease when a queue starts to form. In reality, however, this is often unrealistic. Consider an urban area such as the downtown of a city. When there is congestion, the average flow decreases essentially everywhere; on the micro-level, cars and queues hinder each other, so the more congestion there is, the lower the overall flow becomes. This phenomenon is called *hypercongestion*, and does not occur in the bottleneck model of congestion. An alternative theoretical model of congestion, the so-called "bathtub" model, captures this by assuming that the average speed in an area depends on the number of vehicles in that area. Analysing congestion pricing in this model, but still accounting for the dynamic nature of congestion (drivers have different departure times, and congestion builds up and then dissipates) leads to very different conclusions than in the bottleneck congestion model (Fosgerau, 2015). The conclusions are in many ways similar to the conclusions from the static analysis, but since dynamics are accounted for in the model, the analysis can also show how incentives for departure time shifts can increase the benefits of charging.

Costs and benefits of congestion pricing in practice

Costs and benefits for drivers

Car drivers are affected in three ways by congestion charges: they benefit from improved travel times and travel time reliability, but on the other hand they pay the congestion charge and adapt their travel patterns to the charges (which constitutes a welfare loss). Adding these effects together, the average effect for drivers is usually negative. It is therefore not surprising that most drivers are usually opposed to congestion charges. However, there are exceptions to the rule of thumb that drivers are worse off on average, and there are subgroups of drivers who are winners. Drivers with high values of time – distribution traffic and business travellers for example – may value the times gains more than the paid charges, and may hence be better off. Some drivers may enjoy benefits of reduced spillback congestion without actually paying the charge. “Spillback congestion” refers to queues propagating from a bottleneck onto other roads, blocking traffic not actually going through the bottleneck. Reducing such queues by charging the bottleneck will hence benefit traffic not going through the bottleneck. This traffic will hence get time benefits but no increase in travel cost, and are obviously net winners. Reduction of spillback congestion was an important effect both in Stockholm and in Milan. In Milan, Danielis et al. (2012) calculate that private drivers were actually on average better off from the Ecopass system, because of large time savings outside the zone (over three quarters of time savings occurred outside the zone).

Note, though, that this describes “objective” economic consequences. Whether car drivers in reality will *feel* like “winners” or “losers” is also influenced by several other factors, in addition to objective or rational self-interest. We will discuss public attitudes to congestion charges below; at this point, let us just stress that although economic self-interest is an important determinant of attitudes to congestion charges, it is not the only important factor by far.

Many drivers seem to overestimate monetary and adaptation costs *ex ante,* and underestimate the benefits the traffic reduction yields. Surveys before the introduction of the Stockholm charges indicated that private car traffic would be reduced 5–10% across the cordon during charged hours. When the survey was repeated three months after charges were in place, the result was the same: the answers from respondents indicated that the private car traffic over the toll cordon had been reduced by 5-10%. However, traffic measurements showed that in reality, private car traffic had been reduced by around 30%. In other words, around 3/4 of the reduction in car trips across the cordon seemed to have gone unnoticed by the drivers themselves. This is most likely because travel patterns vary considerably across days and months, so small changes may go unnoticed by travellers themselves. In Stockholm, less than a quarter of the charged vehicles on any given day are made up of "habitual" car drivers, who drive across the cordon daily. The remaining three quarters of traffic only pass the cordon occasionally or rarely. Travel patterns also change because circumstances change. Some illuminating Swedish figures: during one year, 20-25% of the workforce change jobs, and 15-20% of the population move. Clearly, identifying specific "winners", "losers" and "who changed" in such circumstances is difficult, and in the long run almost pointless.

Revenues for the government

From drivers' point of view, then, congestion pricing may not seem such a good idea. However, the revenues from the charges are of course not lost; they are transferred to the government. The whole point of congestion charges is that adding toll revenues and drivers' welfare losses together gives a positive net social benefit. In other words, the toll revenues are more than enough to compensate the drivers. Whether drivers will be net "winners" or "losers" therefore depends on how revenues are spent (remember, though, the caveat that attitudes in reality depend on several other factors in addition to self-interest).

From the point of view of the government, congestion pricing is thus an attractive source of tax revenue. Whereas standard taxes, such as income tax or value-added tax, have negative net effects[4] on the economy (deadweight losses), congestion pricing is a tax source which has *positive* net effects on the economy. However, this also means that the net benefit of congestion pricing depends on how revenues are used. For example, if a large share of revenue is needed for investment and operating costs, net benefits may become negative; or if the government uses the revenue inefficiently on, say, infrastructure with costs exceeding benefits (and which would otherwise not be built), total benefits may also turn negative.

Congestion pricing increases efficiency – but not necessarily accessibility

The point that net benefits are positive although drivers may lose (on average) shows that what congestion pricing really does is increase the *efficiency* of the road system: a scarce resource, road space, is allocated in a more efficient way. But congestion pricing does not necessarily increase *accessibility;* on the contrary, drivers may (on average) feel that their accessibility has in fact decreased, since their generalized travel costs increase if they value the shorter travel times less than the cost of the tolls.

Whether congestion charges will increase or decrease accessibility in a real case depends on several factors. The possibility to achieve an overall increase in accessibility is higher when

[4] Of course, the social benefits generated by *spending* the tax revenue are (hopefully) larger than the social loss caused by collecting them (the deadweight loss).

drivers are heterogeneous (e.g. have different values of time) and when spillback congestion is widespread (i.e. concentrated bottlenecks cause congestion over large areas).

Consequences for public transport users

Public transport passengers may suffer from increased transit crowding when some drivers switch to transit. This can be remedied by increasing transit capacity, and the cost for this may at least partly be covered by increased fare revenues. If the transit capacity is limited and difficult to increase, however, and if the relative passenger increase is large, increased crowding may cause substantial social costs, and this must be taken into account when designing a congestion pricing system and when evaluating its social costs and benefits. However, this potential problem is often exaggerated. In many cities, analyses and experiences show that the increase of transit passengers is small in relative terms, simply because transit passenger volumes are often large where road congestion is severe. For example, London, Stockholm, Gothenburg and Milan all experienced an increase in transit volumes by just a few percent. Whether increased transit crowding is a problem in a specific city hence depends on local circumstances.

Transit passengers may benefit if less street congestion improves the running times and reliability of buses. There is empirical evidence that this indeed happened in London (Leape, 2006), Stockholm (Eliasson et al., 2009) and Milan (Danielis et al., 2012).

Most cities which have introduced congestion pricing have combined it with an expansion of public transport. This may have dual benefits: it can make alternatives to driving more attractive, which tends to increase the benefits of the congestion charge (the demand curve in

Figure 1 becomes flatter), and it amends the potential problem of increased transit crowding. Perhaps the most important reason, however, may be to increase public acceptability: spending money on public transport may signal to voters that the charge is not "just another tax" but part of a strategy to improve overall accessibility.

Environmental benefits

Environmental benefits of congestion charges are usually comparatively small (Eliasson, 2009), but may still be important. The reason that they are usually relatively small is that while congestion is a non-linear phenomenon, meaning that a moderate traffic reduction may lead to huge congestion reductions, environmental benefits are essentially linear in traffic volumes – a 10% traffic reduction reduces emissions by around 10%. (Better traffic flow may increase the emission reduction somewhat, but on the other hand, heavy vehicles emit more per kilometre and that traffic is usually reduced less than average.) However, environmental benefits exist and are usually positive, and although they may be relatively small, they may be politically significant: voters tend to care much more about environmental issues than about efficient use of scarce road space.

Environmental benefits may still be substantial, however. The Milan Ecopass system was expressly designed to curb emissions by charging the most polluting vehicles, and it also succeeded in decreasing traffic with these vehicles substantially, resulting in lower emission levels. Still, emission benefits were still smaller than other kinds of benefits (Danielis et al., 2012). The general lesson that can be learnt is that differentiating the charge with respect to vehicle type can have a considerable effect on the composition of traffic and on vehicle sales. Stockholm results confirm this: in its first years, the Stockholm system exempted alternative-fuel vehicles, and this contributed to a considerable increase in sales of such vehicles (Börjesson et al., 2012; Whitehead, Franklin, & Washington, 2014, 2015).

Safety benefits

The sign of safety effects of congestion charges is theoretically ambiguous. Lower traffic levels tend to decrease the number of accidents, ceteris paribus, but higher speeds may counteract this effect and even lead to an increase in severe accidents. Empirical evidence, however, indicates that the net effect is positive and can in fact be substantial (Danielis et al., 2012; Green, Heywood, & Navarro, 2016). Eliasson (2009) reaches similar conclusions, using accident modelling based on traffic measurements for Stockholm.

Investment and operations costs

Building and operating a large-scale urban road pricing system is not cheap: investment and operating costs may be substantial compared to the benefits delivered by the charges. If the purpose of a road user charge is just to generate revenue, there are usually more cost-effective ways to do this. What increases the cost of urban congestion charges compared to common toll roads is, first, that it is easy to restrict access to toll roads to stop non-paying vehicles from entering, and second, that toll road operators do not have to care much about the time lost for drivers queuing to pay. Since the fundamental reason for congestion pricing is that space is scarce, space-consuming toll plazas are not an option, which (usually) means that physical access restrictions are infeasible; and since the main benefit of congestion pricing is time savings, having a system which wastes drivers' time in a new form of queue is not beneficial. This means that congestion pricing systems must build on automatic free-flow identification. The problem is not the added technical complexity – in fact, the technical cost of such systems is nowadays not very high; the main cost drivers are the handling of payments and setting up an enforcement system. Especially the latter can be legally complicated, which can increase costs. For example, different countries may have different regulations regarding what constitutes a legally valid proof-of-passage. Is an automatic registration of a number plate enough? Does there have to be a photo of the number plate, or even of the entire car? If so, are such photos compatible with privacy legislation? These questions (and many others) can be extremely complicated and expensive to solve.

Operating costs vary widely between cities, although exact figures are seldom published. The London system is by far the most expensive, with an operating cost around 1€/vehicle (Transport for London, 2015). The Milan Area C system now appears to have reduced its operating cost to slightly more than 0.3€/vehicle, which would be less than half the cost from the time of Ecopass. The Stockholm and Gothenburg systems have operating costs of around 0.13 €/vehicle, slightly higher than most of the largest Norwegian systems, which have an average operating cost of around 0.11 €/vehicle (Odeck, 2008). Investment costs also vary. In Milan, a camera identification system was already in place before the Ecopass system, so the investment cost for Ecopass was limited to 7 M€ (Croci & Douvan, 2015). The Stockholm and London systems had investment and startup costs of around 200 M€ (Eliasson, 2009; Hamilton, 2011; Santos, Button, & Noll, 2008). In both cases, the technical systems were developed "from scratch", which presumably increased costs compared to a situation where a system can be acquired "off the shelf". The extremely heated political context in the two cities also contributed to high costs, since the government, the responsible public agencies and the contractor all wanted to be certain that the technical system worked flawlessly from the start. Hamilton (2011) provides an excellent discussion of political and technical cost drivers for congestion charging systems.

Wider economic effects

Changes in accessibility have repercussions on the rest of the economy, such as the labour market, the housing market and the market for commercial floor space. If congestion charges cause a drop in overall accessibility, this may cause additional social welfare losses since there are distortions on these markets in the form of taxation and agglomeration/spillover effects.

Parry and Bento (2001) point out that if there are distortionary taxes on labour income, and if congestion charges cause accessibility to decrease, and if this in turn leads to a decrease in labour supply, welfare losses on the labour market may outweigh the benefits in the transport system. It is crucial how the toll revenues are used, however. If they are spent on decreasing the distortionary labour taxes, then the congestion charges are guaranteed to yield a net social surplus. To this should be added (although Parry and Bento do not explicitly point this out) that in equilibrium, the marginal benefit of public spending should be equal to the marginal cost of public funds (i.e. the marginal deadweight loss of taxation); otherwise, the government should simply decrease both their spending and the taxes in the initial situation. Hence, as long as the government spends the revenues on something where the marginal benefit is at least as high as the MCPF, congestion charges are guaranteed to deliver net benefits, even considering welfare losses on the labour market. Anderstig et al. (2016) analyse the interactions between the Stockholm congestion charges and the labour market. They conclude that the effect on economic output is in fact positive, since workers with high values of time experience an increase in accessibility, and the relationship between economic output and accessibility is much higher for workers with high values of time than for workers with low values of time.

A common fear is that congestion pricing will affect retail in the charged area negatively. However, studies of such effects have not found any support for this hypothesis, except possibly for locations close to the toll border (Croci & Douvan, 2015; Daunfeldt, Rudholm, & Rämme, 2009, 2013; Quddus, Bell, Schmöcker, & Fonzone, 2007; Quddus, Carmel, & Bell, 2007). This coincides with the conclusions of Eliasson and Mattsson (2001), who use a generic simulation model to show that location effects can be expected to be (very) small, except possibly close to a toll ring. However, there is some evidence from Singapore (Agarwal et al., 2015) that the rents retailers pay for their floor space may decrease, which may be a sign that the gross profitability of retail stores decrease. On the other hand, if this is compensated by decreased rents (which would be the theoretical expectation), then the overall supply of retail would stay more or less constant (although property owners might lose). Agarwal et al (2015) do not find any similar effects on rents for office or residential real estate.

Equity effects

A common argument against congestion charges is their supposedly negative equity effects. Whether equity effects in fact are negative depends on the specific travel pattern of the city, the design of the system and also on the use of revenues. Very broadly speaking, most equity studies have concluded that rich people will pay more in tolls than the poor, since they drive more, especially in inner cities where congestion is most severe.

However, it should be stressed that equity effects are often discussed in a short-term or narrow way, simply comparing the situation before and after charges are introduced. But congestion charges are not an instrument for redistributing income: it is a way to make the price of driving more "correct", to make it better reflect the true social cost of driving. Generally speaking, consumer prices for services and goods are almost always the same for everyone, regardless of income or wealth (for very good reasons). The desire for increased income equity is instead usually handled by taxation and welfare systems; not even essential goods such as food and clothes are usually subsidized (except in special cases). If the default position therefore is that prices are, generally, equal for everyone, then it is natural to argue that the distributional effects of corrective taxes – taxes which are introduced to make the prices "right" in the sense that they reflect full social costs – are in fact essentially irrelevant. At least, one should realize that arguing against such corrective taxes with equity arguments is logically equivalent to arguing that the good in question (car travel in rushing hours, in this case) should be *subsidized* for equity reasons – and this is often a much less persuasive or intuitively appealing argument.

Public and political support for congestion pricing

Public attitudes to congestion pricing

Individuals' attitudes to congestion charges depend on many factors. Rational self-interest is obviously one of them: people will tend (all else equal) to be more positive to congestion charges the less they pay, the more travel time they gain, the higher they value travel time savings, and the easier they have to adjust to the charges (for example the more satisfied they are with public transport). Individuals also become more positive if revenues are used in a way they appreciate, which can be viewed as a form of self-interest (Börjesson et al., 2016;

Eliasson, 2014; Eliasson & Jonsson, 2011; Gaunt, Rye, & Allen, 2007; Hamilton, Eliasson, Brundell-Freij, Raux, & Souche, 2014; Hårsman & Quigley, 2010; Jaensirisak, May, & Wardman, 2003; Jones, 2003).

But self-interest is not the only determinant by far. Attitudes to congestion charging are also affected by a number of other factors:

- Environmental concerns and engagement strongly increase support for congestion charges (Börjesson et al., 2016; Eliasson, 2014; Eliasson & Jonsson, 2011; Hamilton et al., 2014; Jaensirisak et al., 2003). In the political debate, environmental benefits often play a more important role than time savings and efficient use of space, since environmental issues usually invoke stronger positive emotions than transport efficiency.
- Support for congestion charges is related to trust in the government, and support for public interventions in general (Hamilton et al., 2014). Scepticism to congestion pricing can be caused by scepticism to the government's ability to design and manage such a system, or use the revenues efficiently (Dresner, Dunne, Clinch, & Beuermann, 2006; Kallbekken & Sælen, 2011). It can also be associated to a more fundamental dislike of public interventions in general. This finding may partly explain the apparent paradox that left-wing parties are often more in favour of congestion pricing than liberal/conservative parties, despite the latter usually being more in favour of market-based solutions.
- Support for congestion pricing is correlated with viewing pricing mechanisms in general as "fair", for example supporting general principles such as "user pays" or "polluter pays".

Hamilton et al. (2014) and Börjesson et al. (2016) show that self-interest only explain 20-50% of the total explained variation in attitudes (using data from Stockholm, Helsinki, Lyon and Gothenburg); the rest is explained by the attitude factors above.

How attitudes to congestion pricing is linked to other attitudes, such as fairness, equity, environment and so on, most likely depends on how congestion charges are *framed* in the specific local discourse – in other words, what congestion charges are "perceived" as. When people are faced with a new issue where attitudes are not well developed, attitudes to the new issue is often formed by associating it to some other issue which is perceived to be "similar" in some sense, and where the individual already has a well-developed attitude (Heberlein, 2012). The new issue then inherits the attitude from the familiar one. (This is similar to what Kahneman (2011) calls the *substitution heuristic*). Such new attitudes, which are based on limited experience, knowledge and emotions, tend to be less stable, and may change comparatively easy. In particular, they may change if they are associated to another issue, a process sometimes called *reframing*. For example, depending on how it is framed, congestion charges may be perceived as a tax, an environmental policy or a way to improve efficiency – and this perception may change if charges are reframed, for example due to how the local debate evolves. Eliasson (2014) argues that it was not until congestion pricing was reframed from solely a transport-efficiency policy to an environmental policy that it entered the political agenda in Stockholm. This came at the price of a more polarized debate, since arguments turned from mostly technical/rational to more moral/emotional. This might have been a necessary price to pay, since without this moral/emotional association, the policy might not have generated enough political engagement. Once the charges were in place, however, the moral/emotional dimension was gradually discharged, not least due to the earmarking of revenues for a new road, which could be interpreted as signalling that congestion pricing was not an “anti-car” measure, but merely a tool technical/rational tool for traffic control, similar in nature to traffic signals or speed limits. Since then, the Stockholm congestion charges have more or less stopped making any particular political controversies.

In most cities where congestion charges have been introduced, support has increased after the introduction. The same phenomenon has been observed for the US HOT lanes (Burris et al., 2007; Finkleman, Casello, & Fu, 2011). Part of the explanation seems to be that benefits turn out to be larger and problems smaller than expected (Eliasson, 2008; Schuitema, Steg, & Forward, 2010). However, status quo bias (and possibly reframing) seem to be at least as important (Börjesson et al., 2016; Eliasson, 2014). Schade and Baum (2007) show that support increases when respondents think that the change is unavoidable.

Gaining political support

Gaining political support for congestion pricing is different from getting public support (or acceptability). Obviously, politicians’ willingness to introduce congestion pricing is influenced by public attitudes – but public support is neither a necessary nor a sufficient condition for getting political support. Crucial for the analysis and understanding of political acceptability are power issues: the power over the design of the charging scheme, the power over the revenues, and how the charges and their revenue stream will affect decisions and funding of transport investments in general. Many politicians have stated that their main argument against introducing the congestion charge is the uncertainty about the political power over scheme design and revenues. Adding to these uncertainties is the uncertainty about how the existence of a new revenue stream might affect the complicated negotiations between national, regional and local levels about infrastructure financing.

The future of congestion pricing

The social benefits that congestion pricing can bring will continue to increase, as urbanization continues and urban space becomes an ever scarcer resource. A very large number of cities around the world are exploring the possibilities, and are more or less actively considering introducing congestion charges.

Congestion pricing is now a mature policy measure. There is a large body of evidence and experience regarding design, effects and technology which can be used by other cities. Almost all systems now use some variant of automatic number plate recognition linked to an automatic invoicing system. This begs the question whether more advanced technology that allows even more fine-tuned pricing schemes (say, distance-based pricing differentiated in time and space) is an attractive way forward. So far there is little to support that the added benefits of such systems would be worth the higher costs. Passage-based systems seem to be flexible enough to deliver high benefits at a relatively low cost. Satellite-based technologies which require installations in the vehicle but little roadside investments are attractive alternatives when the charged area is large, the number of vehicles is small and those vehicles are already subject to public regulations and inspections; the typical case is heavy goods vehicles in an entire country. For urban congestion pricing, however, the area is usually small, the number of vehicles huge, and they are subject to limited inspections and regulations, which makes passage-based systems which require no intervention in the vehicles more attractive. Hence, I would personally not expect that satellite-based technology becomes the method of choice for urban congestion pricing any time soon.

However, despite available technology and overwhelming evidence that congestion pricing works, the political case for congestion pricing remains difficult. In my own experience, there seems to be four main political obstacles:

- Loss aversion and status quo bias are hard-wired in human nature. The potential losses of paying charges and having to adjust loom larger than the potential gains of travel time in the minds of voters and decision makers. Even those who would not be directly affected can be subject to pure status quo bias. This makes it difficult to build enough public and political support *ex ante*. Even if that can be done, it needs to be maintained during the several years it takes to go from idea to implementation, which can be extraordinary difficult in an unstable political landscape.
- It is easier to identify the losers from congestion pricing than the winners. The losers are here and now, and are easy to identify and organize in self-interested pressure groups. The winners are more dispersed, and perhaps only exist in the future, or may not realize that they will win *ex ante*. Moreover, there are often many winners who win a little and few losers that feel that they lose a lot. Perhaps surprisingly, this is not a recipe for a successful political idea, despite that there are more winners than losers. This is because winners may not care enough to let it affect how they vote, while for the losers it can be the most important issue in an election.
- Congestion pricing increases the efficiency of the transport system – but not many voters care enough about efficiency that it becomes an important political issue. Congestion and the resulting long travel times can be an important issue – but *increasing* travel costs just because travel times are long is incredibly counterintuitive for most voters. However, voters *do* often seem to care about urban environmental issues – emissions, noise, more space for pedestrians – so this may sometimes be a more important selling point. For an issue to be politically interesting, it must generate enthusiasm among a sufficiently large group of voters. Since transport efficiency is not an issue that many voters feel strongly for, the issue has a very limited political upside. Even large gains in transport efficiency may not be valued enough by voters to be worth the political cost in terms of some voters feeling that they will become worse off.
- For many politicians, the main obstacle is not so much the lack of public support but uncertainties regarding the power over revenues, scheme design and so on, and how introducing congestion pricing (and especially the resultant toll revenue stream) may upset the delicate balance of power between national, regional and local levels, and the continuous negotiations about e.g. financing responsibilities and allocation of funding.

The fundamental obstacle for congestion pricing is that its primary positive effect – more efficient use of scarce space – is something that only generates lukewarm enthusiasm. While most would agree that efficiency is worth striving for in principle, it does not stir up enough positive emotions to be worth substantial political risks. Congestion pricing is in many respects similar to other traffic control measures, such as traffic signals and speed limits; most would agree that they are needed, but few are enthusiastic supporters of them. The difference is that traffic signals and speed limits are already there, while congestion pricing is still something new and unknown – and then, status quo bias decides the issue for most people.

In the cities where congestion pricing has been successfully introduced, it is often because of an alliance between three groups: traffic planners wanting the efficiency gains, environmentalists wanting the environmental benefits and politicians looking for a revenue source. When this works it can indeed be a powerful political strategy. Many lessons can be learned from the cities which have succeeded and those who have failed – both things to do and things to avoid.

However, congestion charges in the hands of politicians merely looking for revenues is a dangerous tool. One of the most insightful (albeit a little cynical) arguments against congestion pricing is that it is dangerous to open up a new source of tax revenues which may be perceived as "free money" by politicians – especially if a large share of traffic comes from other constituencies. There are clearly incentives for politicians to over-charge drivers from other constituencies, and to over-invest in infrastructure by borrowing money against future toll revenues: spending the money today and leaving the bill to future car drivers. Institutional frameworks which enforce fiscal discipline and prevent tax exporting are virtually necessary.

Still, congestion pricing deserves to be used much more than it is. It has the potential to bring huge social benefits at a comparatively low cost, and can also have desirable long-term consequences on urban structure and overall travel patterns. The technology is available, there is experience and evidence of how charges should be designed, and as long as benefits are delivered and revenues are not squandered, it is possible to build public support for it. More cities should dare to make the leap.

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