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Distributional effects of urban transport policies to discourage car use: A literature review

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Distributional effects of urban transport policies to discourage car use

A literature review

Environment Working Paper No. 211

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Keywords: Inequality, Income distribution, Environmental externalities, Road pricing, Fuel tax

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Abstract

This report takes stock of scientific findings to date regarding the distributional effects of policies discouraging car use in urban areas. These policies include cordon tolls, distance-based charges, fuel taxes, parking measures and public transport subsidies. The report describes the mechanisms responsible for the distributional effects of these policies and offers insights regarding how such policies can be designed to minimise adverse equity outcomes. It also provides recommendations regarding the design and procedural modifications that standard instruments require in order to be more acceptable to the public and to governments. Finally, it identifies a number of issues that warrant further research in the pursuit of greater equity in the outcomes of urban road transport policies.

Keywords: Inequality, Income distribution, Environmental externalities, Road pricing, Fuel tax

JEL Codes : D63, R40, H23, Q52, Q54, Q56

Résumé

Ce rapport fait le point sur les résultats scientifiques obtenus à ce jour concernant les effets redistributifs des politiques décourageant l'utilisation de la voiture dans les zones urbaines. Ces politiques comprennent les péages cordon, les redevances basées sur la distance parcourue, les taxes sur les carburants, les mesures de stationnement et les subventions aux transports publics. Le rapport décrit les mécanismes responsables des effets redistributifs de ces politiques et donne des indications sur la manière dont ces politiques peuvent être conçues afin de minimiser les effets négatifs sur l'équité. Il fournit également des recommandations sur la conception et les modifications procédurales des instruments standards qui les rendraient plus acceptables pour le public et les gouvernements. Enfin, il identifie un certain nombre de questions qui méritent des recherches plus approfondies afin d'atteindre une plus grande équité dans les résultats des politiques de transport routier urbain.

Mots-clés : Inégalité, Répartition des revenus, Externalités environnementales Tarification routière, Taxation des Carburants

Classification JEL : D63, R40, H23, Q52, Q54, Q56

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Executive summary

Discouraging car use constitutes an area in which inclusive policy action is urgently needed. Road traffic generates local, regional and global externalities, which have considerable social costs. The use of motorised vehicles causes congestion, accidents, time losses, local air pollution and fuel waste. While some of these social costs are experienced on the spot or in the short term, others are incurred over longer time horizons. For instance, road passenger transport generates up to 10% of greenhouse gas emissions that lead to global warming and climate change.

This paper takes stock of policies discouraging car use in urban areas, focusing on their equity dimension. The review examines the potential of these policies to stimulate desired behavioural changes, the environmental impact of these changes and their documented distributional effects. Policies investigated in the paper include, but are not limited to: i) cordon tolls, ii) distance-based charges, iii) fuel taxes, iv) parking measures and v) public transport subsidies. Attention is paid to whether these policies treat similar cohorts of the population equally (horizontal equity) and impact different cohorts in a comparable manner (vertical equity). Furthermore, the paper investigates whether car-restraint policies have uniform impacts across space (spatial equity).

As summarised in the table below, the review spans a wide array of varying results. Most analyses find that congestion pricing schemes are vertically regressive, i.e. they disproportionately affect low-income groups. The spatial distribution of income is a key factor in determining the equity implications of such schemes, in particular when they take the form of cordon tolls. Then, congestion pricing can be progressive if higher-income households are predominantly located at suburban areas and commute by car to a central business district. At the same time, congestion pricing reduces traffic externalities such as air pollution, which often disproportionately affect low-income households. Studies agree that cordon tolls are spatially inequitable, even if they are vertically progressive. This occurs because they tend to favour all inhabitants within the cordoned areas independent of their income level. Fuel and distance-based taxes are found to have comparable effects on vertical equity. They tend to be regressive in high-income countries where car ownership is widespread and lower-income households tend to travel greater distances. Car dependence and the absence of feasible public transport alternatives tend to exacerbate these effects. In contrast, distance-based charging and fuel taxes tend to be progressive in lower-income countries, where car ownership is currently limited to high-income groups.

Summary of the economic efficiency and equity effects of examined policies

Policy	Vertical equity impact	Spatial equity impact	Efficiency impact	Comments and observations
Cordon tolls / Congestion pricing	Context-specific	Inequitable	Positive*	Vertical equity (i.e. equity across income cohorts) depends on: (i) car ownership of low-income groups, (ii) the location of the cordon, (iii) the systematic income differences between residents within and outside the cordon, and (iv) the correlation between income and public transport coverage in locations outside the cordon.
Flat km tax	Context-specific	Equitable	Positive*	Vertical equity effects depend on car ownership of low-income groups, and the correlations between: (i) driving distance and income and (ii) driving distance and public transport coverage. In monocentric cities, regressive effects subside if higher income households reside further away from CBDs[a], and *vice versa*.
High Occupancy Toll lane	Mixed	Low	Positive	Vertical equity depends on the correlations between: (i) income and carpooling, i.e. the measure tends to be progressive when lower-income households have more flexibility to carpool; as well as (ii) income, value of time, and value of reliability. With respect to (ii) the measure generates time savings and reduces travel time reliability, gains that tend to favour higher-income groups more.
Motor fuel taxes	Mixed	Mixed	Country-specific	Progressive in low-income countries where car ownership is confined to high-income groups. Tend to be more regressive when vehicle fuel economy increases rapidly with income.
Public transport subsidies	Progressive	Context-specific	Mixed	Efficiency impacts depend on (i) the social cost of revenue raising taxes, (ii) the social benefit from the accompanying reduction in externalities.
Investments in public transit service quality	Context-specific	Context-specific	Context-specific	All effects depend on the location of investments and the income level of the main beneficiaries.
Parking fees	Context-specific	Inequitable	Positive	Progressive if high-income households drive more in CBDs [a]
Low emission zones	Regressive	Inequitable	Unknown	Stated effects are based on the hypotheses that: (i) income positively correlates with ownership of low emission vehicles and (ii) residents of low emission zones have higher incomes
Minimum parking requirements	Regressive	Inequitable	Negative	
Residential parking permits	Regressive	Inequitable	Negative	

Note: The stated effects are not generic, and should be interpreted with caution, as they substantially depend on a number of context-specific parameters. Notably, equity impacts depend on the sum of the primary and secondary effects of a policy. Primary effects of fuel taxes on vertical equity, for example, are determined by income level and the proportion of income spent on transport. Secondary effects occur via factors that determine a household's exposure to policy-induced welfare losses. In the case of fuel taxes, this could be a household's accessibility to public transit insofar as this allows a household a degree of flexibility in adjusting how much they drive and thus the proportion of their income spent on the policy-relevant transport expenses.
[a] Central Business Districts * Applies to contexts where traffic levels exceed their socially optimal levels.

Several policy instruments may mitigate the regressive impact of car restraining policies. Lower-income households may benefit from revenue recycling schemes that provide direct or indirect benefits. Enhancing public transport coverage and subsidising the use of public transit modes can ensure that low-income, car-dependent communities do not become disproportionately burdened by road pricing schemes. Policy makers could also consider remedial measures that are not horizontal but instead target specific groups that have been negatively affected. Such measures include exemptions, but may also expand to other benefits that can be provided in a targeted way.

Overall, the findings suggest that differentiating policy stringency according to characteristics with distributional relevance, such as income, geographic location and accessibility, can improve the equity of policy outcomes. Although acceptability is often quite low for new measures to discourage car use, evidence suggests that it can be improved if the purpose and benefits of a policy are clearly understood. Acceptability can also increase when the objectives of the scheme address public concerns, as well as when revenues are earmarked to support the transport sector. Efficiently addressing the external effects of car use without exacerbating existing inequalities is unlikely to be achieved in different contexts with the same instrument. Given the diversity of policy features, national contexts and urban characteristics, regulating traffic externalities without generating additional distributional consequences will require approaches tailored to these conditions.

Given the diversity of contexts and policy measures available, including policies with little precedent to date, research on a number of issues should be prioritised in order to improve the equitability of restraint policies in urban areas. More knowledge will particularly be needed regarding policies supporting the uptake of electric vehicles, encouraging the introduction of ride-sharing services, and trading permits for road use.

1 Introduction

The transition to a low-carbon economy will require drastic changes in road transport and the management of environmental externalities from urban traffic. Road transport is responsible for approximately 16.5% of global energy-related CO_2 emissions, about 40% of which are generated in cities (Sims et al., 2014[1]). Apart from contributing to climate change, urban road transport generates congestion, which entails high social costs as it leads to considerable time losses and waste of fuel. It also generates outdoor air pollution, which has significant health consequences and can eventually lead to premature mortality (OECD, 2016[2]; OECD, 2019[3]). Finally, motor vehicle activity in urban areas is responsible for traffic accidents that cost the lives of around 1.25 million people annually and leave tens of millions of others injured (WHO, 2018[4]).

The ultimate success of policy measures to discourage car use will depend on the extent to which they stimulate desired behavioural changes without generating excessive or unfairly distributed welfare losses. The negative welfare impacts arising from increased transport costs limit their political support. The high levels of opposition to recent increases in transport costs have been the topic of frequent headlines around the world. In France, for example, a proposed fuel tax sparked the yellow vest movement and was later rescinded. A year later, a 4% increase in public transport fares in Chile led to mass protests and civil unrest. Both policies were perceived as regressive since they substantially increased the travel costs of medium- and low-income groups. These examples demonstrate that the current design of measures to discourage car use may overlook important distributional considerations, an omission that undermines their political feasibility. Greater attention from researchers and policy makers is warranted to develop policies that achieve their economic and environmental objectives without substantial repercussions on equity.

The point of departure and primary environmental policy objective considered in this paper is the mitigation of negative externalities associated with motor vehicle travel in urban areas.[1] As noted above, however, policies seeking to mitigate these negative externalities can generate impacts that are unequally distributed across groups along a number of dimensions, including income and space.[2] The aim of this paper is to assess when and how the environmental

[1] This is to be distinguished from the policy objective of reducing pre-existing inequalities per se. In some cases, this environmental policy objective can be aligned with the social objective of reducing existing inequalities, such as in the case of remediation of brownfield sites.

[2] Economically efficient policies to address environmental externalities entail Pigouvian taxes according to "*the polluter pays*" principle. In a system with zero transfer costs, combining Pigouvian taxes with transfer payments would be both economically efficient and horizontally equitable (see Section **Error! Reference source not found.** for definition of horizontal equity). However, as transfer costs for compensation mechanisms exist, the core objective of environmental policies (i.e., to incentivise behaviour change at the margin) will inevitably be in partial conflict with notions of equity. To the extent that environmental policies can generate welfare impacts outside of the environmental sphere (e.g., health impacts), such impacts can nevertheless be mitigated in order to improve the equitability of environmental policies.

objectives of such policies can conflict with equity objectives. The paper also offers perspectives regarding the ways in which these policies can be made more inclusive.

To this end, Section 1 introduces different measures of equity and outlines the framework of the analysis. Section 2 takes stock of the documented distributional effects of policies discouraging car use in urban areas, including cordon tolls, distance-based charges, fuel taxes, parking measures and public transport subsidies. The paper also describes the mechanisms behind these distributional effects. Based on these observations, Section 3 offers policy recommendations on possible ways to address the external effects of car use without exacerbating existing inequalities or generating additional distributional consequences in urban areas. Section 4 outlines areas in which more research is required to better understand the extent of, and strategies for addressing, distributional effects. Section 5 concludes.

1.1. Defining equity

1.1.1. Dimensions of equity

Equity can be defined in various ways. It is sometimes used synonymously with fairness, and the two terms will be used interchangeably in this paper. Equity has a number of dimensions in transportation that can both overlap and conflict. The following summary draws on the relatively comprehensive list of dimensions provided in Thomopoulos et al. (2009[5]).[3] The three most commonly cited and encompassing dimensions of equity are horizontal equity, vertical equity and spatial equity.

Horizontal equity dictates that comparable individuals be treated in a comparable way. Horizontal equity supports the *benefits-received* or *user-pays principle* that the beneficiaries from a good or service should pay for it. Horizontal equity is also consistent with the corollary *polluter-pays principle* according to which those who create pollution or other negative externalities should pay for the costs, either by mitigating the externality or by compensating the victims.[4] **Vertical equity** concerns how a policy instrument affects the well-being of individuals with different incomes, privileges or social classes. Redistributing wealth from higher-income or more-privileged individuals to those with less is generally considered to enhance vertical equity. **Spatial equity** refers to geographical location: where individuals live relative to destinations they wish to visit such as workplaces, schools, shops and recreational areas. Spatial equity is affected by vehicle ownership, proximity to public transport, personal mobility and other factors (Viegas, 2001[6]; Weinstein and Sciara, 2006[7]). Spatial equity is sometimes considered an aspect of vertical equity if it relates to needs and mobility challenges. This may hold in particular if individuals have a limited ability to relocate. Insofar as households do have the option to relocate in the long run, however, spatial equity concerns tend to be less relevant. Eliasson et al. (2018[8]) argue that spatial equity is even more important than vertical equity insofar as income inequity may be easier to ameliorate with social assistance and other policy instruments.

[3] Various other sources provide generally shorter lists of dimensions. See, for example, Viegas (2001[6]), Raux and Souche (2004[243]), Levinson (2010[34]), van Wee (2011[18]) and Litman (2021[112]).

[4] Although horizontal equity often equates with economic efficiency, this is not always the case. A fuel tax, while horizontally equitable insofar as it taxes every household the same rate per unit of fuel used, is not necessarily economically efficient because the marginal social cost of fuel use is not equal across space.

Thomopoulos et al. (2009[5]) also define several other dimensions of equity, three of which are relevant to a discussion on the distributional effects of transport policies to discourage car use.[5] **Regional or territorial equity** refers to the equitable treatment of geographical areas (e.g., states, provinces and municipalities) within a jurisdiction. Equity may also embody a temporal dimension, as those experiencing the policy effects *ex-post* may differ from the control group (i.e., those who are using the transport facility subject to the implemented policy *ex-ante*). This temporal dimension, referred to as **longitudinal equity** (Viegas, 2001[6]), was proposed in a setting where road tolls were imposed for the first time, thereby obliging motorists as Viegas (2001, p. 291[6]) puts it “to pay for what previously was freely available and taken by many as a basic right”. This facet of equity can be considered an application of spatial equity at an aggregate, rather than individual, level. Longitudinal equity is most relevant for major policies that are implemented over long time horizons. Carbon taxes that grow over time are a prominent example.

The objectives of different equity criteria may conflict. For example, while horizontal equity requires that individuals bear the direct and external costs in proportion to the goods and services they consume, vertical equity calls for subsidies to disadvantaged people (Bonsall and Kelly, 2005[9]; Manville and Goldman, 2018[10]). This creates a divergence between the objectives of horizontal and vertical equity (Blaug, 1985[11]; Eliasson, 2019[12]).

This paper primarily focuses on policy impacts on *vertical equity with respect to income*. Thus, it considers a tax, user fee or policy-induced constraint as *progressive* if the pecuniary cost it imposes increases more than in proportion to income. Consequently, the tax or fee is *neutral* if the outlay rises proportionally with income, and it is *regressive* if the outlay grows less than proportionally.[6] Although less common, quantity controls and regulations can be classified in the same way. Thus, a control or regulation is deemed to be progressive if the monetised welfare cost increases more than proportionally with income. Neutral and regressive quantity controls and regulations are defined analogously.

As these definitions indicate, the incidence or burden of taxes and user fees is measured as a fraction of income. The situation differs for public expenditures since, by convention, a neutral expenditure scheme allocates the same amount to everyone regardless of their income.

[5] Among the others are **territorial cohesion** and **solidarity**, both of which relate to transport and cohesion policies within the European Union.

[6] These definitions are appealing insofar as income is a good measure of well-being, but this assumption can be disputed on three grounds. First, income only measures the financial resources available to individuals, not their physical capabilities or needs. Second, while gross (i.e., before-tax) income is an appropriate basis on which to decide income taxes, it is unclear whether gross or after-tax income should be used for assessing the burden of other taxes or user fees since income tax schedules are typically determined with distributional concerns in mind. (The scope to address distributional concerns using the income tax system is discussed below.) Third, gross annual taxable income itself is not a perfect measure of financial health. Taxable income excludes gifts and other non-taxable sources of money. Moreover, taxable income can fluctuate from year to year, and it usually changes considerably over a person’s lifecycle. Annual expenditures are sometimes proposed as an alternative to income as a metric of financial health since expenditures tend to be less volatile. Because there is less variation in transport expenditures when measured as a fraction of total expenditures rather than as a fraction of income, the distributional impacts of policies that impact transport costs can appear dampened when measured in terms of expenditure versus income. However, expenditures are more difficult to measure, and they can include expenses that reflect need and can vary considerably from person to person (e.g., medical expenses).

1.1.2. Whose equity matters?

With the exception of regional and territorial equity, the dimensions of equity listed in Section 1.1.1 are defined in terms of individuals rather than groups. Yet, equity judgments are often made for groups. For example, policies may be devised so that they leave no income group (e.g., quintile or decile) worse off on average. However, a policy can affect those in the same income group quite differently, and well-being is perceived by individuals rather than groups (Santos and Rojey, 2004[13]; Eliasson, 2016[14]). Moreover, individuals differ in many ways besides income. As a result, equity concerns often cannot be adequately addressed by designing policies on the basis of their average incidence within income groups or geographic regions. While vulnerable individuals may be clustered geographically, they can also be "scattered as a consequence of life circumstance" (Preston, Holvad and Hine, 2000[15]).[7]

Despite the above considerations, there are practical reasons for assessing equity by income class, urban zone or region. First, administrative data may be unavailable at the individual level, and collecting individual data can be costly and constrained by privacy rules. Second, assessments by urban zone or region are suitable when the policy under examination has a strong spatial component. For instance, many countries implement regional policies designed to support rural, remote or sparsely populated areas. Major investments to expand and maintain the transport system to these areas are localised by nature, as those benefiting from them are spatially concentrated. Third, policies may be governed by election results that are determined at the municipal or regional level, and outcomes at these scales that are perceived to be disadvantageous may prove contentious. Large disparities between regions can also induce migration that is inefficient from a national perspective. For instance, the first city to introduce road tolls may lose residents and businesses to neighbouring cities or regions even if tolling improves the efficiency of transportation and potential well-being of the city's inhabitants (Schlag and Teubel, 1997[16]).

Another challenge of assessing equity at the individual level is that a majority of individuals live in households with other people. Decisions about labour supply, where to live and work, and vehicle ownership are often made at the household level. Household members can take on responsibilities according to their relative abilities, and ease the burden on any member with mobility restrictions or other disabilities. Consequently, treating the household as the unit of analysis may be more suitable for assessing equity.[8] Moreover, due to economies of scale, housing and other expenditures increase less than proportionally with household size. These economies can be accounted for using equivalence scales that adjust for the number and ages of household members (OECD, 2013[17]). Thus, it can be more appropriate to assess both financial and physical well-being at the household level, rather than the individual level.

[7] As quoted also by Rajé (2003[183]). Moreover, transport-related disadvantages due to residential location could be offset by other factors. Consider two *ex-ante* identical households. Household 1 rents an apartment in the city centre, and Household 2 buys a house in the suburbs. Household 1 enjoys low transport costs to most destinations, but has cramped accommodations. Household 2 incurs high transport costs, but has spacious living quarters. Should Household 2 be given a transport subsidy while offering no assistance to Household 1? A housing advocate might instead lobby for a housing subsidy for Household 1.

[8] Studies in The Economics of the Family (see Vermeulen (2002[234]) for a literature review) often adopt so-called collective models in which households are assumed to reach efficient outcomes in which one member cannot be made better off without leaving at least one other member worse off. However, the outcomes may not be equitable. For example, Shaheen et al. (2019[72]) note that in households with fewer vehicles than drivers, women may lack access to a vehicle but still bear a disproportionate share of household and childcare responsibilities.

Nevertheless, except if indicated otherwise, no distinction will be made in this paper between individuals and households.

1.1.3. Why be concerned with the equity implications of transport policies?

Instruments that mitigate transport-related external effects in an economically efficient way often increase vertical or spatial inequality. Such effects may undermine cohesion and fuel social discomfort, as recent unrest in many parts of the world indicates. The corresponding impacts can be considerable, as transport costs typically account for 3-10% of household expenditure, a number that increases further for low-income households and car-dependent households with long commutes. Therefore, it is important for policy makers to be informed about these trade-offs, their magnitude and the existence of policy alternatives that can mitigate or avoid them. Such second-best options are possibly less efficient but also less likely to exacerbate inequality.

As it is the case with all environmentally relevant commodities, there is no consensus regarding the social desirability of policies aiming to achieve equity in the transportation (or any other) sector. Many transportation policies are motivated by efficiency goals such as reducing traffic congestion and air pollution. However, other transportation policies (e.g., fare subsidies) are driven by equity concerns. The logic of the latter policies has been questioned, as dealing with transportation costs is just one of the many financial challenges a lower-income household typically faces. According to this critique, subsidising particular commodities and services such as transport or housing in a piecemeal fashion mitigates the financial burden of the low-income cohorts only partially. Furthermore, it reduces the costs of some types of commodities relative to others in a way that can be viewed as paternalistic (van Wee, 2011, p. 81[18]). Providing income support rather than subsidizing transport costs addresses both these criticisms (Mohring and Anderson, 1994[19]).

Another policy issue concerns the role of income tax adjustments as an instrument to mitigate stringent environmental policy. In particular, a series of contributions in public finance suggest that the revenue from environmental externality taxation could be used to reduce labour income taxes. This could generate a "*double dividend*", as the social benefit from the environmental mitigation could be combined with a reduced income tax burden. Most importantly, this combination could be achieved in a revenue-neutral way, curbing concerns about fiscal sustainability.[9] The idea behind the double dividend hypothesis has also been examined in a transport-related context, where urban congestion externalities coexist with taxes on labour and housing property.[10] However, while revenue-neutral tax swaps are economically efficient, their use is rare in practice and their distributional impacts are not precisely known.

Furthermore, the degree to which the labour tax could act as a realistic, stand-alone lever to mitigate the distributional impacts of transport-related externality taxes is unknown. Governments have the potential to raise resources by making labour income taxes more progressive. Consequently, these resources can be used to compensate directly the groups

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[9] Goulder (1995[51]) and Bovenberg (1999[52]) provide extensive reviews of double dividend literature. Parry and Bento (2000[[211]]). extend consideration to consumption goods in addition to labour supply.

[10] Relevant citations in the urban transport counterpart of double-dividend theory include those by Parry and Bento (2001[40]) and Parry and Bento (2002[41]). Tikoudis, Verhoef and van Ommeren (2015[44]) examine the double dividend in a spatial context of a monocentric city, and Tikoudis (2020[45]) expands the analysis in a polycentric setting. Tikoudis, Verhoef and van Ommeren (2018[46]) include property taxation in the analysis of congestion taxes in a monocentric city. Bento, Franco and Kaffine (2006[280]) examine the distributional impacts of anti-sprawl policies such as land and property taxes, fuel taxes and urban growth boundary in a monocentric setting.

affected by environmentally related policies. This avoids creating the efficiency losses that fuel, transit fare and other subsidies may generate by altering relative prices. On the other hand, the revenue raising potential of the income tax could be, to some extent, undermined by the tax avoidance and evasion.[11] Lump-sum income transfers based on ability would partly avoid this problem, but ability cannot be observed precisely.[12] Hence, governments undertake much of their redistribution through the expenditure side (Boadway and Marchand, 1995[20]). They provide welfare services and pensions. They also subsidise merit goods such as education and health care, as well as goods such as public transport that facilitate work. They also tax heavily commodities such as tobacco that have adverse effects, as well as luxury goods that are positively correlated with income and ability (Arnott and Stiglitz, 1986[21]).

In conclusion, there are solid arguments for subsidising certain goods and services such as public transport. Nevertheless, it is neither efficient nor equitable to subsidise them for everyone. Targeting subsidies narrowly on low-income or other groups is preferable (Tassonyi and Kitchen, 2021[22]), and examples of such policies are mentioned later in this paper.

1.1.4. The potential for efficient and equitable transport policies

Given the wide diversity of individual circumstances and preferences, it is nearly impossible to devise any transport policy that leaves everyone better off. Cost-benefit analysis is based on the premise that a policy yielding an aggregate net benefit is worth implementing. The distribution of that net benefit among social groups or regions, as well as the possibility that a proposed policy may render some of them worse-off, are typically ignored. This approach is endorsed on the grounds that the gainers could compensate the losers without sacrificing all their gains.[13] However, compensation *per se* is not required, as the analysis omits the social cost of inter-group transfers that would support such a compensatory mechanism.[14]

It is currently unknown which transport policies operate in a progressive or regressive way. Limited information is available regarding the way transport services and infrastructure are financed, although it is widely known that modern transport systems are largely financed by fuel taxes and other user charges (Transportation Research Board, 2011[23]; Manville and Goldman, 2018[10]). As discussed in Section 2, the evidence is mixed on whether these sources are regressive. Transportation systems are also funded by a blend of taxes outside the sphere of

[11] The literature is inconclusive on whether the level of income tax has a causal effect on tax avoidance and tax evasion (Godar, Paetz and Truger, 2015[288]) (Freire-Serén et al., 2013[289])

[12] Lump-sum transfers could be implemented with a universal basic income that, by design, everyone receives. A number of academics and some countries have studied universal basic income systems, but they raise concerns about the high costs of paying for them and the work disincentives they might create. One-time lump-sum transfers, such as those that have been granted as assistance during COVID-19, may be justified on humanitarian grounds. However, ostensibly one-off transfers could have adverse incentive effects if they create expectations of further transfers in the future.

[13] The ability of winners to compensate losers is formally called a Hicks-Kaldor hypothetical compensation, or Potential Pareto Improvement.

[14] In a static world with perfect information on the marginal utility or valuation of income, such a mechanism could be set without any loss of economic efficiency. Stiglitz (1998[239]) and Rietveld (2003[279]) explain why actual compensation would be very difficult, given lack of information about each individual valuation, and uncertainty about the policy's precise effects. Some individuals could be overcompensated, and others undercompensated. Resources for compensation could be scarce, and the public might not expect the government to provide compensation permanently. Compensation could also have adverse incentive effects. People may overstate their costs, and the practice of compensation could lead to a culture of rent-seeking.

transport services, including sales and property taxes that can be regressive. Individuals who drive and ride public transit at peak times are often subsidised by those who travel at off-peak times and pay the same road user charges and fares (Giuliano, 1992[24]). Thus, the existing resource allocation within the transport system may be both inefficient and vertically inequitable. Yet, when judging the equity of a new policy such as tolls, the *status quo* is often implicitly assumed to be fair. As Manville and Goldman (2018[10]) note, this can create a bias against the introduction of new policies such as tolls.

1.1.5. Accessibility

Transport policies that discourage car use affect the cost of driving, the ability to make some trips by car (e.g., because of an urban vehicle access ban), or both. These policies may also affect other transport modes and, in the longer run, location and land-use decisions. To assess the distributional effects of such policies, it is necessary to measure their welfare impacts at the household level.

Travel speed is a common measure, but it has three disadvantages. First, it overlooks the monetary cost of travel. Second, it ignores preferences for mode of transport. Third, it ignores travel time, which depends on the distances to the destinations that people wish to visit.

Another widely-used measure of travel capabilities is the *cumulative opportunities* that can be reached within a given travel time or cost constraint, such as the number of shops located within 30 minutes of a household's residential location. The cumulative opportunities measure is relatively easy to calculate and understand, but it treats all destinations within the delimited area as equally reachable, and it also ignores heterogeneity in individual preferences across shops, travel modes and travel times (Herszenhut et al., 2021[25]).

A third, and now widely endorsed, measure of travel capabilities is *accessibility*. Definitions of accessibility vary. Following Eliasson (2020[26]), accessibility is defined in this paper as the net benefit that an individual obtains when they choose their preferred destination and travel mode for a given trip. This metric simultaneously accounts for individual preferences regarding destination and travel mode, as well as the overall or so-called *generalised cost* of travel by the preferred mode. For a trip by car, the generalised cost includes the cost of fuel and other vehicle operating costs, any cost of parking and tolls, and the opportunity cost of time spent traveling. Individuals travel to various destinations: work, school, shops, healthcare facilities, recreational areas and so on. To account for this, accessibility can be computed as a weighted average of accessibility for each trip purpose, where the weights reflect the relative importance and frequency of each type of trip (Zheng, Oeser and van Wee, 2019[27]).

A transport policy to discourage car use such as a ban on driving in the city centre reduces accessibility if no offsetting behavioural changes occur or compensatory policies are implemented. As a result, such measures stand to exacerbate existing disparities in accessibility and associated social exclusion.[15] Hence, the importance of identifying and implementing policies that mitigate adverse distributional effects of efforts to control car use.

[15] An inability to engage in activities, or participate in community life. See Rajé (2003[183]), Bonsall and Kelly (2005[9]), van Wee (2011[18]) and Lucas (2012[247]).

1.2. Policy measures to discourage car use

This paper considers three types of urban policies for discouraging car use: (1) price-based policies including tolls, fuel taxes and parking fees; (2) quantity controls and regulations including car-free zones, traffic calming and parking restrictions; and (3) policies that support public transport and active travel. Consideration is also given to policies designed to support the purchase and use of electric vehicles that have precedent in a number of countries around the world. These policies do not discourage driving per se, and could even contribute to traffic congestion. However, they do represent a shift toward travel that is more environmentally friendly than travel by conventional fossil-fuel vehicles.

Other policies may also contribute to reducing the environmental impact of road transport. Such policies may include subsidies for the purchase of electric vehicles, interventions promoting soft mobility (e.g. bike) or alternative modes of transport (e.g. electric scooters), and bonus-malus schemes. However, such policies cannot be considered car-restraint policies per se, and are therefore not analysed in this paper.

Many other policies that affect car use, either directly or indirectly, are not considered. Some, such as road capacity expansion, may reduce traffic congestion at least temporarily, but tend to encourage rather than discourage car use. Others, such as commercial parking sales taxes, are designed primarily to generate revenue. Still others, such as land-use policies, car sharing and bicycle sharing, are omitted due to lack of sufficient evidence on their equity effects.[16]

1.3. Challenges in assessing the distributional effects of transport policies

Assessing the distributional consequences of transport policies is challenging for at least four reasons. First, the overall effect of a policy depends on *policy stringency* (Transportation Research Board, 2011[23]). The level of a toll, the area over which a parking regulation is imposed, or the amount of road space reallocated from cars to bicycle lanes determines the size of the welfare changes across population cohorts. Policy impacts depend furthermore on 2) the transportation alternatives available to individuals and their willingness to change behaviour, 3) the policy's impact on travel times across modes, congestion, local air quality and GHG emissions, and 4) the recycling of revenues from price-based instruments to the economy. Many revenue recycling options exist, including the supply and maintenance of transport infrastructure and subsidies for public transport. Recycling can take place at the local level or can benefit regions that are not related to the tax base that generated the revenue in the first place.

A major policy change such as a substantial increase in fuel taxes can raise costs for businesses and lead to higher retail and other market prices. The effects on prices depend on how much of the cost is absorbed by suppliers and how much is passed on to consumers. Part of the cost increase may be incurred by non-residents (e.g., visitors) or exported to other regions. Depending on the relative incomes of visitors and residents, this can increase or decrease equity as measured by the financial burden.

[16] Other excluded policies include telecommuting, staggered work hours, flexible work hours, park and ride facilities, automobile fuel efficiency standards, and operational strategies such as traffic signal priority and ramp metering. Carbon taxes are not mentioned explicitly because their effects on car use are equivalent to fuel taxes.

A second challenge in assessing the distributional impacts of a policy is that some effects, such as changes in land use and residential density, play out over long time periods. Such changes can be difficult to model, and other changes may occur in the meantime that complicate attempts to isolate the effects of the policy.

Third, the effects of a policy can depend on the presence of coincident policies (Feitelson, 2003[28]). Two policies can be synergistic or antagonistic in the sense that implementation of policy A could strengthen or weaken the justification for, or effectiveness of, policy B. For example, tolls may be more effective in a city with a well-developed public transport system. Similarly, car-free zones may be more effective if a city has an extensive network of bicycle lanes that make bicycling attractive as an alternative to driving. Conversely, encouraging densification could deter the purchase of electric vehicles if it reduces access to recharging stations or parking. Synergistic and antagonistic interactions can also exist for remedial actions to alleviate any adverse distributional effects of policies targeted at reducing car use.

Finally, the distributional consequences of transport policies depend on how they are designed, and in democracies this can be influenced by public acceptability constraints. Policies such as major infrastructure projects and proposals to introduce tolls often experience strong opposition. In order to be implemented, these policies may have to be modified in ways that affect the distribution of gains and losses as well as their overall effectiveness. The approval process varies even across democratic countries (Trannoy, 2011[29]). In countries such as Switzerland and the United States, decisions are sometimes made by referendum, and a proposal is approved if a majority is in favour. In other countries, the way in which individual preferences are represented can be much more complex.

1.4. Mechanisms underlying the distributional effects of policies

As explained in more detail in Section 2, transport policies affect travellers both directly and indirectly. Price-based measures such as fuel taxes, parking fees and tolls impose direct out-of-pocket costs. For example, the “gilets jaunes” (yellow vest) protests in France were induced in part by proposed fuel tax increases that would have taken effect on January 1st, 2019. The tax on diesel fuel would have increased by EUR 6.5 cents. Assuming no change in driving behaviour, the average vehicle owner would have seen an annual increase in fuel expenditure of about EUR 63.[17] As a second example, a study of congestion pricing for Vancouver, Canada[18] concluded that a regional system of charges on bridges and other bottlenecks would impose a median annual cost per household in the range of CAD 1,800-2,700, or EUR 1,233-1,850.[19] The study acknowledged that this would be a significant amount. It also concluded that the benefits from quicker and more reliable trips, and pollution reduction, as well as the potential fiscal benefits from the toll revenues would also have been substantial.[20]

Quantity-based policies and regulations do not impose monetary costs directly. However, they do restrict where and how cars are used, and can indirectly affect the costs of driving by influencing how far individuals drive, how much they pay for parking and so on. Individuals with

[17] Based on average fuel consumption of 6.04 litres per 100 km, and average annual distance driven of about 16,000 km. See https://www.statista.com/statistics/1105126/consumption-of-fuel-average-passenger-car-france, and https://www.statista.com/statistics/1105129/distance-traveled-in-average-by-passenger-car-france.

[18] Mobility Pricing Independent Commission (2018[67]).

[19] Using an exchange rate of EUR 0.685 per CDN on October 5, 2021. Not adjusted for inflation.

[20] The reader is referred to Section 2.1.5 for a detailed presentation of the study.

mobility restrictions may be unable to complete a full trip by car and have difficulty traveling the rest of the way. Both price- and quantity-based measures and regulations can reduce accessibility for households that live far from public transport and lack a feasible alternative to driving. Furthermore, some types of trips, such as shopping for bulky goods and trips by multiple family members, are not easily made by other modes, leaving households little choice but to continue driving.

The effects of time-varying policies, such as peak-period tolls and parking time restrictions, depend on how much flexibility people have to adjust their schedules. Many lower-income individuals have fixed work hours and cannot avoid traveling at peak times. For example, a survey of Stockholm residents in 2004 and 2006 found that the share of workers reporting flexible work hours increased from just 20% in the second-lowest income group to 61% in the highest group (Karlström and Franklin, 2009[30]).

Both price- and quantity-based measures and regulations can have spill-over effects on the urban economy at large. As noted, they can induce changes in the prices of goods and services that affect travellers and non-travellers, consumers and suppliers, and employees and employers. For example, minimum parking requirements (see Section 2) increase the amount of space devoted to parking. The extra land acquisition and construction costs increase the cost of housing and other property developments, which in turn are passed on to households and businesses in higher property prices and rents (Manville, 2013[31]). Inci (2015[32]) summarises the results of studies finding substantial increases in the costs of single-family houses, condominiums and office space. Conversely, eliminating minimum parking requirements would result over time in lower prices for these developments. Transport policies can also affect agglomeration economies (Graham, 2007[33]) whereby worker productivity increases with accessibility and ease of interaction. A policy that facilitates interaction will raise welfare, whereas one that impedes interaction will depress it.

Finally, by affecting business and other activity, transport policies affect revenues collected from income, fuel, sales and property taxes, as well as from vehicle registration fees, parking fees and other user charges. The increase or decrease in revenue affects the total money available to run a city’s transportation system, deliver other services, and (at least partly) compensate those who are disadvantaged by the policy.

2 State of knowledge on the welfare and distributional effects of policies to discourage car use[21]

2.1. Congestion pricing

2.1.1. Overview

Tolling roads is a common practice worldwide. In most cases, the tolls are not levied to curb environmental or congestion externalities. Rather, toll systems are implemented to help cover the costs of road construction, maintenance and operations. Imposing tolls to support efficient usage of roads is still rare. Nevertheless, congestion pricing has been extensively researched.[22] Studies have employed a great variety of models, and come to varying conclusions about the welfare-distributional effects of tolling (Levinson, 2010[34]; Hensher and Li, 2013[35]; David Suzuki Foundation, 2020[36]; Ecola and Light, 2009[37]). The effects depend on many factors, such as the geographical scale and structure of the pricing scheme (i.e., cordons, areas, zones, road links, lanes, or distance travelled) that largely determine its tax base. The degree to which charges are fixed or vary across hours of the day and vehicle type determines also the cohorts that will be relatively more exposed to road charges. Finally, the presence of discounts and exemptions may mitigate the tax burden of road charges in a selective way.

The welfare effects of congestion pricing heavily depend on the pricing scheme and the revenue recycling programme. Each scheme has a unique impact on each socioeconomic group, which primarily manifests as a change in its out-of-pocket costs. However, it also impacts well-being through the changes it triggers to traffic levels, travel times and emissions improvements in public transport service could benefit different groups than investments in road infrastructure. Therefore, the wide variety of road pricing instruments can generate an equally heterogeneous set of welfare impacts across social groups. As a result of this variation, some studies conclude that tolling is regressive while others find that it can be progressive. The following sections briefly review the theory of congestion pricing, and then review practical applications of it and evidence on its distributional effects.

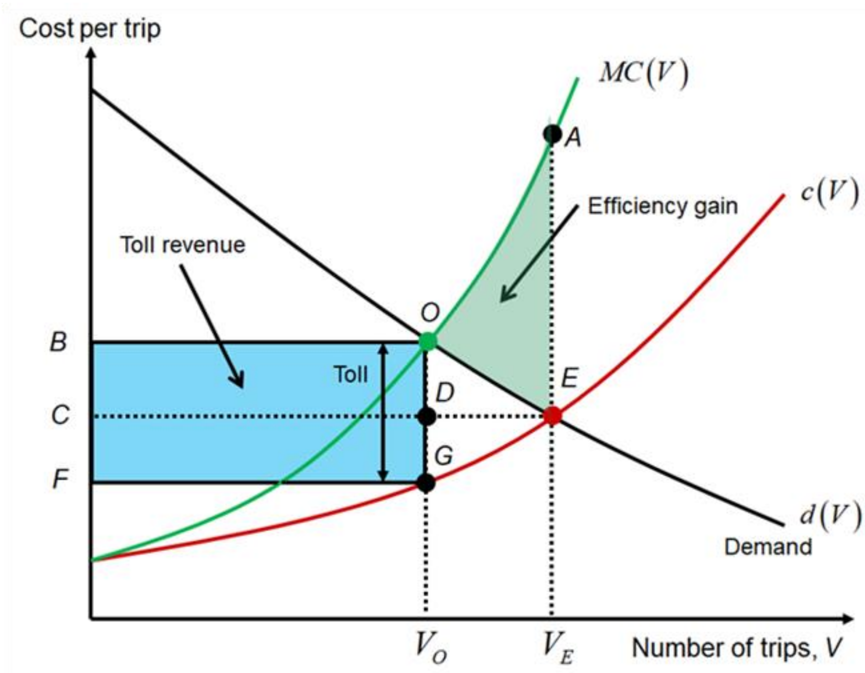
[21] The policies discussed in this section are implement in heterogeneous settings (countries, cities). For a comparative discussion of their impacts in the case of Beijing the reader is directed to Box 2.1.

[22] Literature reviews are found in Levinson (2010[34]), Santos and Verhoef (2011[242]), de Palma and Lindsey (2011[266]), Mobility Pricing Independent Commission (2018[67]), and Lehe (2019[248]).

2.1.2. Review of theory

The economic principles of congestion pricing were first developed by Walters (1961[38]) using a static, supply-demand approach.[23] In his model, individuals have a common origin and destination connected by a single road. They are identical except for their willingness to pay to make the trip by car, measured in monetary units. If they do not drive, they either take another mode or simply forgo the trip. The demand curve for trips is $d(V)$ where *V* (volume) is the number of trips. The total or generalised cost of a trip borne by a traveller is $c(V)$. As noted in Section 1, this includes fuel consumption and other vehicle operating costs, tolls (if any), and the opportunity cost of time spent traveling. Since the road is congested, travel time increases with volume, and $c(V)$ is upward-sloping as shown in Figure 2.1 . The marginal social cost of a trip, $MC(V)$, exceeds $c(V)$ because an additional trip imposes a delay on other trips. Hence, the $MC(V)$ curve lies above $c(V)$.

Figure 2.1. Traffic congestion and optimal toll level in Walters (1961[38]) model



Source: Based on Lindsey (2012[39]).

If there is no toll, the equilibrium number of trips taken, V_E, is defined by the condition that marginal willingness to pay equals private cost. The benchmark equilibrium (i.e., without policy intervention) occurs at point *E* in Figure 2.1. In contrast, the socially optimal number of trips, V_O , is defined by the condition that marginal willingness to pay equals *MC*, which occurs at point *O*. Therefore, in the benchmark equilibrium traffic exceeds its socially level and car travel is socially under-priced, as drivers do not internalise the delay they cause to the rest of road users. The social optimum can be supported by imposing a congestion toll. In monetary terms, this is equal to the gap between the demand and private cost curves at volume V_O (i.e., the distance OG). Toll revenue is measured by the rectangular area $FBOG$, shaded in blue. The toll improves

[23] Pollution and other externalities can be added without changing the main insights.

efficiency because it deters trips along the demand curve between points O and E with benefits less than the social cost. Trips on this segment of the demand curve are "tolled off". Their total *monetised* social cost is equal to the area OAV_EV_O, while their total *monetised* social benefit is equal to the area OAV_EV_O. Therefore, there is an efficiency gain that the society benefits from, measured by the area OAE, shaded in green.

The total effect of the toll on the well-being of the average household can be decomposed as a series of different effects. Before the toll revenue is recycled back to the economy, the toll leaves the travellers worse off. This occurs because the total net benefit from the mitigation of externality (area OAE), falls short of the total toll charge imposed to society (area $FBOG$). The toll increases the total pecuniary cost of each trip. The generalised cost of a trip (excluding the toll) drops, as lower levels of traffic translate into less time and gasoline wasted in congested conditions. That decrease is equal to the difference between the ex-ante and ex-post pecuniary cost of a trip, $V_EE - V_OG$, and is equal to DG. However, the imposed toll, which is equal to OG, exceeds this amount by OD.[24]

[24] In aggregate, travellers lose benefits equal to the area $CBOE$. Those who continue to drive each lose OD. Those who stop driving lose an amount ranging from OD down to nothing for the person located at point E on the demand curve who is indifferent about driving before the toll is imposed.

Table 2.1. The social welfare accounting of a congestion tax without household heterogeneity

Component	Area in Figure 2.1	Explanation / Comments
Social benefit from congestion relief	OAEG	The total benefit stemming from congestion relief deriving from time and fuel savings for the remaining cars on the road. A wider view of the component includes noise and pollution reduction, a reduction of road accidents, as well as climate change mitigation benefits.
Social cost of foregone trips	OEG	The foregone private benefits (i.e., total willingness-to-pay minus total private costs of trips cancelled due to the implementation of congestion pricing).
Total pecuniary toll costs	FBOG	The total tax revenue paid by car users to the authority collecting it.
Total social cost of toll implementation	$\delta \cdot$ FBOG	Taxing car use could indirectly increase the social cost of commodities that are socially over-taxed.[a] In that case, the amount of collected revenue has to be multiplied by $\delta > 1$: the cost of transferring one dollar from the private to the public sector [b] via the toll system.
Preliminary effect (without revenue recycling)	$OAEG - OEG - (\delta \cdot$ FBOG) = $OAE - (\delta \cdot$ FBOG)	The monetised impact of the toll before its revenue is recycled to the economy.
Value of recycled revenue	$\theta \cdot$ FBOG	$\theta = 1$ if the revenue returns in a lump-sum manner; θ may exceed 1.0 if used to finance cuts in the taxes of socially overpriced commodities.[c]
Total effect	$OAE - ((\delta - \theta) \cdot$ FBOG)	Disregarding any wider economy impacts of the toll system, implementation costs, and assuming a lump-sum revenue recycling implies $\delta = \theta = 1$. The total welfare gain is equal to OAE

Note: The analysis in this section assumes that the toll constitutes a transfer from travellers to the government, and has no wider impacts in the economy. Sources: [a] For an analysis on how congestion pricing may negatively interact with the labour market see Parry and Bento (2001[40]), Parry and Bento (2002[41]), Hirte and Tscharaktschiew (2020[42]) and Tikoudis and Van Dender (2021[43]). The spatial considerations regarding this interaction are further analysed in monocentric contexts by Tikoudis, Verhoef and van Ommeren (2015[44]) and in polycentric contexts by (Tikoudis, 2020[45]). Interactions of road tolls with urban property taxes have been explored in Tikoudis, Verhoef and van Ommeren (2018[46]). [b] δ, the marginal social cost of funds (MCF), depends on the type of tax, the level of the tax, the size of the jurisdiction where it is levied, and whether long-run effects on capital investment, firm location choices and so on are taken into account. The MCF can be less than one for commodities that are initially undertaxed. For the personal income tax, Kleven and Kreiner (2006[47]) obtain estimates of the MCF of about 2.00 for countries with high tax rates (i.e., Denmark, Germany and France). For countries with low tax rates, estimated MCF are much lower. Boardman et al. (2020[48]) report estimates mostly ranging between 0.12 and 0.34. Dahlby and Ferede (2012[49]) estimate MCFs for personal income taxes, corporate income taxes and sales taxes for Canadian provinces. Their estimates range widely across provinces and tax categories, with a minimum of 1.00 for sales taxes, and a maximum of 30.6 for corporate taxes. Barrios, Pycroft and Saveyn (2013[50]) estimate an EU-wide average MCF of only 1.08 for energy taxes, although with significant spillover effects between EU member countries. [c] The theory of double dividend (see Goulder (1995[51]) and Bovenberg (1999[52]) for elaborate reviews) proposes the recycling of environmental tax revenue to cut taxes on commodities or services with the highest marginal excess tax burden (see for example Browning (1987[53]) and Mayshar (1990[54])).

The analysis with this basic model yields several lessons. First, tolling improves efficiency of travel by preventing excessive use of the road. Second, it increases travellers' private costs so that they are likely to oppose tolling unless they are compensated in some way. Third, tolling yields revenue. If enough of the revenue is used to benefit travellers, they could end up better off in aggregate. If the revenue is returned in an equal lump-sum fashion to the whole population, then those who did not travel *ex-ante* will clearly be benefited *ex-post*. Those who travel both before and after the toll will be better off if the benefit from revenue use exceeds OD per trip. For those who stop traveling, the benefit required is intermediate between OD and nothing.

The above analysis does not convey much about equity since individuals in the model are identical, except for their willingness to pay for a trip. Many dimensions of individual heterogeneity have been considered in the literature. The most widely studied dimension is the opportunity cost of time spent traveling, mentioned above, which is responsible for the upward slope of the cost curve, $c(V)$. Often called the *value of time* (hereafter, VOT), it represents the maximum amount of money an individual is willing to pay for a quicker trip.[25] Someone with a high VOT benefits more from a given travel time saving than someone with a low VOT. Indeed, someone with a high VOT who does not drive without a toll could decide to drive when the toll is imposed if the monetary value of the travel time saving exceeds the toll. Thus, as Layard (1977[55]) showed, in addition to the group of travellers who are "tolled off" by the toll, there can be another group who are "tolled on" and who gain from tolling.

The benefits from road pricing depend on income and other socioeconomic characteristics. Empirical literature suggests that VOT is strongly related to income, with studies suggesting that higher income groups have, all else equal, higher time valuations (Abrantes et al., 2011[56]). Hence, the time savings from tolling generally benefit high-income individuals the most. Similar reasoning holds for any other individual characteristic that is correlated with VOT savings, but is not affected by the policy *per se* (e.g., gender, age, ethnic background) or any characteristic is mutable by the policy only in the long run (e.g., commuting distance, employment status). Such characteristics predict VOT directly (i.e., by affecting the time constraints of individuals, or via their impact on income). Therefore, road pricing produces asymmetric benefits, even across population cohorts of similar income levels but different combinations of these characteristics. For example, applying a toll in the context of the illustration in **Figure 2.1** Figure (i.e., same commuting distance) will create a benefit (i.e., the area OAE) that will be valued differently by retired low-income men, working low-income women from an ethnic minority group, etc.

Inferring whether tolling is progressive or not requires additional analysis of the costs the policy imposes to the various groups. As it is the case with benefits, the costs of a congestion pricing scheme are distributed across population cohorts in a non-uniform way. For distance-based pricing schemes such as kilometre taxes, commuting distance is the most important determinant of the burden that the scheme imposes on households. That burden grows with the amount of inelastic car travel households need to do. Thus, it is considerably larger for households that face long commutes and cannot easily use another mode. This implies that if commuting distance is negatively correlated with income, a distance-based road-pricing scheme is more likely to be regressive. However, the distributional impacts of road pricing in actual settings are more complex. The evidence, some of which is described later, is mixed. It depends, in part, on how willingness to pay to drive, VOT and other socioeconomic characteristics are distributed in the population and across space. In any case, individuals with the lowest VOT among those who continue to drive fare the worst from tolling, as they pay the toll and gain the least from the travel time saving (Small, 1983[57]).

Insofar as a revenue-recycling programme is an integral part of the road pricing policy, it can also render the policy more regressive, or less. In particular, if revenues are used to finance public goods or services that favour high-income areas and users, the programme will make a regressive road-pricing scheme even less inclusive. Investments in high-speed motorways serving high-income areas are a characteristic example. In contrast, using revenues to finance investments in public transport could mitigate the social impact of a regressive pricing scheme. Horizontal lump-sum transfers can be implemented in the form of dividends, a system that is *per se* progressive, as the same amount of money is valued more by low-income groups.[26]

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[25] A broadly representative value of the VOT for commuting trips in developed countries is EUR 10 per hour.

[26] Alternatively, the revenue can be directed to the provision of public services enjoyed uniformly by all cohorts.

Finally, the Walters (1961[38]) model is static, and ignores the time dimension of travel. In practice, traffic volumes are highest during the morning and evening rush hours, and optimal congestion tolls are greatest then. The welfare-distributional impacts of tolling on individuals then depend not only on their VOT, but also on their flexibility to retime trips. The contribution by van den Berg and Verhoef (2011[58]) studies the welfare effects of time-varying tolls when individuals differ in both VOT and flexibility. They show that congestion pricing can leave the majority of travellers better off even if they do not benefit from the toll revenues. The reason for this is that tolling not only suppresses travel delays, but also reduces the costs from either time wasted when arriving at the destination earlier than desired, or the productivity loss from arriving late to work or for an important appointment.

Table 2.2. Characteristics of road-pricing schemes

	Singapore Electronic Road Pricing (ERP)	Stockholm Congestion tax	Gothenburg	London Congestion Charge	Milan Ecopass	Milan Area C
Inception	September 1998	Trial: Jan 3 – July 31, 2006 Permanent: Aug 1, 2007	January 2013	February 2003	January 2008 – December 2011	January 2012
Goals	Primary: congestion relief. Secondary: promote transit	Primary: congestion relief. Secondary: promote transit and pollution reduction	Primary: revenue generation. Secondary: congestion relief and pollution reduction	Primary: congestion relief. Secondary: promote transit.	Primary: pollution reduction. Secondary: congestion relief	Reduce traffic and pollution, and promote public transport
Tolled area or infrastructure	Expressways, arterial roads, and cordon charges for three restricted zones around CBD.	Cordon around 30 km² inner city area and Essingeleden motorway.	Cordon around central Gothenburg	22 km² area around city centre; extended to west from Feb. 2007 to Jan 2011	Restricted zone of 8 km² in city centre	Same as Ecopass
Toll application	Per passage; inbound crossings of restricted zones	Inbound and outbound crossings; 18 control points	Inbound and outbound crossings & E6 main road passing the city; 36 control points	Paid daily; includes parking on public roads	Paid daily; 43 control points	Same as Ecopass
Time variation	Vary separately by time of day for arterials, expressways and CBD; often zero; charges change in 5 or 30-min. steps; charge levels reviewed quarterly	Original: 10, 15, or 20 Swedish kroner, depending on time of day from 6:30 am to 6:30 pm; daily maximum of 60 kroner; no charge on weekends, holidays, or day before holidays Present: 11, 15, 22 or 30 Swedish kroner, depending on time of day; daily maximum of 105 kroner	Present: 9, 16, or 22 Swedish kroner, depending on time of day from 6:00 am to 6:30 pm; no more than one payment per hour; daily maximum of 60 kroner.	Original: Flat charge of GBP 5 from 7:00 am to 6:30 pm on weekdays; no charge on weekends or holidays. Present: Charge of GBP 15 from 7:00 am to 10:00 pm every day	Flat charge 7.30 am to 7.30 pm on weekdays. EUR 2 to EUR 10 depending on engine emissions standard. Most-polluting vehicles banned from Oct. 15 to April 15.	Flat charge 7.30 am to 7.30 pm on weekdays. EUR 2 for residents, EUR 3 for "service vehicle", EUR 5 for standard rate. Banned: Certain diesel vehicles.
Toll differentiation by vehicle and user	Differentiated by four vehicle types **Exempt**:	**Exempt**: Buses, vehicles for disabled	**Exempt**: Buses, vehicles for disabled	**Exempt**: Motorcycles, vehicles for disabled	**Exempt**: Motorcycles & various other vehicle	**Exempt**: Motorcycles, scooters, electric

characteristics	Police cars, ambulances, fire engines and scheduled buses.	people, motorcycles, emergency vehicles, taxis (abolished after trial), electric and hybrid cars (until 2012), traffic between Lidingö island & rest of county that spends less than 30 minutes crossing the charging zone. **Discounts**: none.	people, motorcycles, emergency vehicles	people, vehicles with 9+ seats, taxis, motor tricycles, roadside recovery vehicles, breakdown vehicles. Cleaner vehicle exemption for battery electric and hydrogen fuel cell vehicles to be discontinued in December 2025. **Discounts**: 90% for residents. Additional charge of GBP 12.50 for most vehicle types that do not meet an Ultra Low Emission Zone standard.	categories. Also clean conventional fuel vehicles & several types of alternative fuel vehicles. **Discounts**: 50% rebate for 1st 50 entries, 40% rebate for 2nd 50 entries. Residents of restricted zone can buy annual pass for 25x cost of daily charge.	vehicles, varying categories of green vehicles, buses, taxis, public utilities' vehicles, police and emergency vehicles **Discounts**: 40 free days per year for Area C residents.
Earmarking of revenues	None. Surplus revenues returned to motorists paying vehicle taxes	Trial: Not applicable. Permanent scheme: Originally road construction, then Stockholm metro	To an infrastructure package, mainly a rail link	Revenues earmarked to local transport.	Public transport. Net public-sector revenues (not counting penalty payments) were negative	Public transport and sustainable mobility including walking and bicycling
Initial supplementary measures	Multiple vehicle ownership taxes, fuel taxes, parking fees, road expansion, mass rapid rail, buses, taxis, park & ride, car cooperatives, signal timing	New bus lines; extension of existing bus, metro and rail service; new and improved park-and-ride facilities	Increased bus service, bus lanes, bicycle lanes	Increase in bus service, retiming of traffic signals	New bus lanes, revised traffic directions and reduced illegal and on-street parking	Increased bus service

2.1.3. Major urban congestion pricing schemes in operation

Urban congestion pricing has been implemented in only five major cities[27]: Singapore (1975), London (2003), Stockholm (2006), Milan (2008) and Gothenburg (2013).[28] **Table 2.2** lists some of their main features. In Stockholm and Gothenburg, toll motorists pay a fee each time they cross a cordon surrounding the city centre. London and Milan have area licenses that are paid once per day for either crossing the boundary of the tolled zone, or traveling within it. Therefore, in those systems even trips that depart and terminate within the surrounded area are charged. Singapore's scheme is the most complex, with a combination of cordon charges in the city centre and tolls on a large number of individual arterials and expressways. In all five cases, tolls are paid only during daytime hours.[29] Singapore is planning to replace its Electronic Road Pricing scheme with a satellite-based system that will enable distance-based charges.

2.1.4. Distributional effects of the major urban congestion pricing schemes

Studies have come to varying conclusions about the distributional impacts of the urban congestion pricing schemes (Santos and Caranzo, 2021[59]). Selected results are summarised here for London, Stockholm, Gothenburg and Milan.[30]

London

The London Congestion Charge (LCC) is a daily levy on vehicles that either cross the boundary of the tolled zone, or travel within it. Before the LCC was introduced in 2013, only 10% of people entering the city centre in the morning peak did so by car. The rest used transit or one of several modes that were exempt from the charge (see Table 2.3). Santos (2008) summarises the distributional effects of the initial LCC when the charge was GBP 5. She concludes that the 90% of entrants who did not use a car gained from the scheme since they benefited from lower travel times and a better environment without having either to pay, or to change mode, trip timing or destination. Some car commuters with high values of time also gained, as did some car users who could circulate within the tolled zone conducting business during the day at no extra cost. In contrast, Santos argues that commercial vehicles did not fare as well due to their inability to cancel trips, constraints on delivery times, and a claim by the Freight Transport Association that vehicle operators could not pass on the charge to their customers.

The LCC has undergone a number of changes over the years, including a series of increases in the toll, elimination of some exemptions, and reallocation of road space away from cars. Average travel speeds

[27] A few other small congestion charges have been implemented in Europe: Durham in 2002 (The Chartered Institution of Highways & Transportation[238]), Valletta in 2007 (Attard and Enoch, 2011[274]) and Palermo in 2016 (https://www.worldtravelguide.net/guides/europe/italy/palermo/gettingaround/). Norway has a number of urban toll rings. They were created to generate revenues for roads, but some are now being modified to target congestion (Cipriani et al., 2019[270]).

[28] Lehe (2019[248]) provides an extensive review of these schemes, and Gu et al. (2018[254]) list measures taken in London, Stockholm and Milan to address equity.

[29] In 2019, London introduced an Ultra Low Emission Zone encompassing the same area as the congestion charge. Passenger vehicles that do not meet emissions standards have to pay a daily charge of GBP 12.50 in addition to the congestion charge of GBP 15. The emissions fee applies at all hours, and was extended to a larger area in October, 2021. See https://tfl.gov.uk/modes/driving/ultra-low-emission-zone?intcmp=26434.

[30] No systematic assessments of the effects of Singapore's Electronic Road Pricing system appear to have been undertaken. Hosford et al. (2021[69]) review the distributional impacts of all five schemes on physical health outcomes and social interaction.

within the tolled zone have also increased. Consequently, the distributional effects of the charge may have changed as well.

Stockholm

The Stockholm Congestion Tax was trialed in 2006 and implemented permanently in 2007. As in London, a majority of Stockholm commuters used public transport even before the tax was introduced. Karlström and Franklin (2009[60]) conducted one of the early studies of the welfare effects of the tax. They find that drivers who paid the toll suffered an average annual loss (before accounting for the use of toll revenues) of 1840 Swedish krona (SEK) (EUR 181), whereas those who did not pay the toll gained an average of SEK 69 (EUR 7).[31] On average, drivers lost SEK 376 (EUR 37).[32] The average public transport user lost SEK 27 (EUR 2.7); much less than the average driver. A majority of commuters experienced neither a gain nor a loss, and few individuals changed mode. Nevertheless, all income groups suffered losses on average. From lowest to highest quintile, the average losses were EUR 321, EUR 199, EUR 35, EUR 348 and EUR 219. Thus, on average the middle income group lost the least. To a large extent, the irregular pattern is due to cross-quintile differences in the fraction of household members who crossed the cordon by driving a car. The results are notable for both the lack of a regular pattern of losses versus income, and the fact that all income groups suffered losses on average.

In a more recent study, Eliasson (2019[12]) concludes that, before accounting for revenue use, the Stockholm tax is slightly regressive. The lowest income decile pays a higher-than-average proportion of income in tax, while the highest three deciles pay a slightly lower proportion. The congestion charge is more regressive for residents living close to the charging zone, especially for residents within the inner city. Hence, the scheme is reasonably equitable vertically except for the lowest incomes, but it violates spatial equity.

Gothenburg

The Gothenburg scheme was implemented for the first time in 2013. Unlike Stockholm, its primary goal is revenue generation rather than congestion relief, as shown in Table 2.1. Congestion and other externalities related to car use were less of a problem in Gothenburg than in Stockholm. Another fundamental difference was that the share of commuting trips by public transport was much lower. West and Borjesson (2020[61]) determine that the scheme is more regressive than in Stockholm. In part, this is due to a high level of car-dependence at all income levels, and in part because the highest income workers have greater access to company cars for making non-working trips.

Milan

The Milan Area C scheme is an area charge imposed in an 8 square km central sector of Milan. Area C was launched in 2012 to replace Ecopass: a pollution charge within the same area that had lost its effectiveness to control congestion as older polluting vehicles were replaced by newer vehicles that were exempt from paying the charge. In June 2011, a referendum was held on whether to replace Ecopass with Area C. It received 79% support, with a large majority of residents in all city zones in favour.[33]

Beria (2016[62]) describes the effects of Area C during its first year of operation. The charge proved to be effective in alleviating both congestion and pollution, with vehicle entrances into the centre falling by 31%, emissions of particulate matter falling by 18%, and CO_2 emissions falling by 35%. Beria (2016[62]) also

[31] Using an exchange rate of EUR 0.0985 per SEK on October 7, 2021. Not adjusted for inflation.

[32] This loss corresponds roughly to area CBOE in **Figure 2.1**.

[33] The strong support presumably reflects both voters' experience with Ecopass and their expectations regarding Area C.

examines the effects of the toll on five user groups[34]: (1) authorised vehicles and (2) low-emission vehicles that were both exempt from paying, (3) commercial vehicles that paid EUR 3 per day, (4) residents inside the cordon who were granted 40 free entrances per year and paid EUR 2 per day for additional trips, and (5) others who paid EUR 5 per day. Beria finds that none of the groups made large toll payments. Most residents did not exceed their free 40 entrances per year, and 96% paid less than EUR 1 per day, on average. For commercial vehicles and other users, the corresponding fractions are 87% of 97%, respectively.

Overall, most users appear to have benefited from Area C — at least during the first year of operation study. Beria (2016[62]) identifies several reasons. First, before implementation fewer than 20% of people entered the central city by car (a trait similar to that in London and Stockholm). Second, the reductions in traffic and pollution benefited drivers in all five groups, as well as users of public transport, bicyclists, pedestrians and inner-city residents. Third, revenues from the charge were earmarked exclusively to public transport and other sustainable transport policies such as bicycle-sharing stations.

[34] Due to lack of data, Beria does not report welfare effects at an individual level or estimate changes in the generalized cost of travellers who changed mode.

2.1.5. *Distributional effects of other urban congestion pricing schemes*

Many studies have examined pricing schemes that were either proposed but not implemented, or hypothetical. An illustrative sample of studies is summarised here. Santos and Rojey (2004[63]) studied hypothetical cordon tolls in **Cambridge**, **Northampton** and **Bedford** in the United Kingdom. They conclude that the distributional effects of cordon pricing are highly contextual. The scheme can be progressive, neutral or regressive, depending on the locations of residences, workplaces and other destinations. As in Stockholm, an important determining factor is the correlation between income and the frequency of trips that cross the cordon. More recently, Santos and Caranzo (2021[59]) examine the effects of a proposed GBP 2 cordon charge in **Cardiff**, Wales. They find that the effects would be regressive, but vary across local authorities in the region and depend crucially on how many workers commute to Cardiff and what mode of transport they use.

A double cordon toll was proposed for **Edinburgh**, but was resoundingly defeated by referendum in 2004. The scheme entailed a GBP 2 daily charge on weekdays for crossing inwards an inner cordon between 7:00 and 18:30, or an outer cordon between 7:00 and 10:00.[35] Cain and Jones (2008[64]) estimate how many households would have experienced financial hardship if the scheme had been implemented. They find that the fraction of households using a car rose strongly with income, but the charge would nevertheless have been regressive. Even with no charge, on average households in the lowest income quintile spent approximately one third of their income on car travel. Among five trip purposes (work, education, health, food shopping, and social activities), low-income car users would have incurred the charge most frequently for work trips. One reason is that workers in this group had limited flexibility to alter the timing of work trips, in particular to cross either of the cordons before 7:00, or the outer cordon after 10:00.

Bureau and Glachant (2008[65]) assess and compare various tolling schemes for **Paris** designed to achieve a target percentage reduction in traffic. They also consider two revenue recycling schemes: one that provides a rebate to all travellers, and the other a rebate only to public transport users in the form of reduced fares. All combinations of pricing and revenue-recycling schemes turn out to be regressive and welfare-reducing for all five income quintiles of the population. Several factors may contribute to the overall welfare losses they obtain. First, the tolls they consider are flat rather than varying by time of day, and therefore do not target congestion effectively. Second, their model includes mode choice, but not departure time or route choice so that travellers have only limited scope to avoid paying tolls. A third possibility is that none of the target traffic reduction rates they consider (10%, 20%, 30% or 50%) may be close to the socially optimal rate as characterised in **Figure 2.1**. An unexpected finding of their study is that the two revenue recycling schemes have similar welfare-distributional effects. The reason for this is that allocating revenues only to public transport users encourages travellers to shift from driving to transit. Therefore, the toll therefore does not have to be set as high to achieve a given traffic reduction, and the lower toll compensates drivers for not receiving part of the toll revenue.

Di Ciommo and Lucas (2014[66]) study the effects of a hypothetical EUR 3 toll on the orbital road cordon on the motorway circling **Madrid**. They find that individuals who switch from driving to public transit in order to avoid paying the toll experience an increase in generalised trip cost due to longer travel times. Moreover, as a fraction of income the increase is higher for individuals living in low-income districts relative to those living in high-income districts. They conclude that, even in a large European city, public transport may be an inadequate substitute for driving so that it does not offer an adequate defence against potentially adverse distributional effects of tolling.

Mobility Pricing Independent Commission (2018[67]) conducted an ex-ante study of the effects of congestion pricing in **Vancouver**, Canada. It considered various scenarios involving congestion pricing with different

[35] The total daily charge was limited to GBP 2 regardless of how many times each cordon was crossed.

toll levels and charging points on bridges. Scenarios also covered distance-based charges. toll levels at varying fractions of marginal social trip costs. One of the scenarios featured time-of-day and direction-dependent charges on major regional bridges, as well as a cordon around the downtown area. For this scenario, the study estimated total net annual revenues of CAD 1,050-1,460 million. Estimated total annual economic benefits (i.e., consumers' surplus and societal benefits) were estimated at CAD 220-290 million. Changes in consumers' surplus were calculated by accounting for travel-time savings, changes in fuel expenditures, maintenance costs and toll outlays, and any inconvenience costs associated with changing mode or destination. Changes in societal benefits were calculated by accounting for changes in greenhouse gas emissions, road infrastructure and maintenance costs, and tolling system operating costs. In all the scenarios considered, toll outlays increased in absolute terms with household income, but decreased as a percentage of income. Three annual income groups were considered: low (< CAD 50,000, with median CAD 31,000), medium (CAD 50,000 to 100,000, median CAD 75,000), and high (> CAD 100,000, median CAD 162,000). For charges set to 37.5% of marginal social trip costs, median annual toll outlay as a percentage of median income for the three groups was estimated to be 4.1%, 1.8% and 1.0%, respectively. Thus, the scheme was highly regressive.

Kreindler (2018[68]) conducts a field experiment of two congestion pricing schemes for **Bangalore**, India. One scheme features a distance-based charge with a higher rate during peak hours. The other a time-invariant cordon charge for crossing through an area with a longer toll-free alternate route. Despite their significant differences, the two pricing schemes have similar effects: both achieve large travel time reductions, but little welfare gains. Kreindler attributes this to the inconvenience that travellers encounter from retiming trips to off-peak periods. This finding highlights the importance of considering the costs that individuals incur in modifying their behaviour in response to transport policies.

In summary, the studies presented here provide varying conclusions about the welfare impacts and distributional effects of congestion pricing. For instance, while Kreindler (2018[68]) indicates marginal welfare gains, Mobility Pricing Independent Commission (2018[67]) finds welfare losses. This disparity can be partially attributed to varying degrees of policy intensity (i.e. toll levels are not harmonised) and the variety of geographical contexts considered. The heterogeneity of the tolling schemes considered in the various studies is also an important driver behind the variety of results, as pricing schemes may differ substantially in their spatial or temporal structure.

Nevertheless, a few commonalities can be discerned. First, most analyses conclude that the pricing schemes they analyse are regressive. Second, the impacts depend on whether public transport provides a reasonable alternative to driving. Third, in the case of a cordon toll the effects depend on whether individuals live close to the boundary of the affected area, and whether they work inside it. Individuals who live inside the boundary tend to gain more than those living outside (Hosford et al., 2021[69]). Fourth, cordon schemes that charge a fixed toll regardless of distance driven are horizontally inequitable because they undercharge long trips, and overcharge short trips (Liu, Wang and Meng, 2014[70]). Fifth, cordon schemes may lead to shortages of parking space just outside the charging zone where motorists have an increased incentive to park their cars and complete their trips within the charged area using another mode (Rajé, 2003[71]).Sixth, cordon schemes do not deter trips that are made wholly within the charging zone, which may become more prevalent as home deliveries and ride sourcing grow in popularity (Shaheen, Stocker and Meza, 2019[72]). Area charges such as those in London and Milan that do toll trips made inside the charging zone avoid this problem. Finally, individuals who lack flexibility to retime commuting trips tend to suffer greater losses than those who are flexible.

2.1.6. High Occupancy Toll lanes and Express lanes

The five urban schemes just discussed encompass relatively large areas. Congestion pricing has also been implemented on a small scale in the form of High-Occupancy Toll (HOT) lanes. Several dozen HOT lane facilities are operating, under design or under construction in the United States. HOT lanes are a modified version of High-Occupancy Vehicle (HOV) lanes that are accessible only to vehicles with enough occupants (typically 2 or 3 people). Unlike HOV lanes, HOT lanes can also be used by vehicles with less than the occupancy requirement if the driver pays a toll. Tolls on the HOT lanes are adjusted by time of day to maintain free-flow conditions and offer users quick and reliable trips. Motorists can also use "general-purpose" lanes running next to the HOT lanes that are kept toll-free and consequently more congested. This makes it possible for motorists to avoid paying a toll without having to take a different route. They can use the general-purpose lanes, or pay a toll for a quicker trip.

A number of studies have examined who uses HOT lanes. As expected, high-income individuals use them the most frequently, but even they do not use them regularly and most drivers in all income groups take them occasionally when they are particularly pressed for time. An early and representative study by Lam and Small (2001[73]) found that women value the reliability provided by HOT lanes more than men. Lam and Small (2001[73]) conjecture that this may be due to the tighter time constraints that women face as their schedules combine work demands with the largest part of family responsibilities. Consistent with this, Shaheen et al. (2019[72]) report that women make greater use of the lanes than men.[36] Bento et al. (2020[74]) claim that most of the willingness to pay to use HOT lanes is to avoid penalties from arriving late. Such penalties include missing flights and arriving late to pick up children at day care centres. Since most people face such penalties from time to time, the option to take a HOT lane is valuable to most drivers, independent of income, age, sex, race or other socioeconomic characteristics.

One drawback of HOT lane facilities is that introducing tolls on some lanes may lead to greater congestion on the remaining general-purpose lanes. Small, Winston and Yan (2006[75]) investigate the possibility of improving efficiency by tolling all lanes as "Express Lanes", but at differential rates. They use data for drivers with a wide range of incomes, values of time and values of reliability. They find that tolling all lanes can boost efficiency materially while leaving no groups appreciably worse off. Moreover, the distributions of gains and losses overlap considerably across income groups. Low-income individuals with high values of reliability can gain more than high-income individuals with low values of reliability.

Many US cities have extensive networks of roads with HOV lanes that are often underutilised. Safirova et al. (2004[76]) explore the effects of converting all the HOV lanes in Washington, DC, to HOT lanes. They determine that all household income quartiles gain from the policy. This is because drivers who switch from the general-purpose lanes to the HOT lanes do so voluntarily, and also because congestion in the general-purpose lanes is alleviated. Two groups suffer minor losses. First, some carpoolers who previously had exclusive access to the HOV lanes experience small increases in travel times. This occurs because speeds on the HOT lanes drop slightly when more drivers use them. Second, a few zones in the city core suffer increased congestion and parking search costs as more people decide to drive there.

Safirova et al. (2004[76]) also consider two other, more comprehensive tolling policies for Washington, D.C.: one in which all lanes on roads with HOV lanes are tolled (with no HOV exemption), and another in which all major freeways in the city are tolled. In both cases, the effects on travellers are much less favourable than from converting HOV lanes to HOT lanes. Travelers lose in aggregate from the first alternative policy, and all income quartiles lose from the second which has an overall regressive incidence. This illustrates that, although comprehensive pricing may yield substantial welfare gains from traffic reductions, smaller scale and selective schemes can be more favourable to travellers, and hence more politically palatable as discussed further in Section 3.

Roads and other transportation services are funded partly by taxes that are not related to the transport system (e.g., the income tax or sales taxes). Such financing is horizontally inequitable because it violates the-user-pays principle. For instance, two seemingly identical individuals may contribute equally to building

[36] Small, Winston and Yan (2005[240]) also find that toll lanes are favoured by women, as well as middle-aged motorists and motorists in smaller households. Unexpectedly, usage is not affected by whether travelers have flexible work hours.

a new road, but only one of them may use it. Financing transport infrastructure via generic tax revenue can also be more regressive in terms of vertical inequality than doing so through user charges such as tolls. However, an in-depth comparison requires knowledge on the extent to which the overall tax system of a country is regressive and the degree to which earmarked revenue comes from a charging scheme that is regressive. Furthermore, in cases where transport investments are financed by debt, intergenerational equity issues need to be taken into careful consideration. Schweitzer and Taylor (2008[77]) compare the cost burden of paying tolls on the HOT lanes on State Route 91 in Orange County, California, with the equivalent cost burden under Orange County's local-option transportation sales tax. A shift from the sales tax to the tolls leaves individuals in the lowest and highest quintiles of the income distribution better off, and the three middle quintiles worse off. Thus, the shift has mixed effects as far as vertical equity. It appears attractive for the lowest quintile, although within this group individuals who drive a lot will be worse off.

2.1.7. Health effects of tolling

In addition to reducing congestion and improving travel time reliability, tolling decreases overall traffic levels and can therefore mitigate air pollution. The health benefits tend to be greatest in densely populated areas of inner cities. As shown in Table 2.1, pollution reduction is a primary or secondary goal for the Stockholm, Gothenburg and Milan Ecopass schemes. Several studies have examined the effects of these schemes on pollution.[37] Most focus on health effects on adults, but Simeonova et al. (2019[78]) identify a substantial reduction in asthma among young children due to the Stockholm congestion tax. Converting toll facilities from manual collection methods to Electronic Toll Collection (which does not require vehicles to stop) can also reduce emissions. Lin and Yu (2008[79]) find that facility conversion results in substantial reductions in CO concentrations and diesel particulate matter emissions, and Currie and Walker (2011[80]) identify reductions in premature and low weight births.

Manville and Goldman (2018[10]) mention evidence that early exposure to vehicular pollution not only harms low-income people, but can also cause and perpetuate poverty. To assess the potential benefits from tolling, they use data on traffic flows and population densities for the ten most congested urban areas in the United States. In their simulations, they assume that only freeways are tolled. They find that residents who live closer to freeways have lower incomes and are exposed to pollution levels above the average. Low-income commuters are less likely to drive on freeways at peak times, and higher-income individuals drive longer distances on average.

Together, these results indicate that lower-income individuals would benefit disproportionally from tolling without paying a large amount in tolls.[38] In addition to reducing pollution, studies have found that congestion pricing has reduced traffic accidents in London and Milan (Hosford et al., 2021[69]). However, it can adversely affect social interactions. For instance, the London Congestion Charge resulted in a reduction in visits to family and friends, with more pronounced reductions among lower-income households (Munford, 2017[81]).

2.2. Fuel taxes

2.2.1. Background

Traditionally, fuel taxes have served mainly as a revenue source, and they continue to do so in the United States. In the EU, fuel taxes are increasingly used as a tool to reduce carbon emissions and encourage

[37] Anas and Lindsey (2010[275]) summarize some of the early studies. Hosford et al. (2021[69]) provide a more recent review.

[38] As Manville and Goldman (2018[10]) acknowledge, tolls could divert traffic and pollution onto other roads. The distributional implications of diversion are unclear.

the use of public transport. Fuel tax rates differ considerably across countries in the OECD and elsewhere, but they can also differ substantially within countries. Furthermore, different rates apply to gasoline and diesel fuel.

Similar to tolls and other demand-side policy instruments, the distributional effects of fuel taxes depend on individual responses to changes in tax rates. There are several ways in which individuals can react. The effects of fuel prices on vehicle ownership, fuel consumption and distance driven have been studied extensively since the 1970s. Graham and Glaister (2002[82]) survey studies of automobile gasoline consumption across countries, concluding that the average short-run price elasticity is about – 0.3, and the average long-run elasticity between –0.6 and –0.8.[39] Spiller and Stephens (2012[83]) estimate elasticities that are larger for households that face higher gasoline prices, own more vehicles, and drive greater distances, thus spending a significant share of their income on fuel.

Part of the demand response to fuel prices is due to individuals switching from driving to transit. Nowak and Savage (2013[84]) review the literature on the cross-price elasticity of transit ridership with respect to the price of gasoline. For countries with a low transit market share, Holmgren (2007[85]) determines from a meta-analysis that the cross-price elasticity is approximately 0.2 in the short run, and 0.5 in the long run. Spiller et al. (2012[86]) determine that elasticities are higher for households with better access to public transit service. Elasticities also tend to be higher when service operates along the same corridor as major highways, as Nowak and Savage (2013[84]) find is true for Chicago.

Most studies have assumed that motorists react in the same way to changes in fuel taxes and equal changes in overall (i.e., tax-inclusive) fuel prices. However, as Li, Linn and Muehlegger (2014[87]) explain, changes in taxes may have larger effects for two reasons. First, individuals may perceive changes in taxes to be more permanent than changes in fuel prices, which can be perceived as volatile. Due to the cost and time required to alter driving behaviour or buy a more fuel-efficient vehicle, people may respond only to persistent changes. Second, because of the media coverage that tax changes can attract, they may be more salient to motorists. Motorists may also react more forcefully to tax hikes that they perceive to be revenue grabs by governments than to price changes caused by impersonal market forces. Consistent with this reasoning, Li et al. (2014) find using US data that increases in gasoline taxes reduce gasoline consumption much more than equal increases in the overall price of gasoline. This suggests that fuel taxes can be an effective instrument for reducing car use and boosting public transit demand, especially in the long run.

2.2.2. Equity

Fuel taxes are horizontally equitable insofar as fuel tax payments increase proportionally with distance driven. However, fuel taxes may exacerbate vertical and spatial inequity. Poorer households with fuel-inefficient vehicles bear a disproportionate burden. Spatial inequity exists between households with ready access to public transport, and those who live in rural or other areas where service is sparse or absent. Spatial inequities also arise if fuel taxes differ between adjacent jurisdictions or if higher taxes are not justified by better public services. Large tax differences can also induce cross-border shopping or "tank tourism", which increases distance driven, fuel consumption and emissions.[40]

Fuel taxes are generally considered to be regressive, but the evidence is mixed. From a sample of empirical studies, Eliasson (2019[12]) concludes that fuel taxes are slightly regressive for rich countries, but

[39] A price elasticity measures the percentage change in the consumption of a commodity induced by a percentage change in the price of that commodity. For example, with an elasticity of – 0.3, a 10% increase in price is followed by a 3% reduction in consumption.

[40] Tank tourism is a particular problem for trucks with large fuel tanks that can travel long distances between fill-ups. To avoid it, several European countries have implemented distance-based charges for trucks.

progressive for poor countries.[41] Most empirical studies have used data on household fuel tax outlays as a proportion of annual income. As household incomes vary from year to year and over the life cycle, annual expenditures have been proposed as an alternative measure of well-being. Using US data on annual household expenditure, Poterba (1991[88]) concludes that the gasoline tax is slightly progressive over the bottom half of the income distribution. Using panel data on US household incomes, Chernick and Reschovsky (1997[89]) find that the fuel tax is slightly less regressive when inequality estimates are based on expenditure than on annual income. Using data from 21 countries, Flues and Thomas (2015[90]) find that transport fuel taxes are on average not regressive, as households in lower expenditure deciles devote a lower proportion of their expenditure on transport fuel taxes. These varied results illustrate some of the difficulties in assessing the equity effects of fuel taxes.

The *car ownership rate* is an important predictor of the distributional effects of fuel taxation. Santos and Catchesides (2005[91]) examine these effects in the context of the United Kingdom. They report that the tax is strongly regressive when the analysis includes only households that own a car. This finding is in line with the results reported by Crawford and Blow (1997[92]), also for the United Kingdom. When all households are included in the analysis, distributional impacts become more complex, as the tax is more burdensome for middle-income cohorts. For countries where car ownership is still relatively low, the evidence does not indicate that motor fuel taxes are regressive. For instance, Agostini and Jiménez (2015[93]) find that the fuel tax is slightly progressive in Chile. Blackman, Osakwe and Alpizar (2010[94]) determine that the fuel tax has a relatively neutral distributional impact in Costa Rica. Pizer and Sexton (2019[95]) suggest that the direct impact of the fuel tax in Mexico is progressive. The major driver behind their finding is that the share of fuel expenses in household expenditure increases with income, from 0.5% for the 1st decile to somewhat below 4% for the 10th decile of the income distribution. They juxtapose this with the cases of the United Kingdom and the United States, where car ownership rates in low-income groups are much higher, causing the relationship between the two variables to change qualitatively.

Another important aspect in evaluating the distributional effects of fuel taxes is how the revenues are used. Bento et al. (2009[96]) find that the fuel tax is regressive per se, but recycling the revenue via a horizontal lump-sum transfer offsets almost all of that regressive impact. A study for France (Bureau, 2011[97]) suggests that taxes on car fuels are regressive before revenue recycling is taken into account. The monetised welfare loss of the examined tax is 1.9% of income for households in the 5th quintile of the income distribution, and 6.3% for households of the 1st quintile. However, if the tax revenue is returned in the form of a horizontal dividend, the complete scheme becomes progressive. This occurs because lower-income households are less likely to own a car and pay fuel taxes, and have a higher marginal utility of income. For Sweden, Eliasson, Pyddoke and Swärdh (2018[98]) claim that the fuel tax becomes progressive if fuel tax revenues are recycled either on a uniform per capita basis, or in proportion to consumption of welfare services in Sweden. The overall importance of revenue recycling is further discussed in Section 3.1.6.

Finally, policy makers need to consider the degree to which the fuel tax is spatially equitable. Large differences in fuel expenditure are evident when compared across regions. The share of households that incur significant losses from the fuel tax is typically highest for low-income groups living in rural areas. In Sweden, differences in the fuel tax incidence are largest between urban and rural areas, intermediate between central cities and suburban areas (including satellite towns), and smallest among central cities of different size (Eliasson, Pyddoke and Swärdh, 2018[98]). Thus, at least in Sweden, fuel taxes appear to create greater spatial than vertical inequities.

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[41] Eliasson (2019[12]) elaborates on some of the results in Eliasson et al. (2018[8]) for the fuel tax. The fuel tax turns out to be slightly regressive when assessed over the full income distribution, but it is actually regressive only between the first (i.e., lowest) and second octiles of the distribution, and between the seventh and eighth (i.e., highest) octiles.

2.3. Distance-based pricing

Fuel taxes are ideal for internalizing global external effects, for example those caused by the aggregate combustion of carbon-based fuels. However, fuel taxes are ineffective in targeting congestion and other traffic-related costs that vary with location and time. Moreover, in some countries the revenue from fuel taxes declines, as vehicles become more fuel efficient and alternative-fuel vehicles gain market share. Revenues from vehicle sales and annual registration fees may also drop if car sharing and ride sourcing become increasingly common (Adler, Peer and Sinozic, 2019[99]).

These developments have spurred interest in supplementing or replacing fuel taxes with distance-based fees, also called vehicle-miles travelled (VMT) fees or mileage-based user fees (MBUF). Distance-based fees are more efficient than cordon tolls or tolls on individual roads that can induce traffic diversion. They could be cheaper to operate on a large scale, and they would provide a sustainable revenue source from all types of vehicles, including autonomous vehicles that are expected in the future. Nevertheless, uniform charges (per kilometre) do have some drawbacks. They do not account for variations in congestion and other externalities that vary by time of the day and by location.[42] Nor do they promote fuel efficiency unless the tax level is adjusted to a vehicle's rated fuel economy.

Distance-based pricing has been implemented for trucks in several European countries and US states. Under its Road User Charges Act[43], New Zealand imposes distance-based road user charges on vehicles powered by diesel fuel, and vehicles over 3.5 tonnes manufacturer's gross laden weight.[44] Oregon has an opt-in distance-based fee for passenger vehicles called OReGO[45] that allows Oregon residents to pay a fee of 1.8 cents per mile driven on Oregon roads, with credit for fuel tax paid.[46] Utah is also implementing a voluntary per-mile fee system.[47]

Distance-based charges are superior to cordon tolls in terms of spatial equity, since all driving is subject to a charge. As it is the case with the fuel tax, distance-based charges exacerbate vertical inequity insofar as charge-free routes do not exist. Given the relative novelty of distance-based charges for passenger vehicles, their distributional implications have yet to be assessed in the field. However, their effects have been extensively researched. Recent work (Tikoudis, Udsholt and Oueslati, 2022[100]; Tikoudis and Oueslati, 2022[101]) provides *ex-ante* analyses of measures to discourage car use in Santiago, Chile. That work suggests that a kilometre tax on private vehicles will be progressive, both before and after returning the tax revenue to the households in a horizontal lump-sum manner. The main reason behind the vertical equity of the measure is that higher income households are much more likely to own a private vehicle. Consequently, upper income groups generate the largest part of the tax base. This finding resembles the corresponding insights from the analysis of the fuel tax (Section 2.2) for countries where car ownership rates are still low or moderate. However, as car ownership reaches saturated levels, other characteristics that correlate with driving distance and accessibility to public transport possess an increasingly decisive role. As a result, the vertical equity of a distance-based tax depends on the context it is applied. In line with

[42] These capabilities could be enabled using on-board devices and satellite-based technology (Ke and Gkritza, 2018[195]) .

[43] https://www.legislation.govt.nz/act/public/1977/0124/43.0/DLM19000.html

[44] https://www.nzta.govt.nz/vehicles/licensing-rego/road-user-charges/about-ruc/

[45] https://www.myorego.org/how-it-works/

[46] Owners of electric and highly fuel-efficient vehicles (40 mpg or better) in Oregon have to pay large initial registration fees when they acquire a vehicle because they pay little or no fuel taxes. But they can avoid the high initial registration fees if they enrol in OReGO. According to Taylor (2021[278]), 27 other states also charge higher registration fees for electric vehicles. The province of Saskatchewan in Canada has also introduced an annual registration fee of CDN 150, effective October 1, 2021, on owners of electric passenger vehicles (Government of Saskatchewan, 2021[257]).

[47] https://roadusagecharge.utah.gov/

this, the literature review by Yang, Kastrouni and Zhang (2016[102]) concludes that most studies have found distance-based fees to be regressive. Starr McMullen, Zhang and Nakahara (2010[103]) find that a kilometre tax is slightly more regressive than the fuel tax. On the other hand, Ke and Gkritza (2018[104]) find a kilometre fee to be moderately progressive in Oregon. Using data from a one-day survey of Oregon households, they assess the effects of a fee levied at 1.5 cents per mile during peak periods (07:00-09:00 and 17:00-19:00). This contrasts with the findings of other Oregon studies, in which both the state fuel tax and the OReGO distance-based fee are regressive. Nevertheless, Ke and Gkritza (2018[104]) find that residents of rural areas who travel greater distances bear more of the tax burden than urban residents. Thus, similar to the results of Eliasson et al. (2018[98]) for the fuel tax in Sweden, the distance-based fee would infringe on spatial equity.

2.4. Parking fees and regulations

Parking fees and regulations have been widely applied since the early days of motoring. If well designed, they can be efficient instruments for controlling access to scarce parking space. However, they are second-best tools for internalising congestion, pollution and other car-related externalities because they cannot be calibrated as a function of driving distance or route (Verhoef, Nijkamp and Rietveld, 1995[105])). The efficiency and equity effects of parking policies are challenging to evaluate for several reasons.[48] Parking supply is a complex mix of on-street, off-street and garage space. Some parking space is controlled publicly, and other space is private. Some is open to the public, some is reserved for business and some is reserved for residents. Residential parking is provided for people living in single-family homes, apartments and condominiums. Parking is provided at Park & Ride facilities to encourage motorists to use public transport for part of their trips. In all cases, the location of a parking place matters greatly because parking is typically accessed by walking, which is slow and can be arduous. Competition between alternative parking locations is thus highly localised, and the effective “market” to park at a given destination is limited in area.

Parking fees and regulations are also complex. Parking is prohibited at certain times of day and on certain days of the week. Some parking spaces are reserved for mobility-impaired people, and others for electric vehicles so that they can be recharged. Some curbside parking is free, but subject to a time limit. Other parking places charge flat hourly rates despite large fluctuations in demand over the day, and still other parking places charge hourly parking rates that vary with parking duration.

Parking fees and regulations are set with a mix of objectives: to facilitate accessibility to homes, businesses and other destinations; to raise revenue, to control parking and traffic congestion, to reduce pollution, to improve safety for pedestrians and bicyclists and so on. Many policies are both inefficient and inequitable. Parking subsidies in the form of free off-street parking at workplaces, businesses and residences encourage automobile ownership and driving, and induce distortions in land use.[49] Free or underpriced on-street parking is often in short supply. Drivers waste time cruising in search of it, and delay through traffic while they search. Privately-owned garages that charge high prices for off-street parking exacerbate the problem by increasing the demand for on-street spaces.

Researchers and policy makers have been aware of the flaws in parking policy for some time, and various remedial actions have been taken. Some of these actions are briefly described in the remainder of this

[48] Research on parking and parking policy has nevertheless made strides in the last 20 years. Inci (2015[32]) provides a comprehensive review of the transportation economics literature on parking.

[49] The estimated costs of these distortions are comparable to those of congestion and crashes. See http://www.vtpi.org/tca/tca0504.pdf.

section, beginning with parking fees and then turning to parking regulations. Further policy recommendations to redress equity concerns are identified in Section 3.

2.4.1. Parking fees

As user fees, parking fees adhere to the beneficiary principle. Rates that vary by length of stay and duration can also be horizontally equitable in terms of reflecting marginal costs although fees often do not ration parking space efficiently. Higher-income individuals tend to be less sensitive to the price of parking, and have a greater willingness to pay for parking that is convenient and safe. Thus, parking fees may fall short on vertical equity for similar reasons as road tolls that allow motorists to make quicker and more reliable trips.

Parking reforms that entail increases in fees or restrictions in supply have drawn opposition from retailers and other merchants who fear they will lose business. In fact, studies have come to mixed conclusions about this and it is clear that the impacts depend on local circumstances (International Transport Forum, 2021[106]). Any loss of business from motorists can be more than offset by greater accessibility for transit users, pedestrians and bicyclists who may visit more frequently than motorists, or spend more money per visit. To the extent that people arriving by other modes have lower incomes than drivers, such parking reforms promote vertical equity.

Hamer, Currie and Young (2013[107]) describe the effects of a parking congestion levy that was introduced in 2006 on off-street parking spaces in the centre of Melbourne. Since the levy was applied over a wide area, it functioned well with respect to spatial equity. However, the fee did not apply to on-street parking or through traffic so that it did not deter driving comprehensively. Hamer, Currie and Young (2013[107]) conclude that the levy was vertically equitable insofar as drivers who used off-street parking were likely to have higher incomes than those who did not. However, about two-thirds of drivers did not pay the charge because they were compensated (possibly by an employer) and these drivers had a higher average income than those who did pay. Thus, both the horizontal and vertical equity effects of the levy were mixed.

Workplace parking levies are a specific case of off-street parking levies. As Santos, Hagan and Lenehan (2020[108]) describe, workplace parking levies have been implemented in Sydney, Perth and Melbourne. Levies were enabled in the United Kingdom by 2000 legislation, but as of 2020 only Nottingham had adopted them. Potential disadvantages of levies include displaced parking and shifting congestion to off-peak periods.

Responsive or occupancy-based pricing has been a notable innovation in parking fee technology in recent years. This entails periodically adjusting parking meter rates on each city block to maintain occupancy rates within a target range such as 60%-80%. The first large-scale trial of responsive parking, SF *park*, was conducted by the San Francisco Municipal Transportation Agency from 2011 to 2013. The agency now operates a modified scheme on a permanent basis.[50] Similar schemes have been implemented in other cities in the United States and elsewhere (Russo, van Ommeren and Dimitropoulos, 2019[109]).

Occupancy-based pricing has advantages similar to High Occupancy Toll lanes. It maintains a relatively high utilization rate of valuable parking space. It also nearly guarantees that a space can be found on each block (or in each parking lot) so that drivers do not have to search for parking, or walk a long way to their destination once they have found parking.[51] Space is available for short-time parkers, carpoolers, people with mobility challenges and people facing emergencies (International Transport Forum, 2021[106]). In short,

[50] See SFpark (https://www.sfmta.com/getting-around/drive-park/demand-responsive-pricing/sfpark-evaluation). The trial is described in Inci, Section 6 (2015[32])

[51] Drivers are also less likely to double park or commit other parking violations.

most drivers are likely to benefit from occupancy-based pricing. Hence, compared to flat-rate fees, occupancy-based pricing scores highly on both horizontal and vertical equity.

2.4.2. Parking supply and regulations

In addition to being inefficiently priced, parking is often supplied in excessive amounts due to regulations or traditional practices that are no longer justified. Most notable are Minimum Parking Requirements (MPRs) for off-street parking that are pervasive in both OECD and developing countries. MPRs establish minimum numbers of parking spaces that must be provided per unit area of commercial floor space or per residence.[52] As Shoup (1999[110]; 2011[111]) explains, MPRs induce changes in land use and transportation-related decisions that are often counterproductive. They increase the cost of constructing commercial buildings, offices and residences. MPRs contribute to urban sprawl by allocating space to parking at the expense of infrastructure for pedestrians, bicyclists, greenery and other uses. By making parking space plentiful, they encourage vehicle ownership (Russo, van Ommeren and Dimitropoulos, 2019[109]). MPRs are also inequitable in several respects. They increase the cost of housing, which is likely regressive, and they benefit home owners or renters who have cars at the expense of those that do not. By increasing the cost to businesses, MPRs can increase the cost of goods and services for everyone. Similar to sales taxes, this tends to be regressive. It could also be horizontally inequitable, since people who drive and use parking are subsidised by those who take other transport modes (Litman, 2021[112]). Residential parking permits are another regulation that encourages vehicle ownership and driving if the permits are issued free, or for a nominal fee. The cost of the reserved parking space is then paid largely with local taxes, which is potentially regressive and also unfair to households without cars (Russo, van Ommeren and Dimitropoulos, 2019[109]).

Employer-provided free parking is a third practice that encourages vehicle ownership and usage, and therefore distorts mode choice. Russo et al. (2019[109]) determine from a back-of-the-envelope calculation that the implicit subsidy of free workplace parking for a typical city in Europe or North America is EUR 1,000 per year, or roughly 30% of the annual private cost of commuting by car. The fringe benefit is usually exempt from income taxation. Since progressive income tax systems tax higher-income individuals at higher marginal rates, the benefit from tax exemption is regressive. As discussed in Section 3, abolishing residential parking permits and employer-provided free parking would promote both efficiency and equity.

2.5. Driving restrictions

Vehicle ownership and usage are rationed and constrained by a number of methods including quotas on vehicle registration (Li, 2018[113]), daily driving restrictions (Gu, Deakin and Long, 2017[114]), traffic calming (De Borger and Proost, 2013[115]; 2021[116]), car-free zones (Victoria Transport Policy Institute, 2019[117]), speed limits and traffic calming. Their effects are similar in some ways to congestion pricing and parking restrictions. By reducing congestion and pollution, they facilitate travel by public transit and non-motorised modes, reduce injuries and deaths, and improve health for travellers and residents (Shaheen, Stocker and Meza, 2019[72]). By reducing vehicular traffic near schools, they can enable children to travel to school independently (van Wee, 2011[18]). However, driving restrictions can reduce accessibility for individuals with limited mobility (International Transport Forum, 2021[106]).

Low-emission zones are a form of driving regulations that have been implemented in many large cities in Europe (Fageda, Flores-Fillol and Theilen, 2020[118]). These zones provide health benefits by reducing pollution (Wolff, 2014[119]). However, because vehicles that satisfy the low-emissions constraints are more expensive than other vehicles, low-emission zones tend to be regressive.

[52] The minimum depends on the type of business and type of residence.

Large-scale driving restrictions can also create spatial and vertical inequities between residents of the restricted zone and those living outside. Paris, for example, has implemented traffic bans, reduced speed limits and traffic-calming measures through much of the central city. Wealthy residents who rarely travel outside may benefit from reduced pollution and noise. But, the restrictions may create a significant accessibility impediment for people living in the suburbs who work in the city and lack good public transportation service (Reguly, 2021[120]).

2.6. Public transit

Public transport is the main alternative to car use in most large cities. Improving public transport can boost ridership and help reduce traffic externalities. Similar to automobile travel, demand for public transport depends on its generalised cost. That includes the fare, any inconvenience caused by an infrequent schedule, and the time cost of access, waiting and in-vehicle time. The latter costs depend on the accessibility and reliability of service, and can increase with the degree of crowding and concerns about personal security. Therefore, transit can be made more attractive in two ways: by reducing fares, and by improving service quality. This section reviews the effectiveness of these two methods and their impacts on equity.

2.6.1. Public transport fares and subsidies

According to international estimates by Paulley et al. (2006[121]),[53] the fare elasticity of bus travel demand is -0.4 in the short run (1–2 years), -0.56 in the medium run (5–7 years), and -1.0 in the long run (12–15 years). For urban rail, the elasticity is -0.3 in the short run and -0.6 in the long run. Demand is thus moderately elastic in the short run, and increasingly elastic as time passes, offering some scope to increase ridership by subsidizing fares. Subsidizing fares is in fact common practice. With the exception of Hong Kong and Singapore, most public transit systems run substantial deficits, with fare revenues covering only a fraction of their operating costs.

Transit subsidies can serve as a second-best instrument for alleviating automobile-travel externalities if driving cannot be controlled directly using tolls. Transit subsidies could also be justified on efficiency grounds if transit supply has decreasing average costs[54], or if optimal service quality increases with ridership (Van Goeverden et al., 2006[122]).[55] Economic efficiency requires that fares vary with the direct and indirect costs of providing public transport. Hence, fares should depend on distance and time of the day, as well as with the degree of crowding and traffic congestion. Real time monitoring and smart card technology have facilitated fare differentiation in these ways. However, many cities still charge a flat fare for all trips. Flat fares are horizontally inequitable. They overcharge for short trips and trips taken during the off peak, and undercharge for long trips and peak-period trips. In these respects, they resemble fixed cordon tolls for automobile trips that do not vary with distance or time.

The vertical and spatial distributional effects of public transport fares have been studied extensively. Using a literature review, Hörcher and Tirachini (2021[123]) conclude that the effects depend on the mode (bus or rail), the distribution of income and the geographical distribution of residences and jobs. For instance, subsidies have been found to be progressive (and fares correspondingly regressive) in Santiago and

[53] As reported by Hörcher and Tirachini (2021[206]).

[54] Studies typically find that bus operations exhibit positive scale economies up to intermediate sizes of fleets, and then roughly constant economies (Borger and Kerstens, 2007[285]; de Borger, Kerstens and Staat, 2008[286]).

[55] These so-called "economies of traffic density" operate in the long run when additional transit routes, more frequent service, improved payment systems, and so on can be provided that benefit all users (Hörcher and Tirachini, 2021[206]). However, in the short run greater ridership can exacerbate crowding and impose negative, rather than positive, externalities on other riders.

Barcelona. They are roughly neutral in Stockholm where public transport usage is more even across income groups. Subsidies are regressive in Los Angeles because high-income people who travel long distances by rail benefit more than low-income people who travel short distances by bus. Due to differences in geography, flat fares are more vertically equitable than distance-based fares in some cities, and less equitable in others. Using data from Utah, Farber et al. (2014[124]) determine that lower-income individuals use transit for a larger proportion of their trips than higher-income groups, but travel shorter distances. They conclude that these individuals would be better off with distance-based fares than a comparable flat fare system, as would older adults and non-white populations. Nevertheless, distance-based fares could be vertically inequitable if low-income and minority populations live far from workplaces and other destinations.

2.6.2. Public transit service quality

Transit service quality can be improved in many ways. Expanding the network of routes, facilitating connections, increasing frequency and reliability, enhancing security, providing information updates are some of them. Making transit more attractive can reduce car use by shifting trips from cars to transit as well as reducing car ownership. Empirical evidence suggests a moderate elasticity of public transport ridership and car use with respect to public transport network expansion. Bento et al. (2003[125]) estimate that a 10% expansion of a metro network in US cities would reduce automobile use by 4.2%. Using cross-sectional international data for 41 cities, de Grange et al. (2012[126]) determine that a 10% expansion in the metro or rail network would reduce driving by more than 2%. In terms of enhanced ridership, Gonzalez-Navarro and Turner (2018[127]) estimate for a sample of 77 international cities that a 10% increase in the number of subway stations boosts ridership by about 6%.[56] Winston and Langer (2006[128]) find that expanding rail transit in US cities reduces traffic congestion. However, they also find that improving bus service increases congestion, especially when the buses operate on exclusive bus lanes. They attribute the inferior performance of buses to the lower quality of service they provide relative to rail, and to the fact that allocating road space to bus lanes reduces road capacity for cars.

In terms of equity, transit investments benefit disadvantaged groups if their accessibility improves. This depends not only on how far people have to travel by transit, but also their access time to and from transit stations. Connectivity may be poor in suburban and blighted areas, but in inner cities walking distances can be short. Carlson and Owen (2021[129]) summarise a study by Grengs (2015[130]) that found vulnerable social groups in Detroit to enjoy better transit access than higher-income groups for most types of trips except for shopping. Similarly, Farber and Allen (2019[131]) determine that lower-income households in the Greater Toronto and Hamilton Area (GTHA) enjoy higher levels of transit accessibility. This is because they choose to live in neighbourhoods with good access. For both low-income households and households without cars, transit accessibility is strongly and positively correlated with participation in out-of-home activities which are an important dimension of quality of life. Farber and Allen (2019[131]) assess the effects of accessibility improvements on activity participation, finding that the gains are greatest in areas with intermediate levels of accessibility. In the GTHA, these areas are concentrated in the inner suburbs. Hence, transit improvements in these areas would induce the largest increases in activity generation. By contrast, incremental improvements in rural areas would yield much smaller effects because service would still be poor. Incremental improvements in neighbourhoods that are already well served by transit would also offer little benefit because of limited scope to make service even better.

Large-scale efforts to reduce urban automobile usage such as area-wide tolls, large hikes in fuel taxes or low emission zones are liable to reduce accessibility substantially for certain groups. Improving transit service can alleviate this problem, but it is unlikely to fully compensate all low-income and other

[56] In contrast, Baum-Snow and Kahn (2005[276]) document a decline in the fraction of commuting trips by public transit in US cities between 1970 and 2000, even though a growing fraction of workers lived within two miles of a subway line.

disadvantaged individuals. Given the high costs of transit service, especially of rail and subways, it is not economically feasible to deliver comprehensive, reliable and frequent service to all areas of a city (Transportation Research Board, 2011[23]). Moreover, enhancing access to subway lines and smart growth measures such as Transit Oriented Development can increase land values and housing prices in the vicinity, and displace lower-income and minority groups (Shaheen, Stocker and Meza, 2019[72]; Litman, 2021[112]).

In conclusion, evidence on both the efficacy and distributional effects of transit fare subsidies and service improvements is mixed. Enhancing rail service appears to be more effective than improving bus service, but it is more expensive, and by increasing land values near rail stations it can displace disadvantaged groups. Subsidizing fares or improving service benefits is most effective if it improves accessibility at intermediate levels of accessibility for which the increase in ridership tend to be greatest.

Table 2.3. Summary of the economic efficiency and equity effects of examined policies

Policy	Vertical equity impact	Spatial equity impact	Efficiency impact	Comments and observations
Cordon tolls / Congestion pricing	Context-specific	Inequitable	Positive*	Vertical equity (i.e. equity across income cohorts) depends on: (i) car ownership of low-income groups, (ii) the location of the cordon, (iii) the systematic income differences between residents within and outside the cordon, and (iv) the correlation between income and public transport coverage in locations outside the cordon.
Flat km tax	Context-specific	Equitable	Positive*	Vertical equity effects depend on car ownership of low-income groups, and the correlations between: (i) driving distance and income and (ii) driving distance and public transport coverage. In monocentric cities, regressive effects subside if higher income households reside further away from CBDs[a], and *vice versa*.
High Occupancy Toll lane	Mixed	Low	Positive	Vertical equity depends on the correlations between: (i) income and carpooling, i.e. the measure tends to be progressive when lower-income households have more flexibility to carpool; as well as (ii) income, value of time, and value of reliability. With respect to (ii) the measure generates time savings and reduces travel time reliability, gains that tend to favor higher-income groups more.
Motor fuel taxes	Mixed	Mixed	Country-specific	Progressive in low-income countries where car ownership is confined to high-income groups. Tend to be more regressive when vehicle fuel economy increases rapidly with income.
Public transport subsidies	Progressive	Context-specific	Mixed	Efficiency impacts depend on (i) the social cost of revenue raising taxes, (ii) the social benefit from the accompanying reduction in externalities.
Investments in public transit service quality	Context-specific	Context-specific	Context-specific	All effects depend on the location of investments and the income level of the main beneficiaries.
Parking fees	Context-specific	Inequitable	Positive	Progressive if high-income households drive more in CBDs[a]
Low emission zones	Regressive	Inequitable	Unknown	Stated effects are based on the hypotheses that: (i) income positively correlates with ownership of low emission vehicles and (ii) residents of low emission zones have higher incomes
Minimum parking requirements	Regressive	Inequitable	Negative	
Residential parking permits	Regressive	Inequitable	Negative	

Note: The stated effects are not generic, and should be interpreted with caution, as they substantially depend on a number of context-specific parameters. Notably, equity impacts depend on the sum of the primary and secondary effects of a policy. Primary effects of fuel taxes on vertical equity, for example, are determined by income level and the proportion of income spent on transport. Secondary effects occur via factors that determine a household's exposure to policy-induced welfare losses. In the case of fuel taxes, this could be a household's accessibility to public transit insofar as this allows a household a degree of flexibility in adjusting how much they drive and thus the proportion of their income spent on the policy-relevant transport expenses.

[a] Central Business Districts * Applies to contexts where traffic levels exceed their socially optimal levels.

Box 2.1. A comparison of policies to reduce traffic congestion in Beijing

Section 2 has reviewed various policies designed to curb urban automobile use, including distance-based congestion charges, driving restrictions, and public transit expansion. Barwick et al. (2021[132]) compare the efficiency and distributional effects of these three policies in a case study of Beijing.

Two of the policies already exist in Beijing: the one-day-per-week license plate-based driving restriction in place since 2008, and the subway expansion that occurred between 2008 and 2014. The third policy is a hypothetical distance-based congestion charge (henceforth called the toll) that is calibrated to reduce congestion by the same amount as the driving restriction. The driving restriction and the toll are demand-side policies, whereas the subway expansion operates on the supply side. In the model, households choose where to live, but their workplace locations are treated as fixed. Household members choose among six travel modes: car, taxi, bus, subway, walking and bicycling. The population is divided into two income groups, each comprising half the population. The model is estimated econometrically using data on housing transactions and from household travel diaries.

Barwick et al. (2021[132]) find that all three policies reduce the share of trips by car, but in several other respects their effects differ notably. Consider first the driving restriction and toll. Both policies induce households to live closer to work, and the reduction in driving distance adds to the effect of the modal shift in reducing congestion. However, by increasing driving speed, the driving restriction makes driving more attractive on days when individuals are allowed to drive. This effect is stronger for individuals with long commutes, and hence encourages them to drive rather than taking another mode. By contrast, the toll disproportionally reduces driving by those with long commutes, and in most neighbourhoods it reduces commuting distance more than the driving restriction.

The driving restriction and toll also differ in their distributional effects. The driving restriction imposes larger losses on long-distance commuters because they are forced to take another mode on days when they cannot drive. High-income households move closer to the subway, which raises housing prices that induce low-income households to move further away. Hence, the driving restriction has both spatial and vertical equity effects. By comparison, the toll induces a much bigger reduction in driving for low-income than high-income households, and in this respect it is regressive.

Unlike the two demand-side policies, subway expansion increases accessibility. Both income groups move away from their workplaces and commute longer distances. The expanded subway attracts travellers not only out of their cars, but also away from bus, bicycling and walking, and it reduces congestion less than the other policies. Nevertheless, subway expansion benefits residents since it offers a better commuting option. The toll is also beneficial, although it disproportionally affects low-income households. In contrast, the driving restriction reduces consumer welfare, and harms high-income households the most because they are more likely to commute by driving.

Overall, the Barwick et al. (2021[132]) study highlights the trade-offs between efficiency and equity when choosing between alternative policy instruments. It also suggests that the effects of transportation policies on the housing market can have major consequences for both efficiency and equity. The effects on housing are more challenging to assess than the effects on route, mode and other shorter-run decisions. Residential location decisions play out over longer periods, and are subject to frictions, and the supply of housing can also respond.

3 Policy implications

3.1. Assessment of policy instruments for managing and mitigating distributional effects

3.1.1. Overview

As reviewed in Section 2, many policy instruments can be used to discourage car use. Both theory and practice suggest that their efficiency and distributional effects depend on local circumstances and on how they are implemented. This complicates considerations of how any adverse distributional effects of policies can be mitigated without undermining their efficiency. A further complication is that multiple policy instruments to reduce car use can be deployed at once, and multiple instruments to alleviate or redress their unfavourable effects can be adopted, as well.

For ease of reference, policies to reduce car use will be referred to as "*restraint policies*", and policies to mitigate their adverse distributional effects will be called *"remedial policies."* As Litman (2021[112]) notes, remedial policies can be classified as categorical or structural. Categorical policies target specific disadvantaged groups. For example, low-income individuals can be granted transit fare subsidies during off-peak periods. Structural policies are more horizontal and broader in scope, applying to all households. For example, many cities have adopted smartcards that facilitate paying fares for all transit users. Structural policies are often more expensive to implement than categorical policies, but they may yield larger benefits or co-benefits.

Restraint policies and remedial policies can exhibit synergistic or antagonistic effects. For instance, congestion pricing and bus transit investments are synergistic car policies (Turner, 2019[133]). By making driving more expensive, congestion pricing shifts some drivers to transit and also speeds up bus travel times if buses use the same road lanes as cars. If toll revenues are used to fund transit expansion, bus ridership can be expanded further.[57] An example of antagonistic policies might be public transport investments and support for electric vehicles, as the latter are a substitute for public transit, rather than a complement (OECD, 2020[134]). The remainder of Section 3 assesses the merits and limitations of specific remedial policies. In some cases, remedial policies entail modifying restraint policies, whereas in other cases they come in the form of separate measures.

3.1.2. Congestion pricing

As explained in Section 2, congestion pricing schemes are prone to adverse horizontal and/or vertical equity effects. To address these problems, many studies recommend that tolls be accompanied by other instruments as a policy package.[58] These other instruments could include additional travel demand management measures, reductions in other user charges such as vehicle registration fees, public transport

[57] Since using toll revenues to fund transit is a remedial policy (discussed later in this section), this example also illustrates synergy between **use** and remedial policies.

[58] See, for example, Jones (1991[250]), Victoria Transport Policy Institute (2019[117]) and Krohnengold (2020[141]).

investments, reallocation of road space to other transport modes, aid to at-risk groups and so on. Moreover, toll revenues can also be earmarked to fund supplementary measures.

The most obvious remedial policy is to design congestion pricing schemes that do not have severe distributional effects. For example, the boundaries of toll cordons and area-based charges could be chosen so that destinations such as hospitals and employment centres are outside the tolled zone (Bonsall and Kelly, 2005[135]).[59] A more general option is to maintain reasonable toll-free roads for travellers who are not willing to pay a toll. Many jurisdictions require by law that toll-free alternatives be available.[60]

Varying tolls by time of day or week raises both efficiency and equity issues. The congestion pricing schemes in Singapore, Stockholm and Gothenburg feature time variation, as do tolls on High Occupancy Toll lanes and some toll roads. Typically, congestion is worse during peak periods, thus economic efficiency calls for higher tolls during peak periods than during other periods of the day. However, another efficiency-based argument is that tolls should be reduced at peak times because commuting trips are concentrated during these hours.[61] Setting high peak-period tolls may also disadvantage low-income workers who lack the flexibility to commute during off-peak hours (Shaheen, Stocker and Meza, 2019[72]).[62] One option is to cap the toll somewhat below the maximum level dictated on pure congestion pricing grounds. Braid (2018[136]) shows how this can be done without sacrificing a large fraction of the efficiency gains. He also shows that imposing a cap on the toll can make some travellers better off without leaving any worse off.[63]

The remedial policies considered so far do not discriminate directly between individuals. Yet, as shown in Table 2.1 all five major congestion pricing schemes offer toll discounts and exemptions. In particular, the London Congestion Charge has a long list of discounts and exemptions for various vehicle types according to size, function (e.g., emergency service vehicles), ownership (e.g., disabled people), and environmental credentials. Registered residents of the congestion zone receive a 90% discount.[64] The list of discounts

[59] Some cities have natural boundaries for a cordon or area charge. In London, it is the inner ring road, and in Milan it is the circular ring of streets called the “Cerchia dei Bastioni”. Stockholm is on an island, and the bridges connecting it to the mainland form a natural cordon. In such cases, modifying the boundary may be impractical.

[60] For example, toll roads in Spain must have a toll-free alternative that serves the same corridor (Bueno, Gomez and Vassallo, 2017[271]). In British Columbia, Canada, tolls can be implemented only if a reasonable untolled alternative is available (British Columbia Ministry of Transportation, 2003[272]).

[61] Workers pay income taxes and employers pay payroll taxes. Both taxes could reduce net wages and in some contexts reduce labour supply. Evers, De Mooij and Van Vuuren (2008[287]) conduct a cross-country synthesis of empirical studies on the (wage) elasticity of labour supply. Setting high tolls exacerbate labour market inefficiencies (Parry and Bento, 2001[244]; Van Dender, 2003[235]) by reducing the daily net wage and consequently eroding the labour income tax base. The spatial considerations of the negative interaction between road and labour taxes is further explored in monocentric cities (Tikoudis, Verhoef and van Ommeren, 2015[44]) and polycentric (Tikoudis, 2020[281]) urban areas. Hirte and Tscharaktschiew (2020[42]) highlight how this negative interaction subsides in cases where fewer days (and thus fewer commutes) of longer duration can create the same value added. Tikoudis and Van Dender (2021[43]) provide a non-technical presentation of the resulting policy implications.

[62] However, Shaheen et al. (2019[72]) note that low-income workers (and especially low-income women) may not work at peak-hour commuting times. Consistent with this, Cortright (2017[268]) reports that in the Portland metropolitan area, the median family income of individuals who commute during the morning peak is about 20% higher than for those who commute at other times.

[63] In particular, it can leave travellers with low values of time and inflexible schedules better off, whereas they would be worse off without the cap.

[64] Bonsall and Kelly (2005[9]) note that low-paid workers and other groups argued for exemptions as well, but were unsuccessful. They write “Clearly the choice of groups to receive an exemption or discount is a political matter” (page 7).

and exemptions has been modified repeatedly, and various changes have been made to the other four schemes.[65]

Some toll discounts and exemptions may have been necessary to overcome public opposition (see Section 3.2). Nevertheless, discounts and exemptions complicate accounting and enforcement, and reduce revenues that can be used to ease opposition. Discounts and exemptions also weaken incentives to alter travel behaviour in a desirable way, weakening the efficiency of use policies in addressing social externalities. Studies of how to implement congestion charging in London came out against discounts and exemptions, but such measures were implemented anyway for political reasons (Richards, 2006[137]) and in response to public consultations (Santos, Button and Noll, 2008[138]).

Exemptions are a controversial aspect of the proposed congestion charge for the central business district in New York City.[66] Exemptions have been granted for emergency vehicles, vehicles transporting passengers with disabilities, vehicles taking certain routes and Manhattan residents earning less than USD 60,000 per year (Dupuis et al., 2019[139]). Exemptions have also been sought for many other groups: low-income car owners, “essential” city workers, labour and industry groups, bus companies, the trucking industry, low-emissions vehicles, New York City Police Department officers and personnel, vehicle trips to medical or health facilities, New Jersey commuters, politicians, and for tolls paid on “upstream” bridges.[67] According to Komanoff (2019[140]), exemptions would be costly. Exempting just 10% of trips would reduce speeds and the travel time savings induced by tolling in the first place. That is estimated to shrink net benefits by nearly USD 300 million. However, the enabling legislation requires the tolling programme to meet a net revenue target. Hence, if exemptions are granted, higher tolls will have to be charged for non-exempt users (Krohnengold, 2020[141]).

Another concern about congestion pricing that applies not only to New York City, but other cities as well, is how to deal with Transportation Network Companies (TNCs) that provide ride-sourcing services on demand. Ride sourcing has been viewed favourably as a way to enhance accessibility for people who do not own a vehicle. However, several studies[68] have found that ride-sourcing increases traffic congestion and may reduce public transit use. One reason for the greater congestion is the extra distance from “deadheading” as TNC drivers travel empty while moving to pick up their next customer.

These concerns have prompted several cities to regulate TNCs. In 2019, New York imposed a cap on cruising during peak hours, and levied a USD 2.75 charge on all for-hire vehicle trips.[69] In 2020, Chicago introduced a congestion tax on TNCs, with a higher rate for single-passenger trips than shared trips.[70] Imposing the congestion tax on TNCs, but not other vehicles, is vertically inequitable if TNC customers have lower average incomes than drivers. Differentiating the taxes according to vehicle occupancy is also

[65] None of the schemes applies discounts or exemptions according to income. Means-based pricing is not generally practiced in the United States, either. One exception is the Los Angeles Metro which offers LA County residents with incomes below a threshold a one-time credit when they set up their tolling accounts, and a waiver on the monthly account maintenance fee. See https://www.metroexpresslanes.net/offers-discounts/low-income-assistance/

[66] https://rpa.org/work/reports/congestion-pricing-in-nyc

[67] See Komanoff (2019[140]), Krohnengold (2020[141]) and Gold (2021[258]). Justifications have been voiced on efficiency and/or equity grounds for many of the proposed exemptions. For example, low-emissions vehicles contribute little or nothing to pollution, and have been granted exemptions to various degrees with the five existing congestion pricing schemes; see Table . New Jersey residents have argued that they are being asked to subsidize infrastructure in New York City that will not benefit them, and so on.

[68] The reader is referred to Clewlow and Mishra (2017[269]), Erhardt et al. (2019[261]), Diao et al. (2021[265]) and Tikoudis et al. (2021[282]; 2021[290]).

[69] https://www.tax.ny.gov/bus/cs/csidx.htm

[70] https://www.chicago.gov/city/en/depts/bacp/supp_info/city_of_chicago_congestion_pricing.html

unwarranted on efficiency grounds since occupancy has little, if any, effect on the congestion and pollution that a vehicle generates.[71]

A majority of urban congestion pricing schemes exempt buses, fire service, police vehicles and ambulances. These are essential public services that would continue to be provided even if they were tolled. Handicapped people are sometimes exempted too, and tolling them might not induce them to curtail driving even if the toll imposed a severe financial burden. Since these user groups have inelastic demands, tolling them would not alter their behaviour. Charging them lower tolls might be justified on efficiency grounds.[72]

This reasoning supports discounts or exemptions for other user groups as well. As noted above, low-income workers may lack the job flexibility to commute during off-peak hours. If these workers have no reasonable alternative to driving, they will be unresponsive to high peak-period tolls, and granting them discounts or exemptions would promote vertical equity while having little adverse effect on efficiency. It has also been proposed to charge lower tolls on roads or in neighbourhoods located far from public transit service where there is no good alternative to driving.[73] Doing so would enhance spatial equity in terms of accessibility, although it might be difficult to measure accessibility in a consensual way.

3.1.3. Rewards

Restraint policies could be combined with reward measures encouraging desirable behaviour such as traveling during off-peak hours or using environmentally friendly modes. Such measures have been used by both private and public sector decision makers. Employers have long offered rewards such as preferential parking for carpool vehicles or subsidies for using public transportation (Bauer et al., 2018[142]). Governments have also implemented various initiatives.[74] A prominent example is the Dutch Spitsmijden (i.e., peak avoidance) project. The first experiment in 2006 paid participants for not commuting by car during the morning peak. It proved successful in inducing motorists to shift departure time (Knockaert et al., 2012[143]). Several follow-up experiments have been conducted since, and businesses have taken a leading role in providing the rewards.

Many other studies of reward schemes to avoid peak-period travel have been conducted, and some instruments are in regular use. For example, Metropia[75] is a smartphone-based technology that uses rewards to influence departure time and route decisions. A common lesson is that the effectiveness of a scheme depends both on its features and the characteristics of participants. For instance, Tsirimpa et al. (2019[144]) find that car-sharing and carpooling are more popular with younger people, while individuals who prefer to travel by car are partial to car-related mobility solutions. Incentives can be made more effective if they are personalised to reflect individual preferences (Xiong et al., 2019[145]).

The use of rewards has expanded beyond peak avoidance to include modal shifts that reduce emissions, parking-space requirements and so on. Several European countries encourage commuting by bicycle using tax breaks and subsidies (Reuters, 2014[146]). Italian residents can claim a reimbursement of 60% of the cost of a new bicycle up to EUR 500 (The Local, 2020[147]). The city of Bari conducted a trial in 2019

[71] One argument for discounting the tax on shared trips is that the customers who share a ride might otherwise each drive alone and escape the congestion tax altogether. This argument would no longer apply if comprehensive distance-based tolling were implemented on all vehicles.

[72] See Schlag and Teubel (1997[16]) and Trannoy (2011[29]).

[73] See Becker et al. (2017[273]) and Cipriani et al. (2019[270]).

[74] Bauer et al. (2018[142]) summarize a number of examples.

[75] https://www.metropia.com/ (accessed October 16, 2021)

whereby residents were paid EUR 0.20 per kilometre for cycling to work or school, and EUR 0.04 per kilometre for other trips (Speak, 2019[148]).

There has been little research on the welfare-distributional effects of reward schemes. Some effects can be conjectured. For instance, the Spitsmijden initiatives benefit employees with flexible work schedules who take advantage of the rewards by shifting to off-peak times. If implemented on a large scale, travellers who do not shift will also benefit if peak-period congestion is reduced. Bicycling subsidies benefit individuals who travel shorter distances and are physically fit enough to bicycle. Individuals who are proficient with smartphones are best placed to benefit from Platforms such as Metropia.

3.1.4. Parking policies

As explained in Section 2, existing parking fees and regulations are often both inefficient and inequitable. The deficiencies include under-priced or free on-street parking, under-priced residential parking permits, employer-provided free parking and minimum parking requirements. Cities have taken steps to address these problems and improve both efficiency and equity. Some have implemented occupancy-based pricing that efficiently rations parking space and benefits most travellers. Many are reallocating on-street parking and other space from cars to public transit and active transportation, steps that are likely to benefit low-income individuals (Shaheen, Stocker and Meza, 2019[72]).

Off-street parking and workplace parking levies also have a potential to improve efficiency and equity, although their effects have proven to be mixed in practice. Horizontal equity problems can arise if drivers relocate to private or on-street parking spaces and create more congestion or inconvenience for neighbouring businesses or residents. It is also unclear whether employees and other parkers will incur the full cost of the parking levies, or whether employers will absorb some of the burden (Santos, Hagan and Lenehan, 2020[108]). Workplace parking levies are intended to discourage employees from driving to work. Parking cash-outs are an alternative policy that requires employers who provide subsidised parking to offer employees the cash equivalent if they use other travel modes (Shoup, 1982[149]; Shoup, 2011[111]). Cashing-out policies are horizontally equitable in the sense of a level playing field since employees are treated equally regardless of car ownership, preferences for travel mode and income. Moreover, if cash-outs are taxable, the after-tax benefit of the cash is higher for lower-income employees who pay a lower marginal tax rate (Russo, van Ommeren and Dimitropoulos, 2019[109]).

A growing number of cities are replacing minimum parking requirements with other policies that range from maximum parking requirements or ceilings, combinations of minimum and maximum quotas, or even no regulations (International Transport Forum, 2021[106]). As explained in Section 2, minimum parking requirements discriminate against people without cars, and tend to raise the price of housing and other goods and services. Abandoning minimum parking requirements is therefore likely to promote both horizontal and vertical equity. Naturally, parking regulations should be tailored to local vehicle dependency and parking demand. For example, in London parking standards are adjusted to take into account public transport accessibility (International Transport Forum, 2021[106]).

3.1.5. Subsidising public transport fares

Subsidising transit fares discourages car use by reducing the monetary cost of using transit. It also contributes to vertical equity by improving the well-being of transit users who tend to have lower incomes than people who drive. However, lowering transit fares too far can conflict with efficient rationing of transit service to avoid excessive crowding. Large subsidies also lead to major deficits that need to be funded from other, potentially distorting or regressive, revenue sources. Balancing these opposing goals is a challenge. In the long run, the structure and level of fares should also be coordinated with the provision of transit service in terms of frequency, bus or train size and number of dedicated bus lanes (Proost, 2017[150]).

Theoretical work on optimal transit and automobile pricing in Santiago suggests that equity can be improved by keeping bus fares low and car costs high during both peak and non-peak hours (Tirachini and Proost, 2021[151]).[76] An extreme form of transit subsidy is to reduce fares to zero. A number of cities have experimented with free transit, and in some cases made it permanent. Tallinn, the capital of Estonia, made transit free in 2013. More than 30 municipalities in France operate free transit, and in 2020, Luxembourg became the first country to implement it (Yeung, 2021[152]). Fare-free transit has advantages. By eliminating fee collection it reduces dwell times and administrative costs, and it can significantly boost ridership. However, cities have generally found that most of the increased demand comes not from motorists who stop driving, but either from people who switch from walking or bicycling or from more trips by people who already use public transport (de Grange, Troncoso and González, 2012[126]; International Transport Forum, 2021[106]). Furthermore, boosting ridership can also increase maintenance costs and exacerbate crowding. Large transit systems that rely on fare revenues to cover a significant portion of their costs would require substantial increases in subsidies if they eliminated fares. Perhaps for this reason, to date free transit has been introduced only in towns and small cities.

Addressing equity concerns by reducing fares across-the-board is inefficient because it magnifies the subsidy required, and benefits all income groups rather than only those in greater relative need. Instead, some cities target subsidies to particular groups. For example, Paris offers a discount card[77] for low-income individuals, single parents and people on sickness or unemployment benefits. The Seattle Streetcar offers a low-income adult fare[78]. San Francisco provides discounts for low-income individuals, and free transit to low-to-moderate-income seniors who are city residents.[79]

Some cities in non-OECD countries have also implemented targeted subsidies. As Guzman and Oviedo (2018[153]) report, in 2014, Bogota introduced a subsidy for lower-income people that covers 50% to 60% of the regular fare costs. Guzman and Oviedo assess the efficiency of this subsidy as well as variations in which higher-income groups also receive subsidies.[80] They find that transport subsidies are most effective in boosting accessibility in zones with low average income. In zones with intermediate average incomes, subsidies provided little benefit. These results are broadly consistent with the findings of studies mentioned in Section 2.

3.1.6. Use of revenues from pricing instruments

Revenues from fuel taxes, road tolls and other price-based **car-use** instruments can be used in various ways. The choice affects economic efficiency via its impact on the public budget and the ripple effects on the overall economy through changes in the prices of goods and services. The choice also affects horizontal and vertical equity. There are at least three options. First, revenues can be earmarked to support transportation via road improvements and maintenance, or investment in transit and active travel. Second,

[76] The authors consider a revenue-neutral reform of the existing prices where the objective of the planner either does, or does not, attach a weight to vertical equity. In the model, travel demand is divided into peak and off-peak periods. High-income individuals favour traveling by car, and low-income travellers favour traveling by bus. Tirachini and Proost find that in the absence of equity concerns, in peak periods the cost of car travel should be increased relative to the status quo, and the bus fare should be reduced. Conversely, in off-peak periods the car cost should be reduced and the bus fare increased. However, in the presence of strong equity concerns, in both peak and off-peak periods bus fares should be kept low and car cost high. Doing so benefits low-income travellers by reducing the monetary cost of travel, although at the expense of inefficient numbers of trips by each mode in each period.

[77] https://www.solidaritetransport.fr/

[78] https://www.seattle.gov/transportation/getting-around/transit/streetcar/fares-and-orca-card

[79] https://www.sfmta.com/getting-around/muni/fares

[80] The authors measure accessibility using a gravity model that accounts for the generalized cost of travel by public transport to each zone, and the job opportunities there.

revenues can be returned to users who paid the charges as lump-sum rebates or credits, or distributed to all individuals who meet some criterion such as residency in the area. Third, revenue-neutrality can be enforced by reducing other user fees or taxes.

In the case of fuel taxes, practice varies widely across countries. In many countries, revenues are not earmarked but consolidated with other tax revenues in a general fund. By contrast, revenues in the United States are allocated to the Highway Trust Fund to fund roads and public transportation. Practice in other countries is mixed. For example, in Canada a limited amount of funds are earmarked via the Federal Gas Tax Fund[81] that distributes money to provinces and territories that then direct it to municipalities for local infrastructure projects. Three larger Canadian cities, **Montreal, Vancouver and Victoria, also levy metropolitan fuel taxes.** In Saskatchewan, all road-use fuel tax revenue is dedicated to provincial highway maintenance.

The co-existence of multiple taxes, diverse provincial or other subnational policies, and revenue allocations between levels of government complicates the task of assessing the distributional effects of fuel taxes. In general, revenue earmarking is more widely practiced for congestion pricing schemes than for fuel taxes. As shown in Table 2.1, revenues from these schemes are earmarked in London (to local transport services), Stockholm (to the Stockholm metro), Gothenburg (to an infrastructure package) and Milan (to public transport services and sustainable mobility). In Singapore, congestion pricing revenues are not earmarked for a particular purpose, but returned to motorists who pay vehicle taxes. Earmarking is also the general rule for High Occupancy Toll lanes in the United States.

There is a longstanding and extensive literature in transportation on how revenues should be allocated. Most studies have addressed the use of congestion tolling revenues. Goodwin (1989[154]) and Small (1992[155]) were among the first. Goodwin (1989[154]) proposed a "Rule of Three" whereby revenues would be allocated in equal parts to development and maintenance of new road infrastructure, public transport and either reducing the general tax burden or increasing spending. Small (1992[155]) also advocated a tripartite division, although one-third of the revenues would be used to reimburse travellers. Goodwin (1989[154]) designed his scheme to spread benefits widely, whereas Small (1992[155]) concentrated on averting opposition.

Like Small (1992[155]), most later scholars have focused on public acceptability. As noted, one option is to dedicate revenues narrowly to users of the priced facilities. Decorla-Souza (2004[156]) proposed a revenue-neutral scheme for HOT lanes, in which revenues from the tolled lanes would be given to drivers on the free lanes. The transfer would take the form of credits, which could be used for future trips on the toll lanes, transit and parking. Shoup (2004[157]) suggested that parking fee revenue be allocated to neighbourhood public goods. It is not obvious whether the incidence of the benefits from such a revenue recycling mechanism would be progressive or regressive.

Earmarking toll revenues for public transport is the most common practice, and most scholars have supported this on both efficiency and equity grounds. Earmarking facilitates long-term planning because the availability of continued funding is assured. Earmarking can also prevent political abuse of funds, and it tends to enhance public acceptability, as discussed below. Small (2004[158]) describes how congestion pricing can induce a virtuous cycle when transit is provided by buses using the same road infrastructure as cars, and tolls are used to fund transit. In the short run, tolls induce a modal shift from cars to buses, which reduces congestion and shortens bus travel times. Using revenues to expand route coverage and service frequency further enhances bus service quality. Since car travel becomes more expensive, land near major business centres grows in value and is developed at higher densities which makes transit readily accessible to more people.[82] The study by Small (2004[158]) numerically illustrates the short-run

[81] http://www.infrastructure.gc.ca/plan/gtf-fte-eng.html

[82] OECD (2018[284]) investigates the nexus between population density, car dependency and the cost of public transport services.

feedback effects of investments in public transport for London. Russo et al. (2021[159]) observe these effects in Rome, where public transport is provided mainly by bus.

The impact of earmarking toll revenues to support public transport is not beneficial in every context. For instance, while London is an exceptional case where 85% of commuters to the city centre were using public transport before the congestion charge was imposed, the share is much lower in many other cities. This hampers the extrapolation of the beneficial impacts of earmarking toll revenues for public transport to other cities (Richards, 2006[137]). The income distribution of different transport mode users can also vary across cities and countries. For instance, in some contexts public transport users (in particular rail users) may have high incomes. Similarly, lower income groups may be located in car dependent suburbs where housing is more affordable. Therefore, in such contexts making driving more expensive and transit more attractive does not only benefit low-income travellers (Manville and Goldman, 2018[10]). Third, some poorer individuals continue to drive, and benefit from tolling only insofar as travel becomes quicker and more reliable.

Several limitations or potential drawbacks also exist regarding revenue earmarking in general. Locking in the use of revenues for specific purposes reduces the ability of policy makers to respond to sudden changes in priorities, such as those due to unanticipated shocks like COVID-19. Second, a chicken-and-egg problem exists if expensive remedial policies such as public transport investments are needed in order to implement car restraining policies, but the latter policies (e.g., tolls) are needed to fund the investments. Moreover, remedial policies such as metro line expansion take much time, and may have to be implemented sequentially rather than simultaneously. Some regions or user groups will benefit much sooner than others, meaning that some degree of horizontal inequity is inevitable. Another limitation of earmarking is that it can fail to achieve fiscal balance, as it requires coordinated use of instruments controlled by different governmental authorities. This limitation could undermine the trust of those who pay the user fee or tax, and partially explains why survey respondents often reject the use of toll revenues to reduce their income taxes (Kitchen and Lindsey, 2013[160]).[83]

In conclusion, most existing and proposed tolling schemes feature dedicating revenues, often to public transport. The balance of evidence suggests that this would enhance horizontal, spatial and vertical equity.

3.2. Fairness of policies and implications for political feasibility

3.2.1. Public attitudes and acceptability

Transport policies frequently elicit strong opposition that causes proposals to be revised, or withdrawn. Here, attention is focused on road tolls, although taxes are often opposed too. **Ensuring the public acceptability of a restraint policy entails more than ensuring that it is welfare improving and equitable.** Apart from equity considerations, discussed in Section 2, various objections to road pricing are frequently raised. The most common come in the form of the convictions that: (i) mobility is a basic right, therefore the use of roads should not be charged, (ii) it is unfair **to pay for something that was previously free, (iii) road pricing constitutes double taxation, (iv) the tolling system is too complex, and (v) privacy is compromised, as successful implementation requires at least a partial recording of a vehicle's location or route.**

Public attitudes towards road tolls have been studied extensively, and many surveys have been conducted over the years. Most surveys are limited to one country,[84] but cross-country comparisons have also been

[83] It has been alleged that the U.K. government reduced funding to London after the congestion charge was introduced (Richards, 2006, pp. 83, 214[137]).

[84] These include: London (Jaensirisak, Wardman and May, 2005[251]; Schade and Baum, 2007[241]), Stockholm (Hårsman and Quigley, 2011[252]; Eliasson and Jonsson, 2011[262]; Eliasson, 2014[263]), Gothenburg (Börjesson,

made. Noordegraaf et al. (2014[161]) assess factors that contributed to implementation of tolls in Singapore, London, Stockholm and Norwegian cities, as well as to the failure to implement tolls in Hong Kong and Edinburgh. Selmoune et al. (2020[162]) review factors affecting public acceptability of toll systems. Shatanawi et al. (2020[163]) describe the results of a survey of acceptability in five countries where congestion pricing has not been implemented.

These and other studies vary in their conclusions about the public acceptability of road pricing. The balance of evidence indicates that acceptability is often quite low, but can be improved if: (a) the purpose and benefits of the policy are clearly understood, (b) the objectives of the scheme address public concerns, such as environmental issues, and (c) revenues are dedicated to local transport infrastructure or services. Experience with existing congestion pricing schemes demonstrates that attitudes are generally negative before schemes are implemented, but that they tend to improve afterwards. Various explanations have been offered for this somewhat unexpected pattern.

In a study of the Gothenburg congestion charge, Börjesson et al. (2016[164]) test seven hypotheses for why public support increased after the charge was implemented. Their results suggest that revised perceptions of the benefits and costs of the toll (and accompanying measures) played little or no role. Instead, the main influence appears to have been initial resistance to change, which is consistent with cognitive dissonance. To a lesser extent, changes in related attitudes such as concerns about the environment and social equity, trust in government, and acceptability of pricing principles were also relevant. These conclusions are supported by a subsequent study by West and Borjesson (2020[61]), who find no correlation between personal gains and losses, and the voting pattern in a 2014 referendum on the Gothenburg congestion tax. The results are also consistent with a study using Dutch data by Krabbenborg et al. (2020[165]) who find that supporters of the “polluter pays” principle supported road pricing, whereas groups motivated more by concerns for fairness, personal benefits or liberty were against it. It has also been found that psychological and sociological factors can play a significant role in influencing ex-ante versus ex-post support for environmental policy reform (Weber, 2015[166]).

All this is not to say that concern for personal gain has no influence on attitudes. For example, Tvinnereim et al. (2020[167]) study changes in support for a time-differentiated congestion charge in Bergen, Norway in 2016. They find that increases in public acceptability of the scheme were only seen among those who experienced the greatest reductions in travel time as a result of it. [85]

3.2.2. Political economy of road pricing and other measures

In most countries, electorates influence urban transport policy decisions indirectly through voting and lobbying. Intensity of personal preferences governs whether people decide to lobby or vote at all.[86] Policy levers are often distributed across multiple levels of government. Overall, the political process can be

Eliasson and Hamilton, 2016[227]; West and Borjesson, 2020[178]), Milan (Ozer, Beria and Pacchi, 2012[245]), Norway (Tretvik, 2003[237]; Odeck and Kjerkreit, 2010[246]); Edinburgh (Gaunt, Rye and Allen, 2007[259]), The Netherlands (Ubbels and Verhoef, 2006[236]), The Canary Islands (Grisolía, López and de Dios Ortúzar, 2015[255]), the United States (Harrington, Krupnick and Alberini, 2001[253]; Zmud, 2008[232]), Sydney (Hensher and Li, 2013[35]) and Taiwan (Jou, Lam and Wuvs, 2007[249]).

[85] De Borger and Proost (2012[277]) show that the *ex-ante* opposition to tolls can be explained by uncertainties on (i) the availability of alternatives to driving and (ii) the use of toll revenue. Their study predicts that after implementation and resolution of these uncertainties, opposition is bound to subside.

[86] The question of voter eligibility is an important element of the design of referendum processes, especially when considering spatially-explicit policies such as congestion charges and cordon tolls in urban areas. In these cases, for example, referendum results can vary according to whether only urban or both urban and suburban residents vote.

complex and challenging to fully understand. There is an extensive literature on political economy aspects of transportation decision making.[87] To illustrate, several studies are briefly summarised here.

The effects of political economy on decisions concerning road pricing are incisively demonstrated in a theoretical study by De Borger and Russo (2018[168]) of a cordon toll in a monocentric city.[88] They find that the level of the toll depends on several factors mentioned earlier in this paper: the relative populations of different city zones, the ease of access to public transport for low-income travellers, how much revenue is earmarked to public transport, and (in the long run) the number of travellers who choose to live inside the centre cordon.

In addition to tolls, scholars have applied political economy models to study decisions on quantity controls and regulations. De Borger and Proost (2013[115]) focus on measures adopted by a city government to reduce pollution, noise and crashes. Such measures include low emission zones, noise barriers and traffic calming. The role of the electoral base, in this case city residents, is pronounced. To reduce negative externalities, the city government may over-invest in measures that deter outsiders from entering the core of the urban area. It also sets emissions standards at a higher level than a federal government would, as city residents benefit much more from lower pollution levels compared to non-residents. In a similar vein, De Borger and Proost (2021[116]) analyse a setting in which motorists choose between a tolled motorway controlled by a central government, and a parallel secondary road through a town governed by a local government. The local government implements excessive traffic calming to deter through-traffic. To limit traffic congestion on the motorway, the central government sets the road toll above the level it would if it controlled both roads. Thus, both levels of government adopt overly-stringent regulatory measures to deter driving. The study illustrates the potential drawback of granting control of local traffic calming measures to local governments, as well as the benefits of coordinating policies across different levels of government.

Command-and-control regulations and restrictions are more prevalent than price-based instruments for controlling traffic in cities. Only five major cities have implemented tolls whereas, as of 2020, low emission zones (LEZs) had been implemented in 46 of 130 large cities in 12 European countries. Fageda et al. (2020[118]) seek to explain which cities have adopted them. They test the effects of seven variables[89], and determine that only per capita income is statistically significant, with higher-income cities more likely to adopt a LEZ regulation. The explanation is that high-income individuals can afford to buy low-polluting vehicles. They are unrestricted by the LEZ, and benefit from congestion mitigation due to less driving by lower-income individuals who own more polluting vehicles. If high-income individuals are sufficiently numerous, their preferences in favour of an LEZ are decisive.

In summary, these studies illustrate how diverging interests of stakeholders possibly influence transport policy decisions by governments. The outcomes are frequently suboptimal, as alternative policies that leave *ex-post* all parties at least as well off as they were *ex-ante*, exist, but are not adopted. The outcomes

[87] De Borger and Proost (2012[267]) review the literature on competition and coordination between governments. De Borger and Proost (2012[277]) examine political economy aspects of road pricing.

[88] The city consists of three zones: a centre, a mid-city and suburbs. All residents work in the centre. Residents of the centre do not have to commute. In the mid-city, higher-income commuters (the rich) commute by car, while lower-income residents (the poor) commute either by car or public transport, depending on their individual preferences. Suburban residents all commute by car since public transport service does not extend to the suburbs. All car commuters pay a toll to enter the centre. Toll revenues can be either used to subsidize public transport or redistributed in lump-sum fashion to the whole population. The toll is decided by majority voting. The model features multiple conflicts of interest: (a) between central residents who do not pay the toll, and residents outside who do pay if they drive; (b) between car commuters who pay the toll, and public transport users who do not pay but benefit from the fare subsidy; (c) between the rich and the poor who differ in the monetary value they place on reduced congestion; and (d) between landowners who benefit from higher land values from the toll, and renters who pay higher rents.

[89] These are: population density, per-capita income, cars per inhabitant, severity of congestion, quality of public transport service, a measure of income inequality and whether the mayor is left-wing.

can also be inequitable. For example, De Borger and Proost (2013[115]; 2021[116]) show that local governments can impose strict controls on car movements that benefit their residents at the expense of outsiders. Similarly, as Fageda et al. (2020[118]) explain, well-off cities can adopt low emission zones that make richer citizens better off at the expense of others.

4 Avenues for future research

This paper has focused on established and well-studied car-restraining policies. Many other policies such as carsharing, ridesharing, bicycle sharing and land-use policies have been omitted, in part because research on their distributional effects is currently limited. In general, there has been less research on quantity-based measures than price-based measures. For instance, although low emission and zero emission zones are increasingly common in Europe, their political acceptability has not been much studied. The same is true regarding reward schemes for traveling during off-peak periods, travelling using environmentally-friendly modes and other desirable behavioural modifications. This section briefly discusses a few new, or anticipated, travel innovations and policies that warrant further research.

4.1. Electric vehicles

Many national and subnational governments around the world are supporting the acquisition and use of electric vehicles, but that support is frequently revised. Governments are offering purchase subsidies, helping to install charging stations, providing discounted electricity rates for vehicle charging, and allowing electric vehicles to travel in low emission and zero emission zones. They are also giving preferential access to High Occupancy Vehicle and High Occupancy Toll lanes and parking spaces, and offering discounts and exemptions on user fees. While these policies encourage electric vehicle ownership and use, they are environmentally-friendly if the carbon intensity of the electricity mix is low. However, preferential electric vehicle policies could also have some adverse efficiency and distributional consequences. They are inefficient in two ways. First, they may contribute to congestion, and some have been subsequently withdrawn. For example, the former Ecopass toll in Milan provided exemptions for clean vehicles. With time, traffic congestion increased as motorists replaced polluting vehicles with vehicles that were exempt, and in 2012 Ecopass was replaced by the Area C scheme which charges all vehicles. In the same year, exemptions to paying the Stockholm Congestion Tax for electric and other alternative fuel vehicles were eliminated. Discounts and exemptions for cleaner vehicles have been gradually removed for the London Congestion Charge, as well.[90]

Despite such revisions, policies toward electric vehicles remain conflicted. Electric vehicles do not pay fuel taxes and, as noted in Section 2, this has been one motivation for replacing or supplementing fuel taxes with distance-based fees. In July 1, 2021, the state of Victoria in Australia introduced a road user charge on electric vehicles at a rate of AUD 0.025 / km for battery electric vehicles, and AUD 0.02 / km for hybrids.[91] The charge has been criticised as inconsistent with the policies of some other Australian states, as well as incompatible with the goal of supporting growth in the use of electric vehicles. By contrast, New Zealand, which has long imposed user charges on certain types of vehicles, extended the exemption for electric vehicles from December 31 2021, to March 31, 2024 (Government of New Zealand, 2021[169]).

[90] As of October 2021, only battery electric vehicles and vehicles with hydrogen fuel cells are eligible for a discount. In December 2025, the discount will be discontinued (https://tfl.gov.uk/modes/driving/congestion-charge/discounts-and-exemptions).

[91] https://www.vicroads.vic.gov.au/registration/registration-fees/zlev-road-user-charge.

Purchase subsidies that are available to everyone create a second inefficiency since individuals who are willing to pay the pre-subsidy price of an electric vehicle receive these subsidies anyway. Purchase subsidies are also vertically inequitable because electric vehicles tend to be bought by higher-income households. Lower-income households partially finance these subsidies via sales and income taxes, but currently benefit only indirectly from reductions in air pollution and noise. The vertical, horizontal and spatial equity effects of recurring incentives such as toll discounts are hard to quantify since they depend on geographical location and personal circumstances. Gaining access to HOV or toll lanes is of limited benefit in cities with little congestion and few HOV lanes or toll roads (Liao, Molin and van Wee, 2017[170]). Similarly, access to dedicated or free parking space is of little help to individuals who already have access at home and work.

Concerns for vertical equity have induced some jurisdictions to target incentives at low-income households. California and Oregon offer additional purchase rebates to income-qualified households (Argonne National Laboratory, 2021[171]). California has an incentive programme that provides subsidies to low- and middle-income households to scrap old vehicles for newer, cleaner and more fuel-efficient vehicles (Muehlegger and Rapson, 2022[172]). It has also been suggested that low-income households be subsidised to use previously-owned plug-in electric vehicles as a means of enhancing their mobility (Argonne National Laboratory, 2021[171]). The distributional effects of these and other policies deserve investigation.

4.2. Ride sourcing, connected and autonomous vehicles

Ride sourcing emerged as a novel means of transportation at about the same time as electric vehicles. By contrast, connected and fully autonomous vehicles are still under development. Nevertheless, along with vehicle electrification, the three technologies may eventually form the backbone of future urban transport. As Adler et al. (2019[99]) explain, the vertical and spatial equity implications of this new world are unclear. Since technologically advanced vehicles are likely to be more expensive than conventional vehicles, lower-income households may suffer a reduction in accessibility if vehicle ownership continues to be private. Shared ownership, or a full shift to Mobility as a Service (MaaS), would ease this problem. The scope for changes in ownership is likely to be greater in cities than rural areas where opportunities to pool demand are lower. On the other hand, challenges of coordinating mixed fleets of manually driven and automated vehicles are larger in cities. Widespread implementation of MaaS may also undermine the economics of conventional public transport, especially buses. That could disproportionately harm the poor.

Policy makers will need to be cautious in designing fiscal policies for the new technologies. As it is the case with electric vehicles, misinformed policy making that aims to promote such technologies may result in the adoption of instruments (e.g., subsidies and user charges) that serve conflicting goals.

4.3. Tradable permits

Interest is growing in tradable permits as an alternative tool for regulating traffic that avoids the concerns raised for congestion pricing.[92] To make a trip, traverse a road link, or enter a restricted area, a driver must acquire a permit. The amount of travel is controlled by limiting the number of permits. Permits can be traded, and the price is determined by transactions on some form of exchange. Crucially, permits are distributed free so that drivers in aggregate do not incur an out-of-pocket cost. Since distance driven tends to increase with income, lower-income individuals can earn income by selling excess permits. To further enhance equity, the number of permits issued per individual or household can be based on income,

92 See Fan and Jiang (2013[260]), Grant-Muller and Xu (2014[256]), and Dogterom et al. (2017[264]) for literature reviews.

residential and workplace location, number and type of vehicles owned, and other socioeconomic characteristics.[93]

Tradable permits have been applied to a number of markets including taxi licenses, airport take-off and landing slots, and train operating slots. Laboratory experiments with road permits have been conducted, but permits have not yet been put to general use, so their real-world distributional effects are unknown.

4.4. Health concerns

The outbreak of SARS-CoV-2 and subsequent COVID-19 pandemic have upended economic activity and lifestyles around the world. Experts disagree on the impacts of potential future pandemics on cities in the long run (Florida et al., 2020[173]). Cities have adopted a number of mitigation strategies to facilitate social distancing such as reallocating street space from cars to bicycles, pedestrians and greenways, and subsidizing bicycle sharing programmes (Bereitschaft and Scheller, 2020[174]).

These measures could reduce traffic congestion, pollution and safety problems within central cities. Their implications for equity are unclear. Reducing dependence on cars could be vertically equitable for reasons discussed earlier in the paper. Public transport service may suffer due to health safety concerns that curtail demand, and constrained city budgets for maintaining and expanding transit networks. Furthermore, centrifugal forces due to relocation of population to suburbs and rural areas could increase public transport deficits, which tend to be positively related with population density (Savage, 2004[175]; OECD, 2018[176]). Hence, similar to the case with MAAS, health concerns may weaken the economics of public transportation, with likely adverse effects on lower-income individuals and households.

4.5. Research methods

Until recently, lack of data has constrained understanding of the distributional effects of transport policies. Census surveys are costly and infrequent. Before-and-after surveys are also expensive to collect, and recruiting an unbiased sample of respondents can be tricky (Shaheen, Stocker and Meza, 2019[72]). The advent of new technologies and data analytical methods has greatly facilitated the scope to assemble and analyse big datasets. Anonymous collection of smartphone data has enabled researchers to track the movements of people, and to examine their activity patterns (International Transport Forum, 2015[177]). Smartcards also provide a new source of data for analysing public transport usage even for people without smartphones (Hörcher and Tirachini, 2021[123]).

[93] Using a model of a congested road network, Yang and Wang (2011[233]) show that if the permit allocation is based on trip origin and destination, it is possible to make all travellers better-off than in the equilibrium without permits or other forms of regulation.

5 Conclusions

The distributional impacts of restraint policies depend on the characteristics of the policy considered as well as the urban area in which they are implemented. Areas with different population compositions, spatial distribution of incomes, transport network configurations and development patterns will respond differently to similar policy packages. Efficiently addressing the external effects of car use without exacerbating existing inequalities requires context-specific, tailored approaches that are difficult to generalise into an overarching policy strategy.

This paper takes stock of the most prominent policies that affect car use and examines their distributional consequences. It focuses on the mechanisms behind price-based instruments such as congestion tolls, motor fuel taxes and distance-based charges. Each of these instruments has a different *direct impact* on each household, which is proportional to the share of household income or expenditure spent on the underlying commodity. For instance, a fuel tax imposes a larger burden to households that dedicate a larger part of their budget on gasoline or diesel. The discussion expands beyond these direct impacts, by accounting for the behavioural changes that these policies may generate. This includes short-run and mid-term changes, such as adjustments in travel demand and shifts from car to other modes, as well as long-run modifications that include choice of residential or work locations. The availability of alternatives, in particular reliable public transport, may ease the burden incurred by low-income groups. That may render a policy less regressive than it is at the early stages of its implementation. Long-run behavioural margins, in particular residential relocation, should also be considered in policy making, as they may render policies that are inequitable from a spatial viewpoint in the short run more inclusive from a vertical viewpoint in the long run. A characteristic example is congestion pricing schemes, which tend to favour residents within the cordon-toll areas and have therefore been viewed as spatially inequitable. In the long run, some degree of spatial inequity could subside via densification of the areas lying within the cordon, which are favoured by the policy.

The paper highlights the critical role of revenue recycling in policymaking contexts where distributional impacts are relevant. The analysis focuses on the option of using the revenues from taxes targeting car use to subsidise public transport. Widely believed to be one of the most effective strategies for mitigating a tax burden that is disproportionately borne by low-income groups, this use of revenue is not universally accepted. Another overarching finding of the study is that revenue recycling may be a precondition for a policy to be politically viable, or even welfare improving in the first place. Substantial evidence indicates that the private monetary costs of the examined instruments are larger than the benefits stemming from congestion relief and reductions of other traffic-induced externalities. The presence of a distinct revenue-recycling programme ensures that the benefits are larger. This enables a meaningful discussion on equity, which is not possible when a reform is detrimental to overall welfare. In some cases, fine-tuning the recycling mechanism can render the reform progressive and welfare-improving for all. In addition to revenue recycling, differentiating the magnitude of policies across income groups can improve the distributional profile of a reform. Congestion charges, for example, can incorporate discounts and exemptions, and could vary with individual or household income.

Transport policy decisions are typically influenced by diverging interests of various stakeholders. The outcomes of these decisions can be inequitable, and are often suboptimal in the sense that alternative policies exist that could leave all parties better off than the policy selected. Although the acceptability of restraint policies is often low, evidence suggests that it can be improved. This is more likely to occur if the purpose and benefits of the policy are clearly understood, the objectives of the scheme address public concerns, and the revenues are earmarked to support the transport sector.

Given the diversity of contexts and policy measures available, including policies with little precedent to date, research on a number of issues should be prioritised in order to improve the equitability of restraint policies in urban areas. More knowledge will particularly be needed regarding policies supporting the uptake of electric vehicles, encouraging the introduction of ride-sharing services, and trading permits for road use.

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