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Equity Effects of Road Pricing: A Review

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Equity Effects of Road Pricing: A Review

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ABSTRACT *Are road pricing strategies regressive or progressive? This is a question that has been confronting researchers, practitioners, and policy-makers who seek to implement new mechanisms to raise funds for transportation while simultaneously managing demand. The theoretical literature is mixed, as is the empirical literature. In part, this has to do with the various types of road pricing strategies that are being debated, different definitions of equity, and alternative assumptions about revenue recycling. Despite this seeming complexity, the literature is clear that equity issues are addressable. This paper provides a synthesis of the literature to date on both the theory of equity, as applied to road pricing, and the findings of empirical and simulation studies of the effects of particular implementations of road pricing, and suggested remedies for real or perceived inequities. To summarize, while there are certainly potential issues with equity associated with road pricing, those issues can be addressed with intelligent mechanism design that provides the right incentives to travellers and uses the raised revenues in a way to achieve desired equitable ends. These include cutting other taxes and investing in infrastructure and services.*

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Introduction

Social welfare comprises both efficiency, a measure of the degree to which system outputs achieve a theoretical maximum (minimum) using the same level of inputs, and equity, a measure of the distribution of outputs (or inputs) across some population. Political acceptability depends very much on the distribution (and perception of the distribution) of gains and losses to a proposed change. This paper examines equity issues surrounding road pricing, which raises revenue and offers the ability to manage demand on the road network by location and time of day, charging more when and where congestion is in place.

Alternatives to pay for roads are motivated by numerous factors:

- First, there is a trend toward higher mileage cars and ultimately away from gasoline as the fuel of choice for both environmental and economic reasons, affecting gas tax revenue, which in many places is dedicated to roads.

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- Second, there is a desire to better tie road charges to road use, in particular to be specific by time of day and location to address congestion issues.
- Third, there is a need to raise additional revenues for transportation, both to maintain and replace aging infrastructure, and to expand transportation networks to serve growing demand.
- Fourth, there is an environmental interest in directly internalizing the non-congestion externalities of road use, and the fuel tax can only do so indirectly,[1]
- Fifth, private ownership, which is increasingly seen in the roads sector, tends to require a dedicated stream of revenue associated with the specific facility.
- Sixth, there is political advantage to shift the burden of payment and tax exporting.[2]

Ramjerdi writes: "Sen (1992) states that every normative social theory that has stood the test of time demands equality along some dimension that is regarded as particularly important in that theory. Sen also suggests that demanding equality in one space implies inequality in some other space." (2006, p. 67) Within road pricing there are three decisions that affect equity: allocating the burden of charges, spending the revenue, and distributing the externalities (Langmyhr, 1997). Road pricing also affects the amount and type of mobility that is subsequently consumed. Rietveld (2003) argues equity plays two roles in transport: inequity may be a side effect of attempts to address efficiency and environmental issues, and equity may be the target of policies such as building infrastructure in undeveloped areas.

Flynn (2006) reviews the literature and identifies steps necessary to implement pricing in New York, he cites (Jones, 2001) that inequity can be mitigated through five parameters:

- the basis of charging (e.g. point charges, cordon or area charges, trip length charges),
- the area covered by the charge,
- the time period covered,
- discounts or exemptions, and
- linkages to other transport charges such as reduced public transit fares.

The first three items are questions of the design of the system. Roughly pricing proposals break down into facility-based (a road or a High Occupancy Toll (HOT) lane), area-based (a cordon or area-wide charge), or network-wide (distance-based charges or charges on many or every link). The latter two items in the list are questions of what to do with the revenue that is collected.

On the topic of road pricing at the intersection of engineering and economics, equity arises as a central feature in effectiveness, acceptability and implementability. Foster (1974, 1975) was perhaps the first to argue that road pricing discriminates against the poor. Depending on circumstances, this may be true if revenues are not recycled (i.e. used in a way that benefits the lower income group). The marginal utility of money may be higher among the poor (Brekke *et al.*, 1996; Brekke, 1997; Medin *et al.*, 2001), leading to difficulties in analysing the welfare effects of pricing if money is assumed equally valuable.

Any change will create winners and losers, and though there is always a search for Pareto Efficient solutions (at Pareto Optimality no one can gain without someone losing), in practice these solutions are hard to come by, especially if it is

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desired that the losers actually be compensated (Pareto Efficiency only requires that compensation could theoretically be made, not that it actually take place). The Dalton Principle says that transfer of income to a lower income individual from a higher income individual, so long as it keeps the rankings of individuals unchanged, improves equity (Ramjerdi, 2006; Rietveld, 2003).

The equity issues associated with road pricing (on both public and private roads) have not escaped academic attention, a brief review (almost certainly incomplete) has turned up more than 100 papers on the topic. The findings of the important contributions are summarized below.

This paper next develops a typology of road pricing. This is followed by various definitions of equity. Next presented are empirical findings from studies of in-place (or soon to be in-place) pricing trials. Simulated findings from proposed scenarios are described. Acceptability is considered and winners and losers identified. A discussion of what to do with the revenue follows. The paper closes with discussion and conclusions.

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Types of Road Pricing

Figure 1, in the form of a 3-dimensional matrix, organizes the major dimensions of road pricing: the spatial resolution (which set of links are priced: all links, links on a particular facility, or links in or defining a particular region), the pricing objective, and the temporal resolution of how quickly prices shift. This matrix implies $6 \times 5 \times 3 = 90$ different types of road pricing. And while incomplete, this considers much of the literature and likely policy directions. This does not directly address a number of other parameters (e.g. ownership, regulatory regime, duration of pricing period, relationship to other road charges, differentiation between cars and trucks).

The current US situation, where gas taxes applied uniformly over states is best described as the upper left cell of the front page of the matrix: general pricing with uniform links, with average cost prices, that are coarse (unvarying over time, at least within the congested period). The theoretical ideal from an economic efficiency point-of-view is in the bottom right of the last page of the matrix, general pricing with differentiated links (not all links have the same price), using first-best marginal cost prices[3] which vary dynamically over time.[4] The practical difficulties prevent moving from the upper left to the lower right, (not the least of which are implementation (transaction and collection) costs) leaving many interim, sometimes called second-best solutions as the range of potential policy solutions. Verhoef *et al.* (2003) describe potential implementation paths for social marginal cost-based pricing strategies, emphasizing the need to consider second-best pricing approaches rather than switching to road pricing in a 'big bang' all-at-once transition.

There are many types of road pricing, each located at different points on the efficiency and multi-dimensional equity frontier.

Defining Equity: Dimensions and Measures

Dimensions of Equity

The term equity has both a descriptive (positive) and normative use. It is generally considered a question of degree: a situation is more or less equitable; rather

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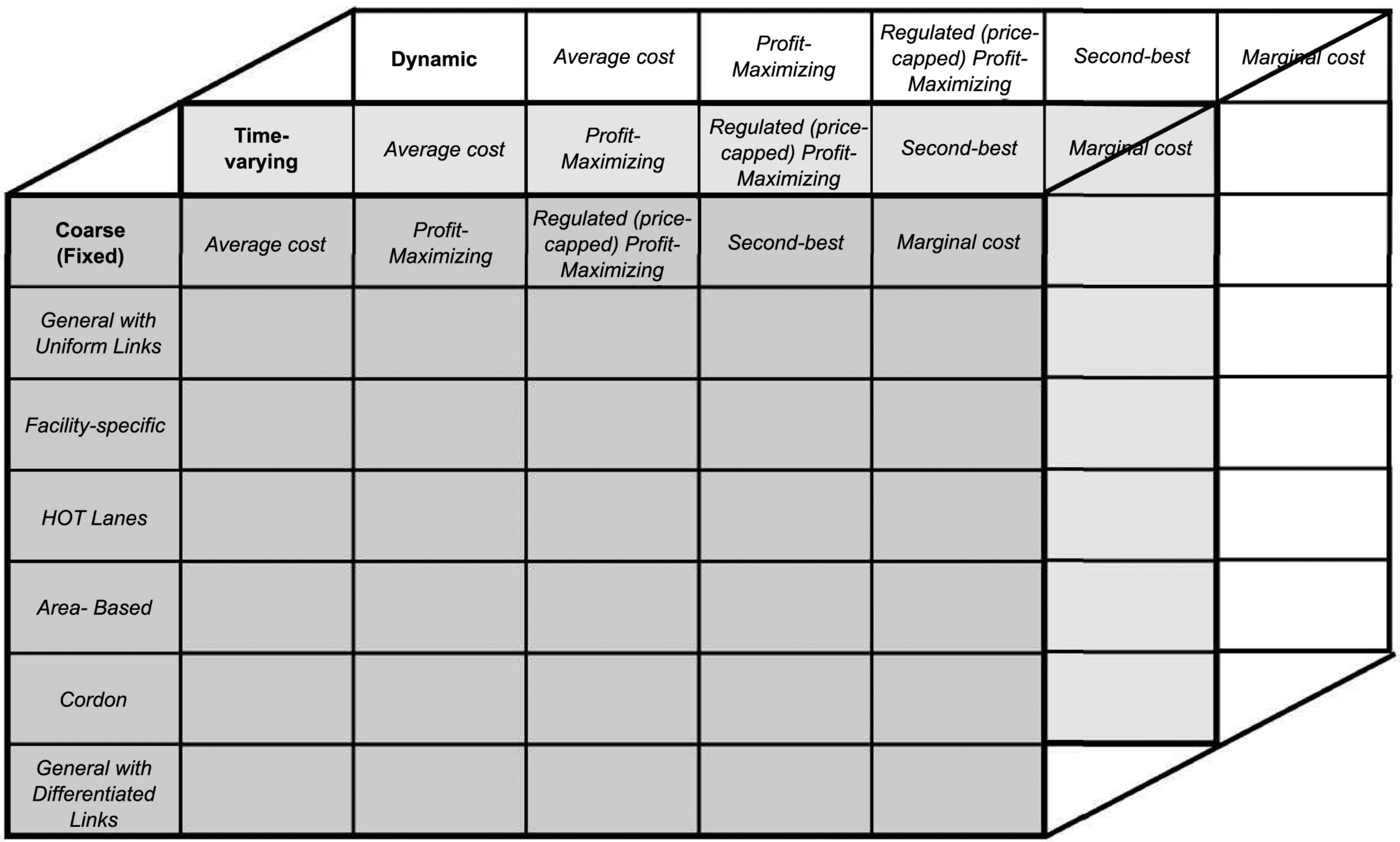

Figure 1. Types of road pricing strategies. Each row indicates a different spatial type, each column a different pricing objective, and each page a different temporal resolution on the pricing strategy.

than an absolute: a situation is or is not equitable. A number of the terms used are discussed below:

- Opportunity, or process, equity—the extent to which there is fair access to the planning and decision-making process (Fairness).
- Outcome, or result, equity—the extent to which consequences of a decision are considered just (Justice).

Within outcome equity, there are a number of dimensions across which equity can be quantified:

- Horizontal equity—the extent to which individuals within a class (e.g. in come, gender, ability, race) are treated similarly
- Vertical equity—the extent to which members of different classes are treated similarly
- Spatial, or territorial, equity—the extent to which benefits and costs are distributed equally over space (Viegas, 2001)
- Longitudinal, generational, or temporal, equity—the extent to which benefits and losses are distributed to the present or the future (Viegas, 2001)
- Market Equity, or the benefit principle, — the extent to which the benefit received is proportional to the price paid
- Social equity—the extent to which allocation is proportionate to need (Jones, 2003).

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The free rider problem associated with the spatial nature of infrastructure exemplifies certain types of equity issues. Roads are provided locally, but used by both local and non-local users. For large jurisdictions, this is a minor issue as most travel is local, but for small jurisdictions, the likelihood of non-local travellers increases. This explains why tolls are more common on the east coast of the USA where jurisdictions are small and interstate travel is a relatively large share of all travel compared with the big states in the western USA.

The benefit principle, where those who benefit should pay in proportion to their benefit rather than in proportion to the cost imposed (which may be related), can also be illustrated. If non-residents free-ride they violate the benefit principle. In contrast, with tolls, if non-residents pay more than their use, cross-subsidizing local travellers, the benefit principle is violated in the opposite direction. King *et al.* (2007) extends Levinson (2001) to identify subunits of government as potential recipients of recycled revenue (as opposed to being the unit which tolls roads) to create a class of beneficiaries from road pricing and thereby shift the political calculus.

Debt financing (or its absence) illustrates a third free rider problem, that of generational equity. With financing, people today can use a road that will be paid for in the future by others, without financing, future users enjoy a road paid for by predecessors. Some of these benefits may be capitalized in land, others not.

Clearly infrastructure is not distributed evenly, and some areas have a surplus and others a deficit, suggesting social equity is not always satisfied.

Identifying Transport Inequities

Most transport equity concerns are determined by those who are a party to the action, that is how does a change affect users. But many changes affect non-users.

These changes are considered externalities. Levinson (2002) identifies two types of externalities in transportation:

- Technical externalities—the classic external costs of air pollution, noise pollution and carbon emissions, borne by those who do not directly benefit from the travel (neither the traveller nor the road agency).
- Mobility externalities—transportation projects benefit some parties but worsen conditions for other travellers. Inter-modal mobility externalities are illustrated by a quote from Ivan Illich "Motorized vehicles create remoteness which they alone can shrink. They create distances for all and shrink them for only a few" (1974, p. 42). Mobility externalities can occur within a mode as well as when a freeway interrupts a local grid of streets, or traffic calming reduces traffic on some streets to the detriment of others. Inequity is endemic in transportation, Levinson (2005) examines the 'micro-foundations of congestion and pricing' and illustrates using game theory for a very simple case that road pricing on a facility where travellers can adjust travel times (with associated schedule delay penalties) may have Nash equilibria that are inequitable. Some travel costs borne are directly by the user while different costs are borne by other users (Nash, 2001).

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Crashes and congestion are both externalities from the individual point of view, my actions create problems for others, but those others are travellers, so these costs are internal to the transportation system.

In discussions of transportation equity, the topic of *environmental justice* is often raised. Environmental justice was established in the USA by Presidential Executive Order, and, when applied to the development of environmental laws and policies considers "fair treatment for people of all races, cultures, and incomes" (Environmental Protection Agency: Office of Solid Waste and Emergency Response, 1994). Forkenbrock and Schweitzer define environmental justice as:

> Concerned with a variety of public policy efforts to ensure that the adverse human health or environmental effects of governmental activities do not fall disproportionately upon minority populations and low-income populations. In the realm of transportation, environmental justice requires that transportation system changes, such as road improvements, be studied carefully to identify the nature, extent, and incidence of probable consequences, both favorable and adverse. (1999, p. 96)

Environmental Justice thus only examines environmental outcomes and only addresses a few strata of affected classes.

The term *social exclusion* (or more positively *social inclusion)* also comes to the fore. "An individual is socially excluded if (a) he or she is geographically resident in a society but (b) he or she does not participate in the normal activities of citizens in that society" (Burchardt *et al.*, 1999, p. 229). Social exclusion may be due to, e.g. physical disability, prejudice, lack of knowledge of the common language or lack of resources.

Measures of Inequity

Ramjerdi (2006) summarizes a number of potential measures of inequality (mean, range, variance, coefficient of variation, relative mean deviation, logarithmic variance, variance of logarithms, Theil's entropy, Gini coefficient, Atkinson measure and Kolm measure), and finds none which are both scale invariant and translationally invariant. In summary, among researchers there is no consensus definition of which equity dimension(s) to consider, and no consensus of which measure to use, and each study defines equity differently. The remainder of this paper will report on the measures that were used in various studies, recognizing no one study is complete by considering all of the dimensions and all measures for each dimension.

Review of Empirical Findings

Area-wide and Cordon Pricing

Singapore had the first road pricing deployment with its Area Licensing Scheme. It was later upgraded to Electronic Road Pricing. Olszewski and Xie (2005) argues the Singapore experience is evidence that road pricing is effective in controlling congestion. Wilson (1988) found that while the Singapore Area Licensing Scheme reduced peak hour traffic by 65%, and bus ridership increased from 35.9 to 43.9%; more travellers (44.1%) saw longer travel time and fewer (36.1%) saw a reduction as slower (and now more crowded) buses substituted for faster cars. While congestion management as in Singapore may lower welfare for some users, investing in grade-separated alternative modes (in Singapore Mass Rapid Transit (MRT) and Light Rail Transit (LRT)) can mitigate the effects of the road charge (Goh, 2002).

Norway had an early implementation of congestion pricing using toll rings, where prices varied by time of day to manage congestion. Langmyhr (1997) uses the Norwegian case to understand equity considerations, developing a thorough framework of different equity concerns. Ramjerdi (2006) argues, after testing scenarios with various types of revenue recycling for a proposed charge in Oslo, Norway, no single equity measure is appropriate to use, and different measures lead to different policy conclusions; therefore multiple measures should be considered.

The case of London has probably received the most attention. Transport for London, the agency tasked with implementing the London Congestion Charging (LCC) scheme, has conducted regular analysis of equity and distributional effects both before and after opening.[5] Banister (2002), writing just before the LCC opening, notes there is almost no empirical literature on the effect of road pricing on land use, and whether it will lead to centralization or decentralization of activities. He argues that while "the impact of road pricing on all travellers is progressive", and bus users will benefit from both the faster speeds and the use of road pricing revenues, "the impact on low-income car owners is regressive" (Banister, 1994). The issue of boundary effects also arises, especially important with cordon pricing schemes as the cost of driving to areas just inside a boundary will be significantly higher than staying just outside. (One might note that spillover parking issues also arise naturally in such a case, especially if parking is uncharged or undercharged. Similarly, under cordon pricing, one would expect parking charges would drop as road pricing increased, since demand for parking is lowered and parking is fixed, thereby mitigating the effectiveness of the cordon charge on locally destined traffic). The nature of the land use effects depends on the nature of the road pricing, and whether it is limited or extensive. If the price of travel increases generally, one

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expects a denser urban form as people try to reduce travel costs. However if the price of travel only increases locally, there may be substitution effects as people avoid the area with higher travel costs *ceteris paribus.*

Ison (1998) discusses the issues of implementing road pricing, and presents evidence that without revenue recycling, pricing is generally considered unacceptable, and the preferred way in the UK to allocate revenues raised from pricing was to public transport locally, and to local roads secondarily.

Ison and Rye (2005) notes how equity in the LCC scheme can be achieved by providing exemptions from the charge for certain groups, e.g. "alternative fuel vehicles; vehicles driven by or carrying disabled people who have registered for a 100% discount; emergency vehicles; vehicles with nine or more seats; motorbikes and mopeds; black cabs and London-licensed mini-cabs; and residents within the charging zone (who get a 90% discount)." "[T]he key in terms of acceptance is to keep the inequity to a minimum."

Eliasson and Mattsson (2006) examine the then proposed Stockholm road pricing case for equity consequences. The two key issues they argue for equity are who is affected by the charge and how is the revenue used, which are much more important than any other issues such as value of time. In the case of Stockholm, it is argued men, the wealthy and those living in the centre city are affected most by the charge, while the revenue spending on public transport benefits women and those with lower incomes, and thus the scheme is progressive.

All of the area and cordon-based road pricing schemes affect those inside and outside the boundary differently, and this boundary effect is well-recognized by travellers (and is likely one of the reasons the proposed congestion charge in Manhattan failed to garner legislative approval). Using the revenue in a way to benefit the losers is critical, and some of the alternative are discussed in the section 'Recycling the Revenue'.

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HOT Lanes

Many implemented facility pricing strategies in the USA fall on HOT lanes, which have been extensively evaluated for their equity implications. Looking at the equity concerns associated with proposed HOT lane projects, which have been derided as 'Lexus Lanes',[6]Weinstein and Sciara (2006) notes that equity may arise as an issue at any stage of project development, and is not something can simply be addressed beforehand, but instead continuous monitoring of the equity implications projects is required both before and after opening. Planners would be wise to engage the issue proactively. HOT lanes are generally coupled with parallel free lanes, where the free lanes may be left for equity reasons (Verhoef *et al.*, 1996).

Parkany (2005) identifies the equity issues associated with transponder ownership. Acquiring a transponder is a barrier to entry for many who wish to use roads metered by electronic tolls, and it turns out that many low-income households do not have either credit cards or bank accounts that are often necessary pre-requisites to transponder ownership. Examination of SR-91 and Pennsylvania Turnpike data shows wealthier individuals are both more likely to own transponders, and use electronic toll lanes more often given they own transponders. For routes like HOT lanes where transponder ownership is mandatory to access the system, this may pose an additional equity issue, while when there are alternatives such as manual payment, the effect is not as severe.

A study of SR91 by Sullivan (2000) found lower-income drivers approved of the lanes almost as much as wealthier drivers, though wealthier drivers did make more use of the facility.

Examining the I-15 HOT lanes in San Diego, Supernak *et al.* states "Equity issues … did not emerge despite the fact that FasTrak users came from the highest income groups." (2002, p. 85) Users perceived the system as fair, as it was seen that travel time benefits went to those who paid.

Smirti *et al.* (2007) summarizes literature and interviews a number of players for various congestion charging proposals in California. There was consensus that to achieve political acceptability, excess revenues should remain within the project corridor, and especially be allocated for transit.

The QuickRide system is a HOT lane along the Katy Freeway in Houston. Burris and Appiah (2004); Burris and Hannay (2003) found that while usage among enrollees did not vary by income, the decision to enroll was correlated with income, with high-income travellers more likely to enroll in the system than those with lower incomes. Further the system is more widely used by long-distance than short-distance travellers, and by commuters more than travellers engaged in non-work trip purposes.

In Minnesota on the I-394 MnPASS lanes, while support was largely independent of income, it is clear that higher income individuals use the system more frequently, in part because of its location serving high-income communities, but even after controlling for location there is an income effect (Patterson, 2007). In the corridor though, income was not related to willingness to pay to save time Tilahun and Levinson (2009). Few individuals in the corridor cited social equity as a concern with the conversion of the carpool lanes to HOT lanes (Douma *et al.*, 2005).

Overall, while the HOT lanes tend to benefit the better-off more than the poor, acceptability after implementation is widespread across groups, and all groups make some use of the guaranteed reliable travel times that HOT lanes offer (everyone is in a hurry sometimes).

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Review of Simulated Findings

There have been far more road pricing proposals than actual implementations. Thus many of the results about road pricing are based on computer simulations of the expected effects of road pricing rather than measurements of actual effects. While actual measurements are to be preferred where available, the relative dearth of road pricing implementations leads us to depend on simulations for some of our evidence. This section summarizes the results from simulations of particular proposed cases.

Urban Road Pricing

Mitchell (2005) considered the environmental justice effects of road pricing in Leeds, looking at the effects of changes on pollution by income category using a modelling approach. For the base case there is an association between economic deprivation and pollution levels. For the case with road pricing, the pollution reduction associated with pricing benefits the most deprived quartile more than the highest income quartile. The exact changes depend on the specifics of the scenario. Further, the author argues that pricing addresses pollution inequity more effectively than Low Emission Zones (LEZs). Bonsall and Kelly (2005) studies the same scheme, concluding road user charging will increase social exclusion for some drivers, especially for low-income, car-captive travellers.

Whether road pricing is regressive or progressive depends on circumstances, and tests via traffic simulation for proposed cordon toll scheme in three UK towns (Cambridge, Northampton and Bedford), even before redistribution, because of the mix of incomes and mix of transit passengers, pedestrians, bicyclists and drivers (Santos and Rojey, 2004).

Raje *et al.* (2004) describes potential exemptions for the proposed Edinburgh congestion charge. It also considers the problems of boundary effects, especially the issue of spillover parking as people park on street at the edge of the congestion charge zone to avoid payment. Exemptions are a strategy to ameliorate some of the equity impacts and make projects more acceptable.

Fridstrom *et al.* (2000) tested a number of first-best and second-best pricing strategies for three scenarios: Edinburgh, Helsinki and Oslo. Prior to revenue recycling, consumers were worse off, but there were positive welfare gains overall as the operator's gains exceeded consumers' losses. In the long-term pricing could reverse urban sprawl, and by increasing density make urban public transport more economically viable with increased economies of scale and increased riderships as travellers switch away from auto. A poll transfer of excess revenue (returning the money equally to all individuals) benefits the poor more than the wealthy, and not all money need be reimbursed in order to ensure a Pareto-improving scenario, just enough so that the poorest group is better off, leaving additional revenue which can be used in other ways. Looking at the question of spatial accessibility, pricing diminishes accessibility by car (using generalized cost, clearly if it improves travel time, time-based accessibility should increase), but increases accessibility by public transit (Fridstrom *et al.*, 2000).

Teubel examines the effect of introducing road pricing on commuters in Dresden, Germany. As is commonly found, in the absence of revenue recycling "All measures indicate that the welfare is distributed more unequally after the introduction of road pricing than before. Both components of the welfare changes analysed before contribute to this effect. The toll itself as well as the travel time gains separately enlarge inequality." (2000, p. 249) Revenue recycling can remedy the inequity provided the toll collection costs are not too high.

Anderson and Mohring (1997) finds from a transportation network model that while a hypothetical comprehensive road pricing system in the Twin Cities would improve system efficiency, it will make most travellers worse off unless revenue is recycled. Mohring (1999) extended the analysis to consider difference by income category. Without revenue recycling under severe congestion, incomes needed to exceed $80 000 for travellers to experience welfare increases.

Johnston and Rodier (1999) running simulation experiments on the Sacramento, California region found from a user welfare measure that pricing would have a detrimental effect on low-income households but positive for middle- and high-income categories in the absence of revenue recycling. Some strategies for investing the revenue in transit could produce positive benefits for all groups.

Testing a proposal to combine day-of-week rationing with tolls to buy out of the rationing, Nakamura and Kockelman state it will be "very difficult to provide a Pareto-improving policy for [the San Francisco-Oakland Bay Bridge] via pricing and rationing" (2002, p. 411) and without revenue recycling, as had been theoretically proposed by Daganzo (1995) because the travel time savings needed to be

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much greater than the simulation found. From an equity perspective, the scheme was most beneficial under pure rationing, with mixed rationing and pricing harming the lowest income group.

Road pricing of various kinds is being seriously considered in the Seattle region because the high congestion levels due to topology and economic growth. Tolling across bridges to pay for their reconstruction, and more systematic approaches have been debated.

Dill and Weinstein (2007) reports:

> A poll of Washington state residents found that more people felt that tolls were fairer than increasing the gas tax if more funds were needed. Respondents who were specially asked about fairness to lower income groups felt even more strongly, with 52% indicating that tolls were fairer than increased gas taxes (27%). (Lawrence, 2006, p. 348)

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Franklin (2006) focuses on the issue of vertical equity, distribution between groups. He simulates in a stylized way proposed charges on the Washington State Route 520 Bridge connecting Seattle to Bellevue, assuming alternatives are also tolled, and testing the tolls for the morning peak period so that most trips are work-related, leaving mode as the primary substitution effect. The regressiveness of tolling will tend to be understated when excluding the income effect, but even without redistribution a toll may be Pareto-improving because the wealthy have a higher value of time.

Kitchen (2008) describes a pilot experiment conducted in the Puget Sound region using 400 in-vehicle GPS-based tolling, where tolls would be assessed across the network (not on every street, but on major streets and highways). The households were all given a travel endowment, which would be drawn upon to pay tolls, and for which the remainder would remain with the household. They found value of time rose with wage rate, from about $10 per hour for the lowest income group to $60 per hour for households making $150 000 per year or more. The study estimated the region would be able to raise about $3 billion per year, which compares with $500 million per year from gas taxes at current rates (though clearly annual administrative costs would be much higher from 1% for gas taxes to up to 8% for network tolling, excluding initial capital expenditures). The study suggests the large revenue collected could be used to ensure fairness.

Maruyama and Sumalee (2007) compares cordon and area pricing schemes, (where a cordon toll requires payment each crossing, while an area-based toll requires payment once per day) testing the cases on a simulation of Utsunomiya, Japan, with a finding that while the area scheme has greater welfare than a cordon (and a higher optimal toll), it also has greater inequity. Larger coverage of either system increased welfare and greater tolls decreased equity.

Safirova *et al*. (2004) considers short-run distributional effects from three pricing scenarios for Washington DC: HOT lanes, limited congestion pricing (on all freeway segments that have High Occupancy Vehicle (HOV) lanes), and comprehensive congestion pricing (on all freeway segments) modelled in their START model. HOT lanes are most equitable, with benefits accruing to all income groups even before recycling, while achieving between 77% and 83% of the efficiency benefits associated with comprehensive road pricing, writing " … HOV lanes, which have disappointed their many advocates, may end up being a Trojan horse for congestion tolls … ," (p. 31).

Safirova *et al.* (2006) considers longer-term responses to policy, such as changes in land use and the location of jobs and residences. Urban economic theory assuming a monocentric city predicts that long-run effects of comprehensive congestion pricing reduces the physical size of the city (i.e. increasing density). However more sophisticated models suggest that industry may leave the central core, and thus pricing might have a decentralizing effect. While workers may select commutes with shorter travel times in response to congestion charges, there is no guarantee that either workers or firms move toward the centre. Safirova *et al.* (2006) models cordon tolls in Washington, DC extending their START model with the LUSTRE model. When considering land use effects, optimal (welfare maximizing) tolls are higher then when considering only transportation effects. However, as noted by Parry and Bento (2001), pricing without appropriate revenue recycling leads to higher wages but higher unemployment. Unlike that paper, the authors still found welfare gains even with lump-sum redistribution.

Looking a bit farther afield, some theoretical studies have examined hypothetical networks of private roads, and compared those with a scenario of publicly owned roads. This is important to consider what might occur should road privatization become more widespread, as evidence suggests this is gaining additional credence with many new toll roads being privately owned and some states (e.g. Indiana) selling, or considering selling (e.g. Pennsylvania, New Jersey) their turnpike systems. Zhang and Levinson (2005) find that under private autonomous links, the disparity in accessibility is much greater than under centralized control. Zhang *et al.* (2008) uses coupled agent-based travel demand and link investment models to examine the effects of product differentiation in a network of private roads. Generally (and assuming no recycling as these are private roads), "users with the lowest value of time harvest the least benefit (or suffer the most loss) from road pricing and investment decisions."

Simulation studies of within metropolitan road charging generally find that pricing properly implemented improves efficiency, but may harm equity (across a variety of dimensions, but particularly in harming low-income travellers) in a way that revenue recycling is required to remedy. A variety of revenue recycling strategies have been tested, these are discussed more below.

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National Road Pricing

Steininger *et al.* (2007) use a Computable General Equilibrium (CGE) approach to model private transportation in Austria with road pricing. Their model suggests that road pricing is in fact progressive, poorer households would bear a smaller burden than wealthier households (this is in terms of money spent, not share of income, for which poor people generally spend a greater share on transport than wealthier). This is because poorer households spend less money on transportation in general, and use public transport more. It is noted that to be effective, redistribution of revenue needs to be independent of use, or it negates the benefits of road pricing.

The proposed national road user charge in England has been examined (Glaister and Graham, 2005, 2006), finding that if revenues are recycled through a reduction in the fuel tax, benefits accrue to rural more than urban residents, in contrast with the current situation in England (with its high fuel tax) where rural residents overpay compared with urban residents.

Bonsall *et al.* (2007) considers the proposed UK national road pricing scheme. The system is a national, largely distance-based charge. Concerns arise because of the prospective complexity of the scheme (which may raise difficulties for travellers without the ability to appropriately deal with the complexity and who find such complexity frustrating). It is especially pertinent as drivers are often unaware of the distances they travel, leading to charges perhaps being perceived as surprises. Further, if charges are higher as well in certain areas (congestion charging), the exact formula may be difficult to discern.

Whitty and Imholt (2005) describes the proposed Oregon distance-based road user fee, extending some of the pioneering methods developed in Oregon from charging trucks (Oregon was also the first state to impose the gas tax).[7] A distance-based charge is more equitable than existing gas taxes according to the benefit principle, costs are tied to benefits received, though of course as with any disruption will create winners and losers.

Forkenbrock (2005) advocates a move toward mileage-based road user charges, ultimately a national scheme for the USA. Forkenbrock (2006) is critical of using electronic tolls on selected arterials and highways, noting the equity issue of double payment, as those tolls may be in addition to already collected motor fuel taxes. Further, if tolls only collected on part of the system pay for the entire system, horizontal inequity may result.

Distance-based charging implemented at a state or national level raises a number of questions not asked of metropolitan- or facility-based schemes. They generally involve in-vehicle GPS units, and provide the potential for more intensive vehicle tracking by time and location. While such charging may better apply the benefit principle (getting what you pay for), whether they adversely affect lower-income travellers is unclear. There will be clear geographical disruptions, though again, this may not be an equity problem, but rather the change may reduce an existing inequity where one area or class underpays relative to use. Owners of smaller fuel efficient cars will pay more, while owners of larger cars will pay less compared with a fuel tax.

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Implementation

An issue related to equity is that of implementation. Inequity or perceived inequity may reduce public acceptability either because of genuine public discomfort associated with unfairness or as a smokescreen for other issues. Identifying winners and losers differs from equity considerations unless one takes the status quo as perfectly equitable. A new system may create losers, but still be more equitable if the losers were better off on some dimension on the previous system. These issues are discussed in turn.

Public Acceptability

Studies of acceptability have been widespread in the field of road pricing, as it is the political concerns, rather than their economic efficacy that have held back implementation (Odeck and Brathen, 1997; Truelove, 1998; Padam and Wijkmark, 2000; Link and Polak, 2003; Marini and Marcucci, 2003; Schade and Schlag, 2003; Whittles, 2003; Jaensirisak *et al.*, 2005). Ungemah (2007) provides a practical set of questions to consider when examining the equity implications of various road pricing projects that may further acceptability. Dill and Weinstein summarizing results from a number of surveys suggest "Support for pricing options was not clearly related to income or ethnicity, as might be expected based upon the debates over equity" (2007, p. 354) because the alternatives such as sales taxes are clearly less equitable. Lyons *et al.* (2004) survey a wide-span of international evidence on the acceptability of road pricing finds acceptance rises "when the revenues are hypothecated to the development of transport generally".

In a survey of Sweden, Japan and Taiwan about perceptions of pricing, perceived fairness was higher in Japan and Taiwan than Japan, and acceptance depends on perceived fairness, which was the most important factor (Fujii *et al.*, 2004). Different cultures respond differently to the *social dilemma* that congestion poses, a decision that is selfishly rational may be detrimental to society.

Raje (2003) conducted a series of focus groups analysing a potential city-centre road pricing scheme in Bristol, England, interviewing groups that are potentially socially excluded (ethnic minorities, non-English speakers, elderly and young). The author concludes "[P]ublic acceptability of road user charging will be directly related to its perceived effects on local residents." Recycling the revenue to local transport initiatives would be important in addressing issues of fairness of the system to socially at-risk groups and thereby promoting social inclusion, but car-based transport will still be important for many members of these groups, and taxi and paratransit should be considered as possible recipients of recycled revenues. Lucas *et al.* (2001) found that even non-drivers opposed the then-proposed scheme in Bristol.

Schweitzer and Taylor (2008) find local option sales taxes, which are popular in California as a mechanism for transportation financing to be more regressive than congestion charging. "The fuel tax is regressive with respect to income, but progressive with respect to highway use" since users of highways with more expensive (and less fuel-efficient) vehicles pay more. Sales taxes in particular penalize non-users. This finding of popularity despite inequity is important for understanding the context of political acceptability.

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Assessing Winners and Losers

In the general analysis of transportation, mobility is considered a good for those experiencing it (they always have the choice not to consume mobility). *Ceteris paribus*, any reduction in mobility (or increase in cost) for those individuals (e.g. due to road pricing), will be perceived by them as a 'bad'. That is not to say that private mobility is necessarily a social good, as mobility generally produces negative externalities. Thus, a reduction in private mobility may also reduce negative externalities, and depending on specific conditions may net out as a social good.[8]

Winners and losers can be identified from road pricing schemes, the literature has identified some classes, e.g. Gomez-Ibanez (1992); Langmyhr (1997); Hau (2005); Kitchen (2008), Table 1 below extends that. While Table 1 identifies the gains and losses among travellers, Lo *et al.* (1996) develop a taxonomy of effects by System Users (stratified by income, mode, gender, geography, trip purpose and cause (those who cause congestion)), Transportation Service Providers and Society. There are other groups who win or lose, most notably the agency collecting the revenue, and those who might benefit from recycled revenue.

Often categories must be considered simultaneously, e.g. the effects of income may be ambiguous depending on auto ownership. Many low-income travellers do not own a car, and thus won't pay user charges (and may benefit from revenue

Table 1. Travelers who win and lose from road pricing

Category	Winners	Losers
Unchanged, fee charged (tolled)	Travelers valuing the time savings higher than the fee.	Travellers valuing the time savings below the fee, but having only unattractive travel alternatives.
Changed to toll facility (tolled on)	Persons now finding it profitable to undertake trip (or change trip timing, route, or mode choice,) even with a fee because the travel time will be reduced.	
Changed from toll facility (tolled off)	Travellers who switch from driving to bus or HOV services which are now better because of lower congestion.	Persons abstaining from travel or changing to less attractive travel times, routes or modes to avoid fee.
Unchanged, fee not charged	Public transport and HOV users experiencing time savings.	Persons experiencing congestion on road or on public transport caused by persons who have changed travel behavior to avoid fee.

Source: Extended version originally developed by Langmyhr (1997, 28)

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recycling if the money is invested in transit modes), while those low-income travellers who do use a car spend an above average share of income on travel (Metz, 2008).

Table 2 provides a matrix that can be used to check if particular equity outcomes (in the columns) for different population groups have been considered, and to assess whether an outcome affects groups differently. One could consider this kind of equity impact checklist for each considered pricing strategy, as suggested by Lo *et al.* (1996) (though perhaps not for all 90 pricing strategies identified in Figure 1). Each row represents a different way of grouping the population: as a whole, by location or jurisdiction, by current vs. future residents, by mode usage, by age group, by sex, by race or ethnicity, by (dis-)ability, by cultural background, or by income. In most analysis of road pricing, income and mode usage are primary categories, and some analyses look at location and current vs. future residents. Each column represents an outcome, the first concerns participation in the decision process, other outcomes are mobility,

Table 2. Equity impact checklist

Stratification	Process	Mobility	Economic	Environmental	Health	Other
Population						
Spatial						
Temporal						
Modal						
Generational						
Gender						
Racial						
Ability						
Cultural						
Income						

Source: Levinson (2002)

economic, environmental and health. Road pricing applications directly consider mobility outcomes, some pricing analysis consider economic outcomes, and this study is interested in environmental effects. One could populate the outcome measures on the checklist with some summary equity measure as described above to quickly flag any equity concerns.

Recycling the Revenue

Many strategies have been proposed to use the revenue raised from congestion pricing with the notional aim of relieving inequity, but also the political aim of increasing public acceptability. The first cost is paying for the implementation of the system, which is much costlier than gas taxes (Levinson and Odlyzko, 2008). The remaining funds may be used for general revenue, additional road investments (either near where the tolls were collected or otherwise), or additional transit investments to help encourage modal shift (both through the higher monetary cost of road travel and the better service provided by alternatives, which in the case of bus transport can take advantage of the faster road speeds as well), or returned to users in some other fashion. In general different ways of recycling will also have different equity outcomes for different population groups and areas.

Currently in England, fuel taxes go into the general fund (and are high enough to account for 10% of total tax revenue, far exceeding the amount spent on roads). Newbery and Santos argue in favour of earmarking (hypothecating or ring-fencing) fuel tax revenue for use in the road sector, as is done in the USA with the Highway Trust Fund. They call for a three-way allocation of road taxes: one part of road user charges dedicated to paying for roads, a second part paying for environmental damages, and a third part which is revenue raising. They write:

> The political attractions of green taxes are obvious they are likely to command more support than other kinds of taxes, as they cloak the painful process of extracting revenue in a mantle of virtue and provide a salve for guilt. The main economic advantage of taxes that reflect the marginal damage is that they leave the user to decide how best to respond, rather than forcing him or her to make one particular kind of decision. (1999, p. 117)

There are limits to the ability of imposing taxes to encourage virtuous behaviour, in England the fuel-duty escalator ended after protests (Smith, 2000; Doherty *et al.*, 2003). Distinguishing green taxes is important, but difficult as accounting for the full costs of transportation, including determining the capital value of infrastructure (which is historically valued at less than replacement cost, potentially leading to under-investment), has not generally been performed in a systematic way. Just as fuel taxes might be hypothecated to the road sector, the same argument can be made for road tolls.

Oberholzer-Gee and Weck-Hannemann (2002) address the question raised by Lave (1994) "Why is the world reluctant to do the obvious?" arguing "marginal cost pricing does not prevail throughout the economy, the information cost of determining Pigouvian taxes are likely to be considerable, and there is ample evidence that policymakers do not maximize social welfare." The authors warn that prices can crowd out 'intrinsic motivation' so that people who were previously doing good because they wanted to be responsible instead become selfish.

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Unfortunately the public tends to overestimate the effectiveness of many behaviours that result from intrinsic motivation (e.g. rewards for carpooling or using public transportation). Charges should avoid displacing people's underlying motives. The paper also argues that effective compensation should be in same dimension as the perceived losses from the charge. Thus if people lose the ability to travel in the peak, they should be compensated by easier travel at other times. Implicitly this argument is in favour of pricing credits of some kind.

Revenue-Neutral Congestion Pricing

Dial (1999) developed the idea of a minimal-revenue congestion pricing, that is, finding a pricing scheme that would replicate the demand resulting from marginal cost prices everywhere while ensuring the total revenue raised was zero (so many links might have a zero toll). From an equity and acceptability perspective, keeping the revenue raised to a minimum need to accomplish the stated ends is important to minimize any distortionary impacts and the perception of gauging. Nevertheless, it is likely that there will be some positive revenue from road pricing, and how to distribute that is an essential question.

Adler and Cetin (2001) proposes that money collected on a more desirable route be redirected to travellers on a less desirable route, in a sense paying people to help achieve a socially optimal assignment, using the revenue to help ensure a socially optimal solution. Levinson and Rafferty (2004) proposes similarly that delayers (those at the front of the queue who impose a higher marginal cost on others) compensate those at the back of the queue, who suffer congestion, and thereby help spread the peak.

Fast and Intertwined Regular (FAIR) Lanes (DeCorla-Souza, 2005; DeCorla-Souza and Barker, 2005) would divide congested freeways into untolled (and congested) lanes and tolled (and uncongested) lanes. Drivers who were not using the toll lanes would earn credits that could be applied periodically to the toll lanes.

Credit-based pricing (Kockelman and Kalmanje, 2005) would return tolls from marginal cost pricing in the form of credits that could be applied to toll facilities. Individuals who drive less than average make a net profit, those who drive longer and more often in peak period than average pay more.

All such strategies, by mitigating the inequity that pricing might cause, should improve political acceptability compared with an approach where revenue collected went into a general fund account. Recycling in this manner does however potentially increase the administrative burden of the system.

Building Winning Coalitions

Button (2006) looks at alternative uses of the money raised by pricing with the hope of finding a winning coalition of supporters for such a change. Goodwin (1989) came up with the rule of three, allocating revenue to roads, transit and reduced taxes, though not necessarily in equal shares, and Small (1992) makes a similar point. The question of earmarking arises as a way to help ensure support and show taxpayers that the money raised will be spent on something they desire, but which may not be economically efficient.

Small (1983) in an early simulated analysis of the effects of road pricing by income class uses a queueing model and a logit mode choice model to understand distributional effects. The highest income group benefitted most from road pricing

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as while they paid more tolls, they had a higher value of time and saved more time. However once revenue was recycled, every income group benefitted, assuming congestion was sufficiently severe.

Mayeres and Proost (2002) use the idea of Pareto-frontier to trade-off efficiency against equity in road pricing, and only consider changes to financing acceptable when they are Pareto-improving. This requires comparison of absolute utility levels across individuals, which is a theoretical difficulty. On the Pareto Equity-Efficiency Frontier, it is impossible to improve one individual's utility without worsening another's. The authors use CGE model of Belgium to argue that revenue recycling is required to achieve equity across income groups when a marginal social cost pricing regime is instituted.

Solving Societal Problems

To address broader social equity concerns (that is, to use transport policies to address societal inequities, not just transportation inequities or the marginal inequities associated with a change in transport policy), Nash (2003) argues for use of distributive weighting systems making use of Ramsey pricing (Ramsey, 1927)[9] while retaining marginal social cost pricing as a starting point, following the ideas laid out in (Feldstein, 1972). This however may not fully recover costs.

Parry and Bento (2001) considers the issue of how road pricing affects labour force participation. Theory suggests higher commuting costs will discourage the marginal commuter (the cost of the toll exceeds the benefit of congestion reduction for most travellers), and in most of the authors' numerical simulations, the welfare gains from road pricing (internalizing congestion costs) is less than the efficiency cost in the labour market. The authors suggest recycling the revenue to reduce labour taxes, offsetting the penalty associated with road prices and that this is more effective than providing transit subsidies or providing a lump-sum payment to households (which does not encourage labour force participation).

Lindsey (2003), citing (Nix, 2001), notes that the Maritime provinces have resisted tolls because of spatial equity and double taxation rationales. He further identifies the issue of spillover effects on customers of firms that have located based on a particular assumption about the costs of freight, which post-tolling would see their cost structure change, citing (Lake *et al.*, 1999).

Levine and Garb (2002) argues that traditional congestion pricing policies are mobility based, and thus may lead to spatial deconcentration as prices discourage driving to congested areas. The authors suggest tolls be redistributed to enhance accessibility (the ability to reach places) rather than mobility (the ability to move on the network).

Evans (1992) notes the redistribution aspects of road pricing may drown the efficiency gains. Minimizing congestion and minimizing emissions can be at odds (Rilett and Benedek, 1994). First-best marginal social cost congestion pricing do not necessarily reduce emissions, but there is a toll pattern which does (Yin and Lawphongpanich, 2006).

Discussion and Conclusions

The trade-off between efficiency and equity emerges naturally as systems mature, as users compete over the allocation of scarce resources rather than growing the resource base. Issues of both process and outcome equity arise. In order to

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achieve process equity, transparency in the decision-making process, in addition to allowing input from all potentially affected individuals or groups representing them, is required. Examples, some of which have been discussed in this paper, include:

- tolling (us vs. them, here vs. there, local vs. through)
- free parking (drivers vs. riders)
- facility siting/investment (here vs. there, rich neighbourhood vs. poor, black vs. white)
- bus vs. rail (operating vs. capital)
- cost allocation (cars vs. trucks, general aviation vs. commercial aviation)
- modal allocation (roads vs. transit)
- infrastructure finance (now vs. later, here vs. there)
- environmental regulations (man vs. nature)
- age, gender, ability

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Because of past experience, citizens will remain sceptical of claims about road pricing projects. The Pareto maxim, that so long as the losers could theoretically be compensated by the winners, the project is worthwhile, cannot be used as a political justification, actual compensation is required. In the absence of such compensation, political opposition will continue to rise and new construction will continue to be more and more difficult. Viegas (2001) posits that the reluctance of politicians to adopt road pricing despite receiving ideas along these lines suggest they are "seeing dimensions of the problem that the economists are not considering."

The perception of equity is highly subjective. A project that may appear equitable to an analyst across one set of dimensions may not to individuals affected by the project. Achieving consensus on decisions (thereby ensuring people believe the decision was equitable) may involve departure from objective 'engineering' rationality, moving into the realm of politics. The issue is further complicated because equity concerns may mask opposition motivated by other reasons (Giuliano, 1994).

Resolving the equity vs. efficiency problem requires a recognition that in complex, politically driven, mature systems like transportation, *equity is efficiency.* Without satisfying potential constituent groups, nothing can be accomplished. An example of this is the recent failure of the road pricing initiative in Manchester, England and the controversy about even studying a national road user charge in England (Richards, 2008). Logrolling, as described by Buchanan and Tullock (1962), recognizes the political efficiency under representative democracies for satisfying multiple groups. Side payments of cash or as an in-kind subsidy, bargaining, bundling of projects,[10] and buying-off losing groups, or in the language of road pricing, revenue recycling, may be necessary to achieve consensus about acceptability, achieving a package that is considered win/win by the relevant players.

Employing a community impact assessment/environmental justice approach, and using a tool such as the equity impact checklist described in Table 2, it will be possible to identify which neighbourhoods and groups will be most affected by road pricing, through reduced road accessibility, and which have good alternatives. Strategies developed with the local community may help find appropriate compensation solutions, such as suggested by King *et al.* (2007), to these problems to enable pricing to be perceived as equitable, politically acceptable and remain efficient.

From an equity perspective, HOT lanes are the pricing strategy least likely to raise public concerns, especially if it involves conversion of underutilized HOV lanes or construction of new lanes without taking new right-of-way. While there is a slight bias in use towards wealthier individuals, all travellers benefit from the additional usable capacity, and the revenue can be recycled to benefit transit users in the corridor. However, these are not as effective as more extreme pricing that is more comprehensive at the urban or national level. More comprehensive pricing (at the metropolitan, and especially at the national level) is not optional in the same way as HOT lanes with parallel free lanes are. Thus it raises more equity issues as to avoid the toll, drivers must switch modes, destinations, or time of day. Revenue recycling offers a way of ameliorating adverse equity impacts.

Both the efficiency and equity of any proposed road charge depends on the travel market for which the charge is proposed. Moreover, what is acceptable in Europe may not be in North America or vice versa. The degree of alternatives (e.g. alternative modes or destinations), the distribution of income and allocation of time by residents will all affect the ultimate conclusion, and some markets will inevitably be more amenable than others to different schemes.

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Notes

1. Though gasoline consumption is a good proxy for carbon emissions, it ties less perfectly with other pollutants, and more importantly is not correlated with the health damages which depend on where the fuel is burned and the rate of intake of those pollutants.
2. Levinson (2000, 2001) examined the issue of using tolls as a form of tax exporting. By placing tolls at boundaries, jurisdictions can ensure that out-of-jurisdiction (e.g. out-of-state) residents pay for their use of the road, and perhaps more than their fair share, in contrast to a system of gas taxes where out-of-jurisdiction residents may never pay their costs (if they buy gas where they live rather than where they drive) and would instead free ride on the road system.
3. The development of first-best pricing is generally credited to (Pigou, 1912), who argues that resources can be most efficiently allocated by setting the price equal to the social marginal cost. This argument depends on a number of assumptions, many of which either don't hold or are difficult to ensure in practice, leading to the development of second-best pricing strategies.
4. Pigou did not deal with dynamics of charging across a period of time, which awaited the development of Vickrey's bottleneck model (Vickrey, 1965; Arnott *et al.*, 1993). Xin and Levinson (2006) distinguishes between *omniscient pricing* (where the toll operator knows both schedule delay penalties and desired arrival times) and *observable pricing* (where the toll operator can observe only delay). It is the latter which is more realistic given information availability, but it may not fully account for individual preferences, and has a slightly lower welfare than omniscient pricing if arrivals are stochastic.

5. These annual reports can be downloaded from the TfL webpage at http://www.tfl.gov.uk/roadusers/congestioncharging/6722.aspx.
6. The origin of the term 'Lexus lane' is unclear, but a brief article on the subject can be found at Toll Road News: http://www.tollroadsnews.com/node/2143, attributing the term to Seattle-based HOV advocate Heidi Stamm.
7. The 1997 Federal Highway Cost Allocation Study found that because heavy vehicles impose road damage disproportionate to their fuel taxes, they underpay compared to other classes of vehicles, and are thus cross-subsidized (Forkenbrock, 2005).
8. One might speculate that policies like road pricing may result in attitudinal and behavioural changes embodied in decisions not to travel, or to travel less, thereby changing the shape of the demand curve for travel, and so less travel might not be a bad for those travellers; those speculated outcomes have yet to be observed.
9. Ramsey pricing charges users in proportion to willingness to pay, using price discrimination to differentiate customers by their elasticity of demand, constrained to recover some amount of money.
10. Bundling ensures that not only is there a net benefit (when all projects are considered together), the number of winners exceeds the number of losers by a significant amount.

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