Congestion Charging and Car Use: A Review of Stated Preference and Opinion Studies

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Abstract

This paper reviews 17 published congestion pricing studies with a focus on the dimensions of the stated preference or opinion survey, especially the type of charging regime and the structure of the charge. The effectiveness and acceptability of different charging regimes, as well as behavioural responses such as changes in departure time, car use, mode, residential and work location, are synthesised, and used to provide insights to enrich our understanding of the potential role that specific road pricing schemes might play in influencing behavioural change.

Keywords: congestion charging schemes, stated preference, stated opinion, car use, behavioural responses, effectiveness and acceptability

1 Introduction

Passenger car use is a major contributor of greenhouse gas emissions, as well as a significant consumer of fossil fuels. In Australia, passenger cars account for 85 percent of all road activity petrol consumption, and contribute to eight percent of national greenhouse gas emissions (Li *et al.* 2010a). Although there have been growing environmental concerns associated with emissions resulting from the increasing use of cars, traffic congestion has also been growing at a rate that continues to exacerbate emissions, as well as add substantially to unproductive and stressful time allocation. Congestion not only increases journey time, but also leads to increasing variability in trip times or uncertainty in arrival times, making trip planning more difficult.

It is estimated that traffic congestion in Australia resulted in AU$9.4[1] billion of avoidable social costs in 2005 (including extra time costs (private and business), extra vehicle operating costs and extra emission costs), increasing to AU$20.4 billion by 2020 (see BITRE 2007). In the USA, the Texas Transportation Institute (2010) reports, in its 2010 Urban Mobility update (http://mobility.tamu.edu/ums/report/) that congestion costs (in constant 2009 dollars) continue to rise from US$24 billion in 1982 to US$115 billion in 2009. This is associated with 3.9 billion gallons of wasted fuel (equivalent to 130 days of flow in the Alaska pipeline), and a $US808 cost impost per average commuter in 2009. The result is a predictable 'tragedy of the commons'.

Roads are possibly the most underpriced, in terms of user contributions, of all the public assets that we avail ourselves of. Regardless of whether some believe that governments should provide more road capacity to combat traffic congestion, it is an undeniable fact that if we provide more capacity under the existing road user pricing regimes and levels (registration and fuel pricing only), then more cars will use the roads, quickly using up the additional capacity. The great sadness about all of this is that there is a presumption that we all have rights to enter the traffic and delay all other motorists, yet not contribute to the true cost associated with delay and lost time – the curse of congestion.

To attempt to contain the growth in traffic congestion as well as to suppress it, some jurisdictions have introduced congestion charging as part of the reform of road pricing. Singapore was the first country to implement congestion charge in 1975, followed by Bergen in 1986, Oslo in 1990 and Trondheim in 1991, London in 2003, and Stockholm in 2007. The majority of existing congestion pricing systems are cordon charging, under which drivers have to pay for entering or leaving the charging zone (normally the central city area) during the designated time periods of the day. In recent years, there has been growing interest in charging regimes that are based on a distance charge ($ per km) across an entire road network. The proposed (but currently deferred) distance based charging scheme in the Netherlands is the most ambitious to date, planned for all vehicles on all roads in the entire country. In 2008, the Dutch Cabinet agreed to an average charge for cars of 3 euro cents per kilometre in 2012 (varying by the class of car), increasing to 7 euro cents in 2017.

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[1] AU$: Australian dollars

Many motorists argue that they pay enough anyway. But do they? There is enough evidence to suggest that they do not, for if they were being charged to use the roads at a level that is efficient, then we would avoid much traffic congestion. Many politicians still believe (as a result of their actions) that roads should be free (toll roads being the exception, although not in all circumstances); however "free" roads are not really free – the choice is between paying with time and frustration, or with money. Feel free to oppose it, but do not complain about the traffic. Opposing efficient pricing means you are choosing to endure continual congestion problems.

What we need to do in sorting out the pricing challenge is not to simply add a congestion charge on top of existing charges, but to undertake a complete overhaul of the entire charging regime, with options to replace some of the fixed charges (e.g., annual registration) with a usage charge based on kilometres driven by location (and vehicle emissions), so that those who obtain the greatest benefits (such as time savings) should contribute proportionally. This then would be a fair system, in contrast to the current system of registration and fuel taxes, which is far from fair. Pundits who claim a congestion charge is not fair should carefully think about how equitable the existing system is? Why should we all pay the same registration fee for a class of vehicle when we all travel different annual kilometres on the roads, at locations where congestion varies from nothing to significant?

To move from the traditional road pricing regimes (such as fuel taxes, parking fees, car registration fees) to a more dynamic congestion charge (in particular a variable user charge) is a radical reform. A congestion charging scheme is expected to have significant impacts on traveller behaviour and choices, impacting on departure time or the mode of travel in the short term (depending on the specific application of the charging regime), impacting in the longer run on the location of residence or change workplace, as well as individual welfare (better or worse off with a congestion charge). Hence, it is crucial to analyse and predict the effectiveness of such a charging scheme (e.g., can congestion be relieved under a proposed congestion charging system?) and public acceptability (in particular the key factors that would influence acceptability of such a scheme, see Jaensirisak *et al.* 2005 for a review on acceptability), before a congestion charge is actually implemented.

Stated preference (SP) techniques represent the state of art and practice approach to understand the potential impacts of a new product or policy and the behavioural responses towards it. In an SP experiment, respondents are asked to choose or rank among a number of alternatives, the attribute levels of which vary according to a statistical design aimed at maximising the precision of the estimates. As such, SP methods allow the analyst to mimic actual choices with a high degree of realism. In addition to SP, some studies use a much simpler way in which respondents are asked to provide their opinions on some policies where the attributes levels are not designed but pre-defined by the analyst (e.g., how acceptable a specific congestion charging regime is on a seven-point scale from 'very unacceptable' to 'very acceptable' - see Ubbels and Verhoef 2006a). This method is also called SP in some congestion charging studies that we review (see e.g., Tillema *et al.* 2010). However, this method is fundamentally different from a standard SP approach, and is more correctly called a *stated opinion* approach. We use this nomenclature to recognise the distinction between two methods.

Tollroad studies are not included in this review,[2] given that the primary purpose of tolling is to finance the construction and maintenance of roads, bridges or tunnels. This focus is on congestion charging, which is either cordon or network based[3], established as a fixed (i.e., a flat charging rate for all circumstances), a time of day (i.e., different rates for different time periods) or a vehicle differentiated charging scheme (i.e., different rates for different vehicle classes). Road charges for emissions, noise and other negative externalities are also excluded from this review. We review 17 published congestion pricing studies with a focus on the dimensions of the stated preference or opinion survey, especially the type of charging regime and the structure of the charge. The effectiveness and acceptability of different charging regimes, including behavioural responses such as changes in departure time, car use, mode, residential and work location, are synthesised, and used to provide insights into the ongoing inquiry into the design of road pricing schemes.

2 Stated Preference or Opinion Studies of Congestion Charging

Verhoef *et al.* (1997) is among the earliest empirical studies that investigated congestion pricing acceptability. Verhoef *et al.* sampled car drivers in the Dutch Randstad area and asked them to indicate their opinions on congestion pricing (e.g., "good idea", "bad idea", "no opinion"); however they did not clearly define the type of charge (e.g., cordon or the entire road network). This study is of limited value since it studied a 'generic' congestion charge[4]; rather in this review we concentrate on stated preference or opinion studies[5] that investigate one or more specific congestion charging regimes and proposed charging levels as an alternative or an element of an alternative option in a stated preference or opinion experiment. The reviewed studies are summarised in Table 1, where their key characteristics are provided, such as the modelling framework, research purpose(s), location of study, survey year, sample size, type(s) of congestion charging schemes presented in the experiment, the decision-making context, and trip purpose(s).

In total, 17 primary studies are reviewed, published between 2000 and 2011, with a data collection period ranging from 1996 to 2010. The sampled respondents are from 11 countries, namely the Netherlands, UK, USA, Greece, Italy, Germany, Norway, Denmark, New Zealand, Taiwan and Japan, with sample sizes varying from 272 (Taiwan) to 1,545 (the USA). Different modelling methods are used across studies such as probit, tobit, logit (multinomial logit (MNL), mixed MNL (MMNL), nested logit or error component) and regression. These studies are primarily focussed on the acceptability of congestion charging (e.g., Schade and Schlag 2003; Ubbels and Verhoef 2006a); and the effects of congestion charging in the short term through the impact on car use, and the longer term impacts such a changes in car ownership, mode or relocation of home or workplace (e.g., Ubbels *et al.* 2008; Tillema *et al.* 2010). Some studies also consider factors influencing the acceptability or effectiveness of congestion charging (e.g., Jaensirisak *et al.* 2005; Ubbels and Verhoef 2006b); and derive

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[2] Li and Hensher (2010), Li *et al.* (2010a) and Hensher *et al.* (Forthcoming) among others, have reviewed tollroad studies.

[3] In the literature, a distinction is often made between cordon and distance based (or variable) congestion charging. However, a cordon charge can be designed as distance based (see Jaensirisak *et al.* 2005; Nielsen 2004). In this paper, we use cordon vs. everywhere (or on all roads) to emphasise the key difference between two main charging regimes (i.e., with or without a spatial boundary).

[4] For example: "How do you positively or negatively feel about road pricing?" in Jou *et al.* (2010)

[5] A number of revealed preference (RP) studies on congestion charging have also been conducted (see e.g., Ozbay and Yanmaz-Tuzel 2008; Karlström and Franklin 2009).

values of travel time savings and travel time variability (e.g., Tseng and Verhoef 2008; van Amelsfort *et al.* 2008). Congestion charging regimes considered in these surveys concentrate on cordon charging (time of day, distance based, zone based or delay-time based charges) and kilometre charging on all roads (fixed, vehicle type differentiated or time of day charges), where the decision-making context covers the charging regime itself, departure time, route, and/or mode. Only Jaensirisak *et al.* (2003; 2005) sampled both drivers and non-drivers (public transport users) and compared the behavioural differences of those two groups; the other studies surveyed drivers only. All studies addressed commuting trips, although a few also considered other trip purpose (see e.g., O'Fallon *et al.* 2004; Jaensirisak *et al.* 2005). Nielsen (2004) also compared the behavioural findings from his SP data with RP (revealed preference) findings; while the other studies only use stated preference or opinion data.

Table 1: Key Characteristics of Reviewed Stated Preference and Opinion Studies

	Stated preference or stated opinion	Modelling framework	Research purpose(s)	Location	Survey Year(s)	Sample size	Respondents	Type(s) of congestion charging	Decision making context	Trip purpose(s)
Ubbels and Verhoef (2006a)	Stated opinion	Ordered probit	To investigate acceptability of congestion charging, and to understand systematic factors influencing its acceptability	the Netherlands	2004	564	Car drivers	*Kilometre charge on all roads* (fixed or vehicle type differentiated charges), and *daily bottleneck charging* (fixed, time of day or congestion-level dependent charges)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting
Ubbels and Verhoef (2005)	Stated opinion	Descriptive statistics	To investigate the effect of congestion charging on car use	the Netherlands	2005	562	Car drivers	*Kilometre charge on all roads* (fixed, fixed with time-of-day daily bottleneck charging, vehicle type differentiated or time of day charges)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting, visiting and others
Ubbels and Verhoef (2006b)	Stated opinion	Tobit	To investigate the effect of congestion charging on car use; and to understand systematic factors influencing its effectiveness	the Netherlands	2005	562	Car drivers	*Kilometre charge on all roads* (fixed or time of day charges)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting, visiting and other purposes
Ubbels *et al.* (2008)	Stated opinion	Tobit	To investigate the influence of congestion charging on car use, car ownership and relocation (residential and work)	the Netherlands	2005	562	Car drivers	*Kilometre charge on all roads* (fixed, vehicle type differentiated or time of day charges)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting, visiting and others
Schuitema *et al.* (2008)	Stated opinion	Ordered probit	To investigate acceptability of congestion charging and to understand systematic factors influencing its acceptability	the Netherlands	2005	562	Car drivers	*Kilometre charge* on all roads (fixed)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting, visiting and others
Tseng et *al.* (2005)	Stated preference	MNL	To estimate values of travel time saving and travel time variability	the Netherlands	2004	1,115	Car drivers	*Kilometre charge on all roads* (fixed)	Departure time, route and mode choice	Commuting
Tseng and Verhoef (2008)	Stated preference	MNL and MMNL	To develop a dynamic framework for estimating time-varying values of travel time	the Netherlands	2004	1,105	Car drivers	*Kilometre charge on all roads* (fixed)	Departure time, route and mode choice	Commuting

			Savings and variability							
van Amelsfort *et al.* (2008)	Stated preference	MNL	To estimate values of travel time saving and travel time variability	the Netherlands	2004	1,115	Car drivers	*Kilometre charge on all roads* (fixed)	Departure time, route and mode choice	Commuting
Tillema *et al.* (2010)	Stated opinion	Ordered probit	To investigate the impact of congestion charging on the decision of relocation (residential and work), and to understand systematic factors influencing relocation probability	the Netherlands	2005	465	Car drivers	*Cordon* (fixed) and *kilometre charge on all roads* (fixed or time of day charges)	Congestion charging schemes (different levels) along with different revenue allocations	Commuting
Schade and Schlag (2003)	Stated opinion	Regression	To investigate the acceptability of congestion charging and to understand systematic factors influencing its acceptability	Athens (Greece), Como (Italy), Dresden (Germany) and Oslo (Norway)	1998-1999	952	Car drivers	*Cordon* (fixed or time of day charges)	Package of road pricing schemes (congestion charging, parking charges and fuel taxes) along with different revenue allocations	Commuting
Nielsen (2004)	Stated preference	MNL and error component model	To investigate behavioural responses towards congestion pricing; to compare SP findings with RP	Copenhagen (Denmark)	N/A	300	Car drivers	*Cordon* (time of day combined with zone based or distance based with time of day and zone based charges (Kr per kilometre))	Route choice	Commuting
Jaensirisak *et al.* (2005)	Stated preference	MNL	To compare acceptability of congestion pricing between car users and non-users	Leeds and London (the UK)	2000-2001	830	Car drivers and non-drivers	*Cordon* (fixed, distance based, time based, or delay-time based)	Condon charging schemes along with traffic improvements revenue allocations, or environmental and	Commuting and other purposes
Jaensirisak *et al.* (2003)	Stated preference	Regression	To investigate the acceptability of congestion charging, and to understand systematic factors impacting the perceptions of personal and society's benefits	Leeds and London (the UK)	2000-2001	830	Car drivers and non-drivers	*Cordon* (fixed, time of day, distance based, or delay-time based)	Condon charging schemes along with traffic improvements revenue allocations, or environmental and	Commuting and other purposes
O'Fallon *et al.* (2004)	Stated preference	MNL and nested logit	To identify the variability in modal shift under a range of policies including congestion pricing	Auckland, Wellington and Christchurch (New	1999 for Auckland and Wellington; 2001 for	732	Car drivers	*Cordon* (fixed) and *kilometre charge on all roads* (fixed)	Mode choice	Commuting, school and other purposes

				Zealand)	Christchurch					
Jou *et al.* (2007)	Stated opinion and stated preference	Ordered probit for acceptability of congestion charges; MNL and nested logit for their impact on travel behaviour	To investigate acceptability and behavioural responses (e.g., modal switch) to congestion charging	Taipei (Taiwan)	2004	272	Car drivers, motorcycle drivers	*Cordon* (fixed or time of day charges)	Mode and route choice	Commuting
Yamamoto *et al.* (2000)	Stated preference	MNL	To investigate the effects of congestion charging on departure time and route choice	Osaka-Kobe metropolitan area (Japan)	1996	657	Car drivers	*Fixed congestion charging* rate on all toll roads	Departure time and route choice	Commuting and other purposes
Agrawal and Nixon (2011)	Stated opinion	Descriptive statistics	To investigate the support levels of a variety of pricing policies including congestion charging	USA	2010	1,545	N/A	*Kilometre charge on all roads* (fixed or vehicle type differentiated)	Congestion charging schemes	N/A

Notes:

The fractional factorial design is used in all reviewed SP studies with the number of SP tasks for each respondent ranging from four to 11, with the exceptions of Jou *et al.* (2007) where the design method is not mentioned.

Ubbels and Verhoef (2005), Ubbels and Verhoef (2006b), Ubbels *et al.* (2008) and Schuitema *et al.* (2008) are based on the same data set, where only Schuitema *et al* used one congestion pricing measure (i.e., fixed), and Ubbels and Verhoef (2006b) used two congestion pricing measures (fixed and time of day) are considered while the other two considered all three pricing policies (fixed, time of day and vehicle type differentiated).

Tseng *et al.* (2005), Tseng and Verhoef (2008) and van Amelsfort *et al.* (2008) are based on the same data set, where Tseng *et al.* (2005) and van Amelsfort *et al.* (2008) used all respondents (1,115) while Tseng and Verhoef (2008) used 1,105 respondents.

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2.1 Stated Preference and Opinion Congestion Charging Studies in the Netherlands

Nine out of 17 reviewed studies were undertaken in the Netherlands. Ubbels and Verhoef (2006a) developed a stated opinion experiment with three main charging measures (see Table 2), where Measure 1[6] is a daily bottleneck charge[7] (Euro (€) per day) that is a fixed, time of day or congestion-level dependent charge, and the revenue is hypothecated to construct new roads and improve existing roads (in total four alternative congestion charging systems); Measure 2 (with seven alternatives) is a distance based charge on all roads, with the rate depending on the type of vehicle,[8] with seven different revenue allocations; and Measure 3 (with nine alternatives) is a distance based charge on all roads with different charging rates and revenue allocations. 564 Dutch car drivers were sampled to obtain their opinions on the various congestion charging schemes. After the description of each measure, respondents were required to indicate how acceptable a specific measure is on a seven-point scale from 'very unacceptable' to 'very acceptable', as well as stating what they believed was the perceived effectiveness of each measure, the latter information subsequently used as an explanatory variable for investigating acceptability. This survey shows a low acceptance level with regard to congestion pricing. A series of order probit models were estimated, with the major findings being that revenue allocation is crucial to the acceptability of congestion pricing; and to use revenues to replace existing car taxes[9] or to lower fuel taxes would lead to a higher acceptance level. Furthermore, personal characteristics were found to influence acceptability, for example respondents with a higher education, higher value of time savings, and with a higher belief in the perceived effectiveness of the pricing regime, tend to be more accepting of congestion charging.

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[6] Measure 1A: charge of €1.00 at all times; Measure 1B: charge of €2.00 on working days, during peak hours: 7.00-9.00 and 17.00-19.00, no charge on other times; Measure 1C: peak-time charge: 6:00- 7:00: €0.50, 7:00-7:30: €1.00; 7:30-8:00: €1.75; 8:00-8:30: €2.50; 8:30-9:00: €1.75; 9:00-9:30: €1.00, 9:30-10:00: €0.50. The same structure for the evening peak (16.00-20.00); Measure 1D: charge depends on traffic density, and more congestion means a higher charge with a maximum of €5.

[7] Bottleneck charging is location based, where a fee is paid when passing a bottleneck (with congestion), which is similar to a cordon charge.

[8] Light cars pay 4 €cents per kilometre; middle weight cars pay 5 €cents per kilometre; heavy cars pay 6 €cents per kilometre. Monthly (extra) costs for the various types of cars based on average kilometres were presented to respondents.

[9] Current car taxation in the Netherlands consists of two main components: a tax on car ownership (annual charge) and a tax paid when purchasing a new car.

Table 2: Stated Opinion Study Attribute Levels in Ubbels and Verhoef (2006a)

Measure	Variant
1: Bottleneck passage	1A: flat toll throughout the week
	1B: coarse toll (flat within peak hours on working days)
	1C: multi-step toll during peak hours only
	1D: toll depends on actual traffic conditions
2: Kilometre charge differentiated by vehicle type	2A: Revenues to general budget
	2B: Revenues to traffic system
	2C: Lower car taxation and new roads
	2D: Revenues to public transport
	2E: Abolition of car ownership taxes
	2F: Lower fuel taxes
	2G: Revenues to improve and construct new roads
3: Kilometre charge with different charge levels and different revenue use	3A: 2.5 €cents, unclear revenue use
	3B: 5 €cents, unclear revenue use
	3C: 7.5 €cents, unclear revenue use
	3D: 2.5 €cents, improvement of road network
	3E: 5 €cents, improvement of road network
	3F: 7.5 €cents, improvement of road network
	3G: 2.5 €cents, abolish existing car taxation
	3H: 5 €cents, abolish existing car taxation
	3I: 7.5 €cents, abolish existing car taxation

Note: In Measure 2, vehicle type actually means car type, defined as light, middle or heavy car.

Ubbels and Verhoef (2005) investigated the effect of congestion charging on car use (the number of trips). In their experiment, sampled car drivers were shown three main pricing measures (see Table 3), where Measure 1 (with six alternatives) is a flat kilometre charge on all roads with three charging levels and different revenue allocations; Measure 2A is a combination of a fixed kilometre charge (2 euro cents per kilometre) on all roads and daily bottleneck charge according to time of day,[10] and Measure 2B is a car-type differentiated kilometre charge[11] where revenues will be used to abolish existing car taxation under Measure 2. Measure 3 (with six alternatives) is a time-of-day kilometre charge with different rates and revenue allocations. The respondents (562 Dutch car divers) were asked to indicate how many trips they make in a normal week for each purpose, and then whether they would change the number of car trips for three different trip purposes (commuting, visiting and other purposes), and to indicate the share of trips that will be changed, and also how they might be changed (such as switch to public transport, walking or bicycle, motorbike, carpool, work at home, travel at other times or give up the trip). This study found that on average, the number of car trips would be reduced by 11 percent under congestion charging, and a fixed distance-based charge would lead to a greater reduction in social trips than in commuting trips. The study also found a time-of-day kilometre charge (Measure 3) was a relatively effective instrument to relieve peak time congestion, which would mainly lead to changes in departure times, especially for commuting trips.

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[10] €per day charging is effective during peak times (morning and evening) on working days at daily bottlenecks: 6:00-7:00: €0.50, 7:00-7:30: €1.0, 7:30-8:00: €1.75, 8:00-8:30: €2.50; 8:30-9:00: €1.75, 9:00-9:30: €1.0, 9:30-10:00: €0.50. The same structure is applied to the evening peak (16:00-20:00).

[11] Light cars pay 4 €cents per kilometre; middle weight cars pay 6 €cents per kilometre; heavy cars pay 8 € cents per kilometre.

Table 3: Stated Opinion Study Attribute Levels in Ubbels and Verhoef (2005)

Measure	Variant
1: Flat kilometre charge with different charge levels and different revenue use	A: 3 €cent, abolition of car ownership taxes B: 6 €cent, abolition of existing car taxation (purchase and ownership) C: 12 €cent, abolition of existing car taxation and investment in new roads D: 3 €cent, revenues used to lower income taxes E: 6 €cent, revenues used to lower income taxes F: 12 €cent, revenues used to lower income taxes
2: Differentiated kilometre charge with different charge levels and different revenue use	A: 2 €cent with multistep (morning and evening) peak time toll on bottlenecks, revenues used to abolish car ownership taxes B: differentiated according to weight of the car, revenues used to abolish existing car taxation
3: Crude peak/off-peak kilometre charge with different charge levels and different revenue use	A: 2 €cent outside peak times and 6 €cent in peak, abolition of car ownership taxes B: 4 €cent outside peak times and 12 €cent in peak, abolition of existing car taxation C: 8 €cent outside peak times and 24 €cent in peak, abolition of existing car taxation and new roads D: 2 €cent outside peak times and 6 €cent in peak, revenues used to lower income taxes E: 4 €cent outside peak times and 12 €cent in peak, revenues used to lower income taxes F: 8 €cent outside peak times and 24 €cent in peak, revenues used to lower income taxes

Ubbels and Verhoef (2006b) applied the same data set from Ubbels and Verhoef (2005); however they only adopted the responses to two main pricing measures (i.e., Measures 1 and 3 in their 2005 paper, see Table 3). With respect to the effectiveness of congestion pricing, Ubbels and Verhoef (2006b) produced similar findings to those of Ubbels and Verhoef (2005). For example, a fixed kilometre charge mainly reduces social trips (e.g., through switch to non-motorized modes); and a time-of-day kilometre charge is preferred for reducing peak time traffic (mainly through departure time changes, and also mode change and working at time). Ubbels and Verhoef (2006b) also found that: 1) the charging rate would significantly impact the performance of the fixed kilometre charge; while only the difference between charging levels (e.g., peak vs. non-peak) has a significant impact on the time-of-day kilometre charge; 2) employed respondents show less willingness to change trips; and 3) people with higher incomes tend to be less price sensitive.

Ubbels et al. (2008) used the data set from Ubbels and Verhoef (2005) to investigate the influence of distance-based congestion charging on drivers' decision making on car use, car ownership and relocation (residential and workplace). With regard to the impact on car use (the number of car trips), Ubbels et al. (2008) reported similar findings to those in Ubbels and Verhoef (2005; 2006b). Respondents were also asked to answer questions on car ownership and relocation, such as whether to sell their car, and the probability of relocating because of congestion pricing. Ubbels et al. found that a kilometre charge only has a marginal impact on car ownership (only two percent of respondents may sell their car, compared with an 11 percent reduction in car trips); workplace relocation would be more substantial than residential change in response to congestion charging. The found some important factors influencing the relocation decision such as gross yearly household income, the annual number of kilometres driven, the degree of travel-cost compensation from employers, respondent education level, and the probability of relocating within two years.

Schuitema et al. (2008) used the car users' opinions in Ubbels and Verhoef (2005) with regard to 'everywhere' kilometre charging (i.e., Measure 1, see Table 3 above) to study the acceptability of such a scheme. In the experiment, the sampled respondents were asked to indicate how acceptable the distance-based charging was to them (from 1-very unacceptable

to 7-very acceptable). On average, car commuters have lower acceptability than other car users. For the whole sample, the order probit model shows that a distance-based charge would be more acceptable: 1) when car users expect a reduction in traffic congestion; 2) for car users with a lower number of annual kilometres driven; 3) when facing a lower charging rate; and 4) when revenues are used to decrease car-related taxes rather than decreasing income taxes.

Tseng *et al.* (2005) developed an SP experiment (see Table 5 for an illustrative example of a choice screen) to estimate the value of travel time savings (VTTS) and value of variability (e.g., values of schedule delay early/late). Each SP questionnaire has four alternatives represented by different modes (the first three alternatives are always car and the last alternative is public transport), routes (trip lengths), departure times and other attributes (e.g., travel times, arrival times, variability in time and costs). The sampled Dutch respondents (1,115 car commuters) were asked to allocate ten trips over these four alternatives, and each of them answered 11 choice tasks. The design[12] is based on a fractional factorial design (orthogonal non-linear main effects design) which has four levels for 13 of the attributes, and two levels for two of the attributes. There are two components of travel cost for car - fuel and a charge where the congestion charge is distance based with a flat rate of four levels (8, 10, 12, and 14 €cents per kilometre). The calculated value of travel time savings (VTTS) for car is €7.95 per person hour, the value of schedule delay early (VSDE) is €12.35 per person hour, and the value of schedule delay late (VSDL) is €16.44 per person hour. This study investigated observed heterogeneity in behavioural willingness to pay (WTP) values. For example, respondents with restricted work starting times tend to have higher VSDE and VSDL. The VSDE would be higher for a commuter with a restricted departure time. Fully compensated commuters generally have higher VTTS, and higher incomers tend to have higher VTTS, but lower VSDE and VSDL. Although, congestion charging is considered in Tseng *et al.*'s SP experiment, they did not specifically investigate the influence of congestion charging. In their utility function, a generic cost for car and public transport, where the cost for car is the sum of congestion charge and fuel, and fare for public transport. One improvement to Tseng *et al.* (2005) and the following two studies using the same data, could be to investigate the different behavioural responses towards congestion charging and fuel cost using separate parameters for congestion charge and fuel cost (see Nielsen 2004).

Table 4: Illustrative SP Choice Screen in Tseng *et al.* (2005)

Alternative A	Alternative B	Alternative C	Alternative D
Mode of transport: car	Mode of transport: car	Mode of transport: car	Mode of transport: public transport
Trip length : 35 km	Trip length: 35 km	Trip length: 49 km	Trip length: 35 km
Travel costs: € 8.10 of which:	Travel costs: € 4.60 of which:	Travel costs: € 6.20 of which:	Price of a ticket: € 3.18
– fuel: €3.20	– fuel: €3.20	– fuel: €4.20	
– charge: €4.90	– charge: €1.40	– charge: €2.00	
Departure time: 08.10	Departure time: 08.25	Departure time: 08.00	Departure time: 07.25
Total travel time between 40 and 50 minutes of which:	Total travel time between 50 and 60 minutes of which:	Total travel time between 55 and 65 minutes of which:	Total travel time: 72 minutes
– free flow: 25 min.	– free flow: 25 min.	– free flow: 40 min.	
– minimum time in congestion: 15 min.	– minimum time in congestion: 25 min.	– minimum time in congestion: 15 min.	
– maximum time in congestion: 25 min.	– maximum time in congestion: 35 min.	– maximum time in congestion: 25 min.	
Arrival time is hence between: 8.50 and 9.00	Arrival time is hence between: 9.15 and 9.25	Arrival time is hence between: 8.55 and 9.05	Arrival time: 08.37
Number of trips …..	Number of trips ….	Number of trips …	Number of trips …

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[12] The design has 44 choice sets, which is blocked into four sets of 11.

Tseng and Verhoef (2008) developed a dynamic framework for valuing time-varying values of travel time savings and variability, using the choice data set collected in Tseng *et al.* (2005). This study revealed significant variations in time-related shadow prices over the morning peak, with WTP values being time dependent, varying by time of day. Tseng and Verhoef argued that these time-dependent variations need to be considered in predicting behavioural responses to policies which may influence the time pattern of congestion during the morning peak. The choice data set collected in Tseng *et al.* (2005) was subsequently used in van Amelsfort *et al.* (2008) to estimate the values of travel time savings, schedule delay early and later. Compared with Tseng *et al.* (2005), the values reported in van Amelsfort *et al.* are systematically higher (e.g., VTTS: €11.38 per hour; VSDE: €17.17 per hour; VSDL: €23.37 per hour) than the values derived in Tseng *et al.* (2005).

Tillema *et al.* (2010) used a stated opinion approach to study the impact of congestion pricing on relocation decisions (home or workplace). Their experiment consists of different pricing measures (distance-based charges on all roads (based as fixed, vehicle-type dependent, or time dependent) and fixed cordon) and different revenue allocations, as shown in Table 5. The respondents (465 Dutch car drivers) were required to indicate whether they would relocate (closer to work) or change their job (closer to home) on a seven-point scale from 'highly unlikely' to 'highly likely', under the proposed congestion charging. Results show that only five percent of the respondents would consider residential relocation, and 13.5 percent would change jobs in response to congestion charging. Compared with an 'everywhere' kilometre charge, cordon charging has a larger impact on relocation decisions, due to its geographic distinction. This study also identified some key factors that influence relocation probability including gross annual household income (negatively), the annual number of kilometres driven (positively), the level of travel cost compensation from employers (negatively), respondent education level (negatively), and the probability of relocating within two years for whatever reason (positively).

Table 5: Stated Opinion Study Attribute Levels in Tillema *et al.* (2010)

Measure	Alternative
1. Km charge (flat) on all roads	A. 3 € cent/km, abolition of car ownership taxes B. 6 € cent/km, abolition of existing car taxation (purchase and ownership) C. 12 € cent/km, abolition of existing car taxation and building new roads D. 3 € cent/km, revenues used for lowering income taxes E. 6 € cent/km, revenues used for lowering income taxes F. 12 € cent/km, revenues used for lowering income taxes
2. Km charge on all roads	A. 2 € cent/km with a morning and evening peak time toll/point charge (time-dependent and stepwise) B. differentiated according to weight of the car, revenues used to abolish existing car taxation (4, 6, 8 € cent/km for respectively light, medium weight and heavy cars)
3. Km charge on all roads (time-differentiated)	A. 2 € cent outside and 6 € cent/km within peak periods, abolition of car ownership taxes B. 4 € cent outside and 12 € cent/km within peak periods, abolition of existing car taxation C. 8 € cent outside and 24 € cent/km within peak periods, abolition of existing car taxation and building new roads D. 2 € cent outside and 6 € cent within peak periods, revenues used for lowering income taxes E. 4 € cent outside and 12 € cent within peak periods, revenues used for lowering income taxes F. 8 € cent outside and 24 € cent within peak periods, revenues used for lowering income taxes
4. Cordon charge	A. 5 € for entering city of minimum 40 000 inhabitants, revenues used for lowering income taxes B. 5 € for entering city of minimum 40 000 inhabitants, revenues used for improving quality of public transport in region C. 5 € for entering city of minimum 40 000 inhabitants, revenues used for improving quality of public transport in whole country
5. Cordon charge	8 € for entering city of minimum 40 000 inhabitants, revenues used for lowering income taxes

2.2 Stated Preference and Opinion Congestion Charging Studies in other Locations

Schade and Schlag (2003) conducted their stated opinion survey in four different locations: Athens (150 respondents), Como (238 respondents), Dresden (281 respondents) and Oslo (285 respondents). Two policy packages were shown to respondents, each consisting of cordon charging (where Strategy A has a time of day charge and Strategy B has a fixed charge), increased parking fees, and increased fuel taxes, along with revenue allocation, and the respondents were asked to provided their acceptance levels (e.g., totally or rather acceptable) with regard to these two strategies, on a four-point scale. The regression results (where the dependent variable is the degree of approval Strategy A or B) show that acceptability is positively related to social norms (the perceived social pressure to accept the strategy), personal outcome expectations, and the perceived effectiveness of the policy. Compared with individuals' perceptions, their socio-economic characteristics have a marginal impact on acceptability.

Nielsen (2004) developed an SP experiment where two alternative routes were presented to the sampled respondents in Copenhagen. Two alternatives were defined as different running costs, congestion charges, free-flow times and congestion times. The proposed congestion charge is a time-of-day cordon charge either based on kilometres driven (which has two categories of charging levels: high kilometre-based pricing and low kilometre-based pricing) or a per-crossing charge which also varies according to time of day (peak vs. non-peak hours), where all of them vary according to the zone travelled in[13] (see Figure 1). After the SP experiment, a field GPS experiment was conducted to observe drivers' real behavioural responses under congestion pricing, where the same charging regimes in the SP experiment were applied in the revealed preference (RP) survey. In the logit models, the parameter of congestion pricing is higher than that of running cost (mainly petrol) suggesting a higher marginal disutility associated with congestion pricing, and hence a lower willingness to pay relative to running cost. In an error components model, the VTTS for free flow time where the denominator is congestion charging, is 34.7 Danish krone (Kr)[14] per hour, and Kr54.5 per hour where the denominator is running cost. The corresponding values for congestion time are Kr52.1 per hour and Kr81.8 per hour. The VTTS from RP is about one third lower than from the SP model, which is the opposite of the finding by Brownstone and Small (2005) which estimated a much lower VTTS from SP (almost half of the RP value). A lower RP willingness to pay suggests that respondents' behavioural changes under congestion charging were overestimated in the SP study. Nielsen (2004, p.251) explains that: "This may be explained by the fact that the level of the changes may force participants to change behavio[u]r due to [the] budget constraint".

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[13] The inner city marked with "A" in Figure 1 is the most expensive zone, the four "B" zones are the second most expensive, the three "C" zones are the third most expensive, and the three "D" zones are the cheapest.
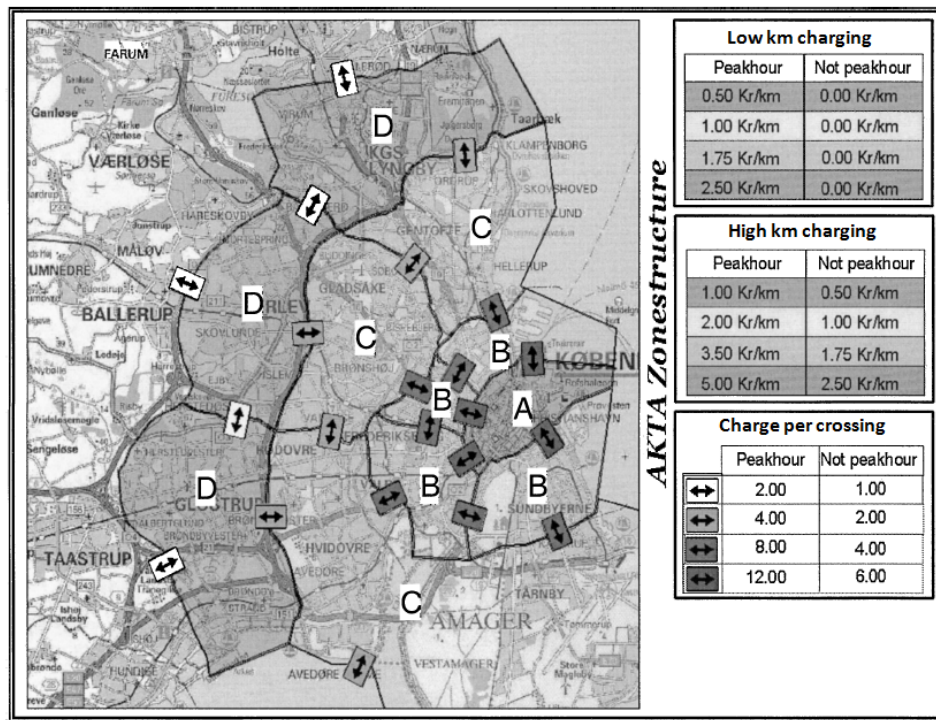[14] 1 Danish krone ≈ 0.18 Australian dollar or 0.14 Euro.

Low km charging

Peakhour	Not peakhour
0.50 Kr/km	0.00 Kr/km
1.00 Kr/km	0.00 Kr/km
1.75 Kr/km	0.00 Kr/km
2.50 Kr/km	0.00 Kr/km

High km charging

Peakhour	Not peakhour
1.00 Kr/km	0.50 Kr/km
2.00 Kr/km	1.00 Kr/km
3.50 Kr/km	1.75 Kr/km
5.00 Kr/km	2.50 Kr/km

Charge per crossing

	Peakhour	Not peakhour
↔	2.00	1.00
↔	4.00	2.00
↔	8.00	4.00
↔	12.00	6.00

AKTA Zonestructure

Figure 1: Variations in Congestion Charges in Nielsen (2004)

Jaensirisak *et al.* (2005) conducted a congestion pricing study in two UK cities with 660 respondents in Leeds and 170 respondents in London. In their SP experiment, a cordon charge was effective from 7am to 7pm on weekdays, established as a fixed charge (£[15] per day with four levels: £1, £3, £5, £7), distance based (£ per mile with four levels: £0.1, £0.3, £0.6, £1 per mile), time based (£ per minute with four levels: £0.02, £0.05, £0.08, £0.12 per minute) or delay-time[16] based (£ per delayed-minute with four levels: £0.05, £0.15, £0.25, £0.40 per delayed-minute). In each SP task, there are four alternatives, and each of them is represented by three basic attributes (congestion charging, car travel time reduction and bus travel time reduction (travel time reduction has three levels: a quarter, a half or three quarters)), plus an additional attribute (either revenue allocation (public transport, tax reduction or 50:50 public transport and tax reduction), environmental improvement (as now, slight or substantial), charged area (small or wide[17]), charged time (7am-7pm or 7am-10am) or charge type. Each respondent was asked to indicate how each alternative situation would benefit herself/ himself and society on an 11-point scale; whether or not to vote for each alternative; and to choose a mode of travel under each alternative situation from four options: car, car with a different departure time, bus, and other. The survey was conducted between 2000 and 2001and each respondent answered one SP exercise (out of five) only with four SP tasks; a fractional factorial design was used.

Jaensirisak *et al.* (2005) found a low acceptance level of congestion pricing in the UK. Compared with car users, non-users show a higher acceptance level on average, mainly because of a lesser impact on them of congestion charging. The MNL model also reveals that

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[15] 1 British pound ≈ 1.60 Australian dollar or 1.16 Euro
[16] Delayed time is defined as "the time spent moving slowly or stopped in congested traffic, at traffic lights, or bus stops", and a delayed-time based charge is a charge according to the delayed time travelled.
[17] Wide and small areas are within the North/South Circular Roads and Inner Ring Road for London, and the Outer Ring Road and Inner Ring Road for Leeds

congestion charging is more acceptable to people who perceived pollution and congestion as very serious issues and the current situation unacceptable, and believed that congestion pricing is able to reduce congestion. Income has no significant influence on acceptability in this study; while older respondents tend to be less likely to accept congestion charging. To achieve substantial environmental improvements is found to have the most positive impact on increased acceptability, followed by reduced delayed time for cars; however revenue allocation is a marginal contributor. Under a cordon charging scheme, Jaensirisak *et al.* also found that respondents tend to prefer a fixed charge over the time, distance, and delay-time based charging mechanisms, mainly because they want to know how much the charge would be before travelling. Li and Hensher (2010) found similar evidence in the context of tollroads: "A distance-based charging scheme appears in reality, to create more uncertainty for drivers, as the amount of toll charge is relatively ambiguous, unlike the flat toll road, where drivers know the exact amount before they use the toll road" (p.560).

The SP data in Jaensirisak *et al.* (2005) was also used in an earlier paper by Jaensirisak *et al.* (2003) to investigate the selfish (i.e., primarily concerned with their own benefits) and social perspectives (i.e., primarily concerned with society's well-being) of individuals. They found that acceptability is both influenced by the perceptions of personal and society benefits, while the impact of personal well-being is stronger. Two regression models (where the dependent variables are the rating ('to self' and "to society") on an 11-point scale) revealed some systematic factors impacting the perceptions of personal and society benefits. For example, increasing the charging level would negatively impact the perceptions of personal and society benefits. Elderly people, non-car users, and London respondents (vs. Leeds respondents) tend to have more positive perceptions of personal benefits under a congestion charge. Relative to socio-demographic characteristics, the perceptions of benefits to society are more influenced by personal perceptions (for example, positively if perceiving congestion charging would be effective in terms of congestion relief; positively if perceiving the current traffic is unacceptable; and negatively if disliking congestion charging).

O'Fallon *et al.* (2004) conducted an SP experiment in three NZ cities: Auckland, Wellington and Christchurch, where 11 policies to reduce car use or improve public transport were considered. For congestion charging, a cordon charge[18] before 10am was proposed with three levels (0, NZ$5[19], NZ$10 per entry for Auckland and Wellington; 0, NZ$2.5, NZ$5). O'Fallon *et al.* also proposed a kilometre-based vehicle surcharge (three levels: 0, NZ$0.1 per kilometre, NZ$0.3 per kilometre) which is of a similar effect to a distance-based congestion charge on all roads. The SP design has ten attributes, where each attribute has three levels. A fractional factorial design was used to create 81 scenarios, where all ten main effects were independent and orthogonal. Each respondent answered nine choice tasks and was asked 'if all these changes were in place on that day, how would you have travelled to work or your place of study? There were seven options for a trip: to continue to drive a car; to become a passenger in a car; to arrange carpooling; to walk and catch public transport; to drive, park and ride public transport; to use a bicycle; and other (including walk, work from home for some or all of the day, taxi, change time of trip). An SP choice screen example is shown in Figure 2.

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[18] In Wellington and Christchurch, the designed cordon areas were the CBD; while in Auckland, it is larger than its CBD.

[19] 1 New Zealand dollar ≈ 0.72 Australian dollar or 0.52 Euro

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We focus on the impact of congestion charging only from O'Fallon *et al*. (2004), given the scope of this review. O'Fallon *et al*. indentified congestion charging as the most effective way of encouraging modal shift (measured as 'a percentage shift of car drivers to another mode') among the selected policies. For example, in Wellington, about 11 percent of sampled car drivers would switch to another mode if a NZ$10 cordon charge were implemented, which is the greatest impact of any single policy. In Christchurch, the distance based charge on all roads would contribute to the most substantial modal shift, for example, a NZ$0.3 per kilometre charge would contribute to an eight percent modal shift in Christchurch. In Auckland, the effects of a cordon charge and an 'everywhere' kilometre charge are similar (modal shift: 4.5 percent and 5.1 percent correspondingly). The different impacts of congestion charging reflect the different travel habits in these city centres (e.g., the percentage of Wellington drivers who had crossed into the cordon area before 10am in the previous week is higher than in other two cities), as well as different geographic characteristics. For example, Wellington drivers generally would find it more difficult to find alternative routes if a cordon charge were imposed (because the Wellington cordon area cuts completely across major through-routes and is bounded by the sea and hills), while Christchurch drivers would more easily find alternative routes under a cordon charge. Given the different impacts of a single policy in three locations, O'Fallon *et al*. suggested that a package with multiple policies should be implemented to address congestion across NZ urban centres.

Figure 2: Illustrative SP Choice Screen in O'Fallon *et al*. (2004)

Jou *et al*. (2007) sampled car drivers and motorcycle drivers to investigate the acceptance level of congestion charging in Taiwan. Cordon charging is first introduced in the stated opinion survey as three cordon schemes: a fixed cordon charge, a credit based charge[20], and a time-of-day charge. Under each charging scheme, the rates are different for cars and motorcycles. Respondents were required to indicate their acceptance level with regard to each measure from 1 (most unlikely to accept) to 5 (most likely to accept), and the acceptable highest price for car and motorcycle (there are five levels of suggested prices). Jou *et al*. also

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[20] That is, drivers are free to enter the planned area a certain number of times per month, and are asked to pay for entering the planned zone after exceeding their limit.

analysed driver choices under each congestion charging regime using an SP experiment, where the respondents were asked to make a choice from seven alternatives (pay and drive a car; pay and ride a motorcycle; drive a car and use the alternate free route; ride a motorcycle and use the alternate free route; take bus; take transit; take bus and transit), and each alternative is defined as a bundle of attributes according to the nature of that alternative (e.g., congestion charge, walking/waiting time; in-vehicle time; gasoline cost parking cost and/or fare). Jou *et al.* found a relatively low level of acceptance of congestion charging, and a low possibility of switching to public transport. Moreover, the time-of-day cordon charge is more acceptable than the fixed cordon charge. They used a series of ordered probit models to study the acceptability of various road pricing schemes for car drivers and motorcycle drivers, and multinomial logit and nested logit models were used to investigate their impacts on commuter travel behaviour. They found congestion charging is more acceptable for car commuters when travelling during peak hours, with longer travel times in the morning trips, with higher willingness to pay, and with more positive perceptions of congestion pricing. In their logit models, the parameter of congestion pricing is marginally significant; the key variables that influence travel choices are travel cost, in-vehicle time and out-of-vehicle time.

Yamamoto *et al.* (2000) undertook an SP study in Japan, interviewing 657 car drivers. The alternatives in the experiment were represented by four attributes with four levels each (congestion pricing period: 1 hour to all day; congestion pricing rate: 100 yen[21] to 700 yen per day; and decreased travel time on freeway, and increased travel time on surface street). A respondent was required to choose an alternative under each hypothetical situation from six options (travel on freeway or surface streets before, during or after the congestion pricing period). A fractional factorial design was used, and each respondent answered four SP tasks. The major finding of this study is that a higher cordon charging rate would lead more drivers to travel before the congestion pricing period; while a longer charging period has a marginal impact on driver choice behaviour. A reduction in travel time on freeways would cause more drivers to choose a freeway during the congestion pricing period, but an increase in travel time on surface streets has no significant influence on choice behaviour.

We only found one published congestion charging study conducted in the US by Agrawal and Nixon (2011), and in their stated opinion survey, they asked Americans' opinions on a national distance based congestion charging which has two alternatives: a one cent per mile[22] charge for all cars and a vehicle differentiated charge with an average rate of one cent per mile. Other pricing scenarios were also considered in Agrawal and Nixon (2011) such as increases in gas taxes and sale taxes. They found that the flat distance based charge has the lowest support level (21% of sampled respondents supported it) and the vehicle differentiated charge is preferred which received 12 percentage points more support than the fixed charge. Safirova *et al.* (2005, p.170) explained the possible reason for so limited stated preference or opinion congestion charging research in the US: "Perhaps because in most metro areas congestion is perceived to be concentrated on major highways located in metro areas—both radial roads and ring roads around cities (beltways)—cordon tolls or area licensing did not seem to be appealing to practitioners and researchers". The road pricing scheme that the researchers in the US and Canada have concentrated on is high-occupancy tolling (HOT). Under such a scheme, a single-occupant vehicle is allowed to use high-occupancy vehicle (HOV) or express lanes reserved for cars with multiple occupants by paying a toll (e.g., State Route 91 (SR 91) in the US). A single-occupant vehicle may also use free lanes to avoid the

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[21] 100 Japanese yen ≈ 1.20 Australian dollar or 0.87 Euro
[22] 1 mile=1.61 kilometre

toll and have to contend with time delays. Although this tolling scheme may reduce congestion to some extent, it is not within the scope of this review paper.[23] Moreover, this form of tolling is less efficient than congestion charging (e.g., cordon), as suggested by Safirova *et al*. (2005), amongst many other researchers.

3. Conclusions

This paper has reviewed 17 published congestion pricing studies where eight studies used stated preference experiments, eight used stated opinion surveys, and one study has both stated preference and stated opinion data (i.e., Jou *et al.* 2007). The key characteristics of these studies are the type(s) of congestion charging schemes in the experiment, the modelling framework, research purpose(s), location of study, decision-making context, and trip purpose. Some common findings are that the acceptance level of congestion pricing is low, and personal perceptions (e.g., perceived effectiveness) of congestion charging are important to gain acceptability. This review also revealed some contradictory findings across the studies. For example, revenue allocation is a key factor influencing acceptability in Ubbels and Verhoef (2006a), and congestion charging would be acceptable if revenues from charging are used to reduce car-related taxes than to decrease income taxes (Schuitema *et al.* 2008), but not in Jaensirisak *et al.* (2005).

Despite low acceptability, congestion pricing would have some significant impacts on traveller behaviour and choices if it were imposed. Given that a congestion charge is typically applied during hours with severe road traffic, and varies according to the time of day (e.g., the Stockholm's congestion charge is effective from 6.30am to 6.29pm, where the highest charging rate is between 8.30 am and 8.59 am, and between 4.00 pm and 5.29 pm), an adjustment to departure time is the most attractive response to this time-of-day charging. Politically this may well be the way to begin, since the opportunity to stay with the car and avoid the congestion charge is real (within limits of flexibility on ability to vary time of day of travel). Some reviewed studies found that congestion charging would shift departure times (see e.g., Ubbels and Verhoef 2006b; Yamamoto *et al.* 2000). Tseng *et al.* (2005) also found that the flexibility in departure times would influence values of travel time savings and travel time variability. In addition to its influence on departure time choice, congestion charging may have other significant impacts on driver behaviour and choices such as reduced car use (e.g., Ubbels and Verhoef 2005; Ubbels *et al.* 2008), a switch to other modes (e.g., O'Fallon *et al*. 2004; Jou *et al.* 2007), and relocation of work and/or residential activity (Ubbels *et al.* 2008; Tillema *et al.* 2010).

Table 6 summarises the potential car use responses to a range of congestion charging schemes. For distance based charging regimes, for example, Ubbels and Verhoef (2005) suggested that a fixed kilometre charge would lead to a 5.9 percent reduction in the number of car commuting trips mainly through mode change (public transport or non-motorised mode); while under a time-of-day kilometre charge 15 percent of commuting trips would be reduced or shift departure time, suggesting the main difference between two charging regimes is with or without an impact on departure time choices. Under the time-of-day charge, 47.7 percent of the trips that would be adjusted would be replaced by trips made during off-peak hours. For cordon charges, O'Fallon *et al.* (2004) predicted that a NZ$10/entry cordon charge would lead to 4.5 percent modal shift from car to other modes in Auckland and 11

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[23] See e.g., Small *et al.* (2005) and Brownstone and Small (2005) for SP studies on tolling in the US.

percent modal shift in Wellington. These findings show that the number of car-commuting trips would be reduced by 4-15 percent under various charging schemes. Given that a five percent reduction in car-commuting trips would have a significant impact on congestion relief, these finding are promising.

Table 6 Summary of Car Use Response to Congestion Charging Schemes

Congestion Charging Scheme	Impact on car use	Country	Reference
Fixed kilometre charge on all roads (3-12 €cents/km)	Commuting trip: a 5.9 percent reduction in the number of trips; Visiting trip: a 14.2 percent reduction in the number of trips	the Netherlands	Ubbels and Verhoef (2005)
Car-type differentiated kilometre charge on all roads (Light cars: 4 €cents/km; middle weight cars: 6 €cents/km; heavy cars: 8 €cents/km)	Commuting trip: a 4 percent reduction in the number of trips; Visiting trip: a 8.4 percent reduction in the number of trips	the Netherlands	Ubbels and Verhoef (2005)
Time-of-day kilometre charge on all roads (Non-peak: 2-8 €cents/km; Peak: 6-24 €cents/km)	15 percent of commuting trips and 14.6 percent of visiting trips would shift to other modes or change departure times, where half of them would be adjusted through the departure time change.	the Netherlands	Ubbels and Verhoef (2005)
Time-of-day distance based and zone based cordon (Non-peak: 0.5-2.5 Kr/km; Peak: 1-5 Kr/km)	7.8 percent reduction in the number of trips	Denmark	Nielsen (2004)
Time-of-day zone based cordon (Non-peak: 1-6 Kr/crossing; Peak: 2-12 Kr/crossing)	0.5 percent reduction in the number of trips	Denmark	Nielsen (2004)
Fixed cordon (NZ$5/entry)	1.8 percent shifted from car drive to other modes in Auckland and 7.9 percent in Wellington	New Zealand	O'Fallon *et al.* (2004)
Fixed cordon (NZ$10/entry)	4.5 percent shifted from car drive to other mode in Auckland and 11 percent shifted in Wellington	New Zealand	O'Fallon *et al.* (2004)
Fixed kilometre charge on all roads (10 NZ$ cents/km)	4 percent shifted from car drive to other mode in Christchurch and 1.3 percent in Wellington	New Zealand	O'Fallon *et al.* (2004)
Fixed kilometre charge on all roads (30 NZ$ cents/km)	8 percent shifted from car drive to other mode in Christchurch and 4.1 percent in Wellington	New Zealand	O'Fallon *et al.* (2004)

Some studies compared different charging regimes. For example, Jaensirisak *et al.* (2005) found that a fixed cordon charge is preferred over a variable cordon charge (e.g., distance based) in the UK, mainly because it is more transparent. However, a major drawback of a fixed charge is a lack of efficiency (i.e., all trips are charged at the same rate, despite that they produce different congestion due to different departure times or different trip lengths). Hence some flexibility needs to be added into the fixed charging regime. Jou *et al.* (2007) found that the time-of-day cordon charge is more acceptable than the fixed cordon charge in Taiwan. Ubbels and Verhoef (2005) encouraged a time-of-day kilometre charge as an instrument to relieve peak time congestion; and Ubbels and Verhoef (2006b) also explain that a time-of-day kilometre charge reduces congestion mainly through departure time changes. There is clear evidence that the difference between charging levels (e.g., peak vs. non-peak) is important to its performance. However, an 'everywhere' kilometre charge is not always more effective than a fixed cordon charge. For example, Tillema *et al.* (2010) found that a fixed

cordon charge has a larger impact on relocation decisions than a kilometre charge on all roads, suggesting a more substantial long-term influence of cordon charging. O'Fallon *et al*. (2004) revealed that a fixed cordon charge is more effective in terms of modal shift (from car to other modes) in Wellington; while an 'everywhere' kilometre charge is preferred in Auckland and Christchurch. The difference is mainly attributed to different travel habits (e.g., a higher percentage of sampled Wellington drivers indicated that they had entered the cordon area before the experiment). When designing a congestion charging scheme, some relevant issues identified from previous studies that need to be considered in future studies are the travel habits of drivers and the geographic characteristics of the city. Moreover, a package consisting of multiple policies is recommended to reduce congestion, rather than a congestion charge alone.

This review also reveals a common weakness of existing congestion charging experiments, namely the lack of systematic treatment of all key themes identified in one experiment including acceptability and effectiveness of charging, alternative charging regimes (cordon or everywhere), the temporal specification of the charge (fixed or time of day), and revenue allocation, as well as the various coping or response strategies that might result from congestion charging such as departure time change and modal switch, and the impact of congestion charging on travel time and travel time variability for alternatives with different charging regimes. For example, Tseng *et al.* (2005) analysed the choice under kilometre charging only in their SP study; however the acceptability of such a scheme, revenue allocation, and alternative charging regimes were not investigated. Jaensirisak *et al.* (2005) addressed the acceptance level of charging, different charging regimes and revenue allocation; however they addressed these elements separately as five unrelated SP exercises. Each separately focused on revenue allocation, environmental improvement, charging period, charging area or charging method, where only fixed cordon charging was considered in the first four SP exercises along with one specific focus. In the fifth SP exercise, although both fixed and distance-based cordon charges were considered, other elements (e.g., revenue allocation[24]) were absent with the total sample divided into five sub-groups with each group participating in only one SP exercise.

We believe that because of the rather partial and somewhat fragmented way in which most previous SP and opinion surveys have investigated the role of congestion charging schemes (embodying the charge the regime and the revenue disbursement strategy), the findings are anything but informative to a limited extent. The challenge in trying to synthesise the evidence in this paper is illustrative of the current knowledge we have on the potential impact of congestion charging schemes on the performance of the road network, consequent of possible behavioural responses. The opportunity to build substantively on the current state of the art (and practice) in using SP and stated opinion methods to investigate the role of congestion charging is significant.

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[24] This may be a reason why revenue allocation is not statistically significant in their MNL model, given that they pooled five individual data sets together.

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