4. Pricing and other instruments for climate change mitigation in private transport

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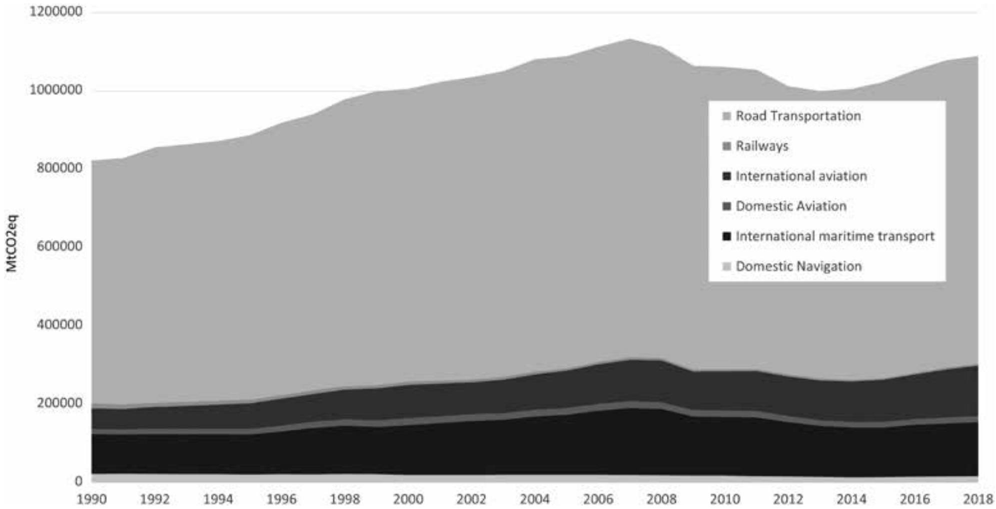
4.1 INTRODUCTION

There are various objectives behind the pricing of transport services. For instance, from the perspective of a transport agency responsible for financing infrastructure the main objective may be cost recovery, e.g. how to charge air-traffic passengers for investing in and running airports. Decisions about pricing can also be made from a broader social perspective taking into account distributional aspects. To facilitate less wealthy groups gaining access to job opportunities or social activities, transport services like public transport may be subsidized. Another objective, which is the one that is often the focus of economists, is the use of pricing to achieve an efficient resource allocation. That is, how can the pricing mechanism be used to influence transport users to reach an optimal level of transport service demand? Due to the several externalities linked to personal decisions on how, where, and when to travel, like congestion, pollution, accident risk, and noise, the discussion on pricing and efficiency often is focused on how to internalize such externalities.

The pricing objective of interest in this chapter is efficiency, and more specifically how to internalize emissions from transportation related to global warming. The transport sector is only one of several sectors that contribute to global warming, but its contribution is significant. For instance, the International Panel on Climate Change (IPCC, 2014) reported that the main sectors for global greenhouse gas (GHG) emissions were electricity and heat production (25%), agriculture, forestry, and other land use (24%), and industry (21%), followed by transportation (14%). Regarding transportation, much public attention today is on emissions from air-traffic, with both private initiatives and government policies on how to reduce the demand for air-traffic and make people either travel less or choose less emitting modes like trains. Given this attention, it is relevant to put its GHG emission into perspective and the aviation industry contributes to about 2% of global GHG emissions, which puts its footprint on par with the emissions from information and communications technology (data centres, mobile phone networks, etc.) (Jones, 2018). Figure 4.1 shows the emissions from different transport modes in Europe. As shown, the main source of emissions is from road transport. Hence, the potential gain addressing GHG emissions from road transport is much larger than from air-traffic and we will therefore focus on GHG emissions from road traffic in this chapter.

Within any decarbonization strategy in the transport sector, passenger cars will play a pivotal role. According to the International Energy Agency (IEA), passenger vehicles account for almost half of worldwide transport sector carbon emissions, and it is the category that requires the largest decline in emissions in the IEA *Sustainable Development Scenario* (IEA, 2019). Different measures will be necessary to facilitate any transition, but economic instruments have an important role to play. One such instrument is pricing, which will be the main focus of this chapter.



Source: Authors' own, data from https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-ofgreenhouse-gases-7/assessment (Accessed 2021-03-04).

Figure 4.1 Greenhouse gas emission from transport in Europe

This chapter is structured as follows. In the following section, we first describe the theory of pricing and the internalization of externalities, and then provide a discussion of a selection of implementation issues. Thereafter in Section 4.3 we provide examples and discuss how to apply different instruments to car usage and ownership. The chapter finishes with some concluding remarks and suggestions for further reading.

4.2 PRICING OF TRANSPORT EXTERNALITIES

In the first part of this section, we briefly describe the motives behind and the theory of pricing transport externalities. We then in the second part discuss some issues of relevance when implementing pricing policies. Again, the discussion is brief and only intended to raise important issues. For more details, see Chapter 2 in this *Handbook* by Achim Czerny and Stefanie Peer, or cited work.

4.2.1 Pricing Motives and Principles

Pricing transport usage is at the core of transport economics. To enhance economic efficiency is the primary economic motivation for pricing transport usage, but it is also of interest from the perspective of financing infrastructure and transport services. Therefore, to a large extent theoretical and empirical research have been carried out within the context of optimal infrastructure usage (see, e.g. Rouwendal and Verhoef, 2006, for a discussion). One issue of major relevance that has been given considerable attention among policymakers and researchers is road congestion (see, e.g. Lindsey, 2012). In a congested road network, an additional trip taken by a road user will inflict a cost on other users since it will contribute to the congestion and slow down the traffic further. By pricing this marginal externality a more efficient use of the current road network can be achieved, and the revenues collected can be used to finance maintenance or investments in the road network.

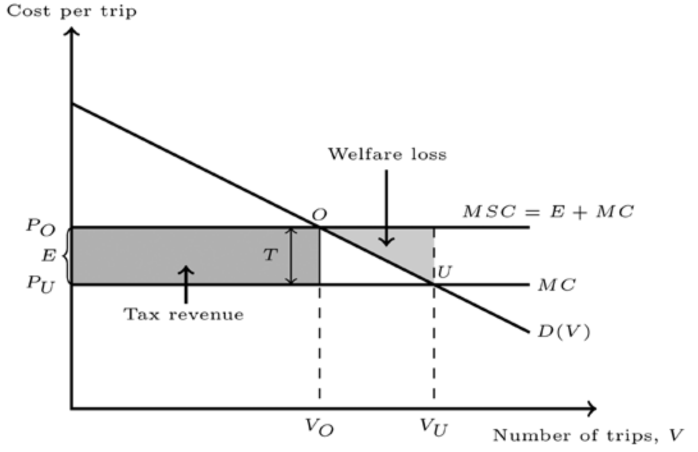
The focus of this chapter is GHG emissions from road traffic, another transport externality. In an unregulated market, the driver or passenger of a vehicle will only consider his/her private costs when making travel decisions. Other costs, like GHG emissions, local air pollutants, noise, etc., are not borne by the driver or passengers and therefore likely to be ignored. A significant difference between the congestion externality and the GHG emission externality is that the former depends not only on the traffic volume but also on the infrastructure available. That is, in contrast to the congestion that can be reduced, or eliminated, by investing in new infrastructure, GHG emissions will still be present after the expansion of the infrastructure with the same amount of traffic volume. Even if total emissions from cars will depend on the traffic situation, i.e. congestion, they are more correlated with the traffic volume and the type of vehicles used. The common feature shared by congestion and GHG emissions is that both can be addressed using economic instruments such as prices. Examples of economic instruments to address GHG emissions from car usage is indeed the focus of Section 4.3 of this chapter, and hence the focus of the discussion below.

The principles of pricing, or taxing, externalities were introduced by Pigou (1920). Figure 4.2 illustrates the basic principles. The downward-sloping inverse demand curve ($D(V)$) represents the marginal benefit (*MB*) of undertaking trips (*V*). The private cost of undertaking the trips is represented by *MC*, and is assumed to be constant. In an unregulated market, only private benefits and costs will be considered by the individual and the equilibrium is given by *U*, i.e. where $D = MC$. Fewer trips would mean that the benefits of undertaking them are higher than the costs, and more trips would mean that the costs are higher than the benefits. Hence, it is optimal for the individual to undertake V_U trips. In a situation without any externalities, the V_U number of trips would also be the social optimal number of trips, since in that case the marginal social benefit (*MSB*) equals the marginal social cost (*MSC*) in *U*.

In this chapter, we focus on GHG emissions from car usage and we now introduce this externality from car trips, *E*, in Figure 4.2, which for simplicity is also assumed to be constant. The total *MSC* from undertaking trips is now given by the sum of the private cost and the externality, i.e. $MSC = E + MC$. Following the reasoning above, the optimal level of trips is when the social benefit of an additional trip equals its social cost. As illustrated in Figure 4.2 the internalization of the externality has increased the price of undertaking trips from P_U to P_O which results in the new allocation *O*, where $D = MSC$, that is at trips V_O. As shown, with the externality each trip above V_O has a social cost that is higher than the social benefit, and hence, provides a negative net social benefit, represented by the yellow area. The optimal tax (*T*) on the externality in our scenario (in which the externality is constant) is equal to *E*, but more generally the tax should be set according to $T = MSC(V_O) - MC(V_O)$. This level of the tax will internalize the externality and lead to a demand for the number of trips where the MSB of that trip equals the private, and social, marginal cost.

4.2.2 From Theory to Practice

The above description of a situation where prices should equal their social marginal costs is often in the economic literature referred to as a "first-best" solution. However, it is well



Source: Author's (Andersson) own lecture notes.

Figure 4.2 Equilibrium in an unregulated market and social optimum

established that first-best conditions do not generally hold due to other unpriced externalities, distortionary taxes, etc. (Parry and Bento, 2002). Solutions according to first-best are quite straightforward, requiring only information about the social marginal cost. Second-best solutions are more complicated, since they require input not only on the market failure studied, but also information on related markets and how they interact. This means that the optimal level of the tax may be different from the value of the externality in optimum and instead could be lower or higher.

Pricing externalities increases the private costs of users (from P_U to P_O in Figure 4.2), and hence public support for them is often weak. Due to the revenues collected the public perception may be that the tax is implemented for fiscal reasons, not to address a market failure. From a Pigouvian tax perspective how the revenues are used is not of importance, but it is both from an acceptance perspective and from a fiscal perspective. Regarding the former, acceptance among transport users may increase if revenues collected are earmarked for investments in the transport sector (Leape, 2006). Regarding the latter, "Pigouvian taxes" are favoured by economists since they not only internalize the externality (i.e. the Pigouvian objective) but can also be used to offset distortionary taxes in the economy, the combined effect often referred to as a "double dividend" (Goulder, 1995). That is, the revenues from, e.g. a tax on GHG emissions can be used to reduce the revenues from a distortionary tax such as a tax on labour. Parry (1995) showed, though, using a labour tax as an example of a distortionary tax, and assuming that the market good to be taxed (due to the externality) and leisure being substitutes, that the optimal level of the green tax should actually be lower than the external cost. Hence, even if green taxes can be used to offset distortionary taxes, in the presence of them the optimal green tax may differ from external cost (marginal damage).

Related to the acceptance of Pigouvian taxes is the public's perception of their fairness. On the one hand, based on the "polluter pays principle" (OECD, 1995) it can be viewed as fair that those who inflict harm on others are the ones who should pay for the pollution. On the other hand, environmental taxes may more heavily affect the welfare of poor individuals than richer ones, i.e. being regressive (Chiroleu-Assouline and Fodha, 2014). Whether distributional aspects should be considered jointly with or separately from efficiency is an ongoing discussion, but it is important to remember that the primary objective of Pigouvian taxes is efficiency and, ideally, distributional effects can be addressed separately if needed. Chapter 6 of this *Handbook* covers the underlying trade-offs in more depth.

Implementing Pigouvian taxes also requires a monetary estimate of the externality. The standard approach to estimating the social value of goods and services without any easily available prices is to either rely on revealed- or stated-preference methods, or both (see, e.g. Freeman et al., 2014). An alternative approach is based on the hypothesis that the public's preferences in a representative democracy are reflected in public decision-making. One issue with this approach is that there is overwhelming evidence that there is a large variation in the estimates of the abatement costs between sectors or industries (Gillingham and Stock, 2018). Other options to estimate the shadow values of these goods and services are to estimate the social cost of environmental degradation, or what costs are necessary to achieve policy targets (see, e.g. Quinet, 2019, for an example and a discussion).

4.3 POLICY INSTRUMENTS FOR PERSONAL VEHICLES

4.3.1 Economic Instruments and Car Usage and Ownership

As described, economic agents typically do not take into account the social cost of their choices or actions, that is, the cost they impose on society. When it comes to transport-related choices this often translates, e.g. into using private rather than public means of transportation, larger rather than smaller vehicles, and more rather than less powerful engines. In the previous section, we introduced the concept of the Pigouvian tax, which can be seen as an attempt to discipline economic agents. This arguably simple framework is the starting point of most economic analyses of environmental problems to date, including problems related to car usage and ownership. Traditional policy instruments have been covered extensively in the literature. For instance, Calthrop and Proost (2003) cover environmental pricing in transport whereas Parry et al. (2007) and Anderson and Sallee (2016) provide a comprehensive overview of automobile externalities.

Determining the level of the tax is, however, a non-trivial task for a number of reasons. First, one has to identify the factors generating external social costs. This could include carbon emissions from transportation, but also local pollution generated by combustion engines and tyres, costs of congestion, accidents, noise and visual pollution caused by driving, wear-and-tear of roads, etc. In recent years, it has been identified that, in some jurisdictions, some external costs have been given more importance than others, which may benefit one technology to detriment of another. For instance, the European Union (EU) legislation has historically been relatively strict in terms of CO_2 emissions but more lenient with regard to local pollutants, which was documented to benefit diesel to detriment of gasoline vehicles (Miravete et al., 2018).

Second, one has to correctly quantify each of the above externalities. Recent evidence of the manipulation of driving tests has given credence to the notion that measurement is potentially of first-order importance, especially in diesel vehicles, which led to the recent re-design of test cycles in Europe. When it comes to electric vehicles, externalities are dependent on local factors, such as how electricity used to charge the electric vehicles is generated (Holland et al., 2016). Third, one has to assign monetary values to each of the above factors. For instance, local pollution generated today might have long-lasting health effects that current research has not yet been able to identify. Fourth, the passing-on of taxes onto prices depends on both the competitive structure and on the characteristics of the supply and demand profiles of a particular market. In particular, firms may or may not pass on the cost of a tax to consumers. Fifth, it assumes that consumers correctly quantify and take into account in their decisions the tax levied on their activities or the products they purchase.

Despite the above limitations, the Pigouvian framework provides the basic toolkit used by economists and regulators in the analysis of environmental problems, also in the transport sector. As described, if carbon emissions are the only external cost of transport imposed on society, then the Pigouvian tax is efficient (or first-best), in that it imposes on consumers the entire external costs their activity generates to society. In particular, a fuel tax is a Pigouvian tax in this specific case, as introducing it tackles both utilization (kilometres driven) and fuel consumption (how many litres a vehicle requires to drive 1 kilometre) of a driver-vehicle combination.

An additional factor making taxes appealing is that they are cost-effective, in the sense that they satisfy the least-cost theorem, an important result in environmental economics (Perman et al., 2003). That is, taxes are able to attain a given environmental target at least cost to the society, which results in an economically efficient allocation of resources. In more concrete terms, if a policy instrument is least-cost, then it satisfies the so-called equi-marginal principle, according to which the cost of abating pollution is equalized among all polluters – in particular, economic agents for which abating pollution is cheaper will abate more than those for which abating pollution is more expensive until the cost of abatement of all agents equalizes.

If consumers are not able to identify and/or quantify the extent of the taxation they are subject to, then they will undervalue the fuel tax and over-utilize transportation. As a result, this is one channel through which the fuel tax loses its first-best property. Therefore, additional policy instruments are called for, such as standards or vehicle taxes. Although they do not tackle utilization, standards have an impact on the fuel economy (or fuel consumption) of a vehicle, making less efficient vehicles more expensive than their more efficient counterparts. Circulation taxes operate in a similar way, but while standards typically influence only the purchase of new vehicles, circulation taxes are charged yearly and thus affect both the new and second-hand car market. The distinction between new and used vehicle markets is crucial since while the former receives considerably more attention, it is only a small (typically single-digit) share of the latter. Thus, one has always to bear in mind the scope of the policy instruments aiming to tackle carbon emissions at the risk of said instruments not having a meaningful impact.

Recent events in the transport sector have brought back attention to local pollutants and shed light on a number of alternative policy instruments tackling pollution in transportation. If local pollutants are not addressed when determining the level of the fuel tax, then alternative policy instruments – especially those targeting diesel vehicles – are called for. These include congestion pricing and driving restrictions, which can occur in various forms.

Finally, considerations about optimal policies have to take into account the political constraints that often prevent a straightforward implementation of those measures. While interventions adopted by governments might not represent the most efficient practice from an economic point of view, they might be the only politically feasible solutions; Bruno De Borger and Antonio Russo deliver more insights on the political economy of transport pricing in Chapter 7 of this *Handbook*. In what follows, we briefly describe the main policy instruments available to mitigate carbon emissions and their applications.

4.3.2 Instruments Based on Marginal Cost Pricing

4.3.2.1 Fuel taxes

The most common pricing measure addressing CO_2 emissions from the transport sector is the fuel tax. Because it is charged on a per-litre or per-gallon basis, it represents a Pigouvian tax on carbon emission conditional on fuel consumption. In particular, fuel taxes help reduce vehicle CO_2 emissions in two distinct ways: first, they encourage consumers to choose energy-efficient vehicles, or an electric vehicle; second, they induce drivers to reduce the number of kilometres driven. The presence of two channels of emission reduction generally makes fuel taxes a preferable solution compared with other kinds of measures, such as standards, circulation taxes, or rebates for the purchase of energy-efficient vehicles. Furthermore, the fuel tax helps addressing other types of externalities linked to vehicle use, such as local air pollution.

Fuel taxes have been adopted in many countries, including various European states, China, India, the United States, and several emerging economies. According to OECD statistics, fuel taxes vary substantially across countries (OECD, 2018). One common characteristic, however, is that the corresponding price per tonne of CO_2 is typically larger for gasoline than for diesel.

The effectiveness of the fuel tax in reducing carbon emissions depends on various factors. For instance, drivers might not correctly understand the impact of fuel prices on the lifetime cost of owning a vehicle, i.e. a 1€ change in (discounted) driving costs are not considered equivalent to a 1€ change in the vehicle purchase price. Correct valuation of fuel costs would require consumers to know and correctly combine information on fuel prices, utilization, and vehicle fuel economy. Therefore, the undervaluation of fuel costs might require complementary policies such as rebates for the purchase of energy-efficient vehicles or information campaigns in order to make fuel costs more salient (Huse and Koptyug, 2022). Current evidence on how consumers evaluate fuel economy and fuel costs suggests that undervaluation occurs but is typically moderate (see Huse and Koptyug, 2022, and references therein).

On the other hand, fuel taxes tend to be more salient than fluctuations in fuel prices due to supply shocks for a couple of reasons. First, changes in fuel taxes are generally advertised on various media. Second, fuel taxes are more stable, and therefore a forward-looking consumer might be more induced to buy an energy-efficient car due to an increase in fuel tax today than to other fluctuations in fuel prices. If that is the case, people might respond to fuel taxes more strongly than equivalent changes in pre-tax fuel prices.

Furthermore, in the way they are currently defined, fuel taxes only affect gasoline- or diesel-fuel vehicles, but not other types of alternative fuel vehicles. Therefore, the expected increase in the market share of plug-in and battery electric vehicles will likely lessen the effectiveness of fuel taxes in the future, especially if a carbon tax is not in place and if fossil fuels still play a relevant role in electricity generation. Further factors working against fuel taxes are their low price elasticity of demand (Brons et al., 2008), obtain short- and long-run elasticities of, respectively, –0.34 and –0.84 in their meta-analysis) and that the demand for alternative fuels seems to be significantly more elastic than those for fossil fuels when both compete directly (Huse, 2018). Taken together, these factors point to a downward trend of fuel tax revenues, which is leading some governments to consider utilization charges such as mileage taxes. These, however, do not directly target carbon emissions.

Nevertheless, currently fuel taxes generate considerable revenues. Hence, they are an example of the "double dividend" discussed above, where fuel taxes help reduce carbon emissions and other externalities (first dividend), and the revenue would allow to fund public expenditure or reduce other distortionary taxes such as income taxes (second dividend). As described, the presence of this double dividend depends on the characteristics of the general tax system: the interaction between an environmental tax and other pre-existing distortionary taxes can also exacerbate the efficiency loss caused by the latter. These factors have important implications on the actual optimal level of a fuel tax, and whether it is lower or higher than the marginal damage linked to CO_2 emissions (Goulder and Parry, 2008).

When evaluating the optimal fiscal policy to address transport carbon emissions, it is important to take into account the practical difficulties that might hinder the implementation of the "best" solution. In particular fuel taxes and carbon taxes in general might encounter significant political opposition, for a series of reasons. First, as discussed earlier, fuel taxes and in general fuel price changes are quite salient to the general public compared to other vehicle-related monetary policies such as circulation taxes or sales taxes. Second, there might be considerable variation in the tax burden, and some specific categories might be affected more strongly than others. For instance, people living in rural areas with little public transport availability, or poorer households that cannot afford to buy a more efficient vehicle. As the 2019 protests of the "Gilet jaunes" ("yellow vests") in France show, the pushback against this type of policy can be stark. The inequalities caused by the implementation of a fuel tax can be mitigated through a tailored redistribution of the tax revenue as a lump-sum transfer towards the most affected categories.

4.3.2.2 Mileage (or utilization) tax

A utilization tax is based on how much a vehicle is driven. It has drawn increasing interest over the years due to technological improvements – the GPS technology necessary to implement such a tax allows collecting it at a high frequency – and due to the foreseen decreases in tax revenues due to improvements in the energy efficiency of vehicles. While a standard mileage tax not depending on energy efficiency would only affect kilometres driven, a more sophisticated one could address both margins, namely energy efficiency and utilization. Nevertheless, this policy instrument does not address congestion and its distributional effects may be adverse, since a mileage tax would more heavily affect rural households, who typically have restricted access to public transport. All in all, utilization taxes should be seen as a complement to fuel taxes, standards, and vehicle taxes from a climate policy viewpoint.

4.3.3 Instruments Based on Average Cost Pricing

4.3.3.1 Vehicle taxes

Along with fuel taxes, vehicle taxes are a very widespread fiscal policy related to the transport sector. They can be either a tax applied only when the car gets registered for the first time (registration tax), or a tax that drivers must pay on a yearly basis in order to use the vehicle (circulation tax, road tax, or vignette). Initially, the amount of the tax was either the same for any vehicle, or linked to vehicle weight, vehicle segment, or sales price. In the most recent decades though, governments started to set the vehicle tax according also to energy efficiency, carbon emission rates and other environmental indicators, thus explicitly providing an incentive to choose energy-efficient/low-emission vehicles. Electric vehicles and other alternative fuel vehicles might benefit as well from lower tax rates.

The main difference between a fuel tax and a vehicle tax is that the latter affects only the choice of the vehicle, but not the utilization, making them in general less cost-effective and less efficient than fuel taxes in reducing carbon emissions in the transport sector. However, vehicle taxes can be a complement to fuel taxes in case consumers tend to underestimate vehicle fuel costs. Important distinctions also exist between different types of vehicle taxes: registration taxes have leverage only in the choice of new vehicles, while circulation taxes influence also the decision on the purchase of second-hand vehicles and on the timing of scrappage. Thus, circulation taxes might have a stronger influence on the composition of the vehicle fleet in the short- and medium-term. In the case of a registration tax based on vehicle CO_2 emissions, the tax is akin to a standard, the key distinction being that it is an explicit rather than an implicit tax.

One advantage of vehicle taxes is that they are easier to implement from a political standpoint, in part because they are less salient to drivers. In particular, they could be used to capture differences in externalities between vehicles with different fuel types when the use of fuel taxes is constrained by political considerations (De Borger and Mayeres, 2007). However, a lack of visibility represents a problem for the effectiveness of these measures, as consumers might not be aware of the existence of fiscal incentives for the purchase of low-emission vehicles. Vehicle taxes directly or indirectly linked to CO_2 emissions have played an important role when it comes to technology adoption (gasoline vs. diesel vehicles) in the European car market, partially explaining the market share commanded by diesel vehicles in Europe (EEA, 2015). As for fuel taxes, vehicle taxes are present in several countries, from most European countries to Japan, China, India, and South Africa.

4.3.3.2 Rebates and feebates

Governments have often implemented a policy instrument whereby low-emission vehicles are subsidized in the new vehicle market through a rebate (Huse and Lucinda, 2014), sometimes coupled with a fee on high-emission vehicles (Adamou et al., 2014). The combination of both policy instruments gives the name of such programmes, feebate.

Feebates are policy measures used to change the relative prices of high- and low-energy efficiency vehicles. Fees are charged to vehicles emitting more than a given threshold emissions level (the pivot point) and generate revenues used to finance the rebates given to vehicles emitting less than said level.

Thus, the rationale of a feebate programme is often that it should be fiscally neutral, i.e. self-financing. However, this requires that the problem be well-calibrated *ex ante*, which is not always the case. While feebate programmes have been adopted in some European countries, noticeably France and Sweden, rebates on low-emission vehicles are more widespread worldwide.

Feebates have been the object of many studies due to the values involved, be it on a per-vehicle basis or in the aggregate (Adamou et al., 2014). The main pitfalls in their implementation are free-riding and low pass-through rates. Free-riding occurs when part of the consumers benefiting from the rebate would have chosen a low-emission vehicle regardless of incentives, or when consumers take advantage of political or administrative borders. In a case of a low pass-through rate instead, part of a rebate on the final vehicle price might not benefit consumers, as car dealers and manufacturers would increase purchase prices accordingly. Either way, such type of behaviour decreases the cost-effectiveness of environmental programmes.

4.3.4 Other Instruments

4.3.4.1 Congestion pricing and driving restrictions

Congestion pricing and driving restrictions (sometimes combined with parking restrictions and pricing) allow local governments to influence the policy arena in the transport sector. Driving restrictions in the form of licence plate bans have been studied by Eskeland and Feyzioglu (1997), Davis (2008), and, more recently, Barahona et al. (2020), whereas Wolff (2014) studied the effect of low-emission zones focusing on the German case. Congestion pricing is more recent, see Lehe (2019) and Chapter 8 of this *Handbook* for comprehensive overviews.

Oftentimes, driving restrictions are imposed due to non-compliance with (local pollution) air quality standards, as in the cases of many EU cities, which are then required to develop a plan for tackling air quality following the Clean Air for Europe Directive (CAFE, 2008/50/EC). The implementation of such a plan has as a by-product the reduction of congestion and carbon emissions.

There are substantial differences between congestion pricing and a low-emission zone (LEZ): congestion pricing charges vehicle owners a fee – which might depend on the time of the day and the type of vehicle – to get access to a specific area, typically a city centre. Instead, a LEZ allows only specific categories of vehicles – typically low-emission or electric vehicles – to enter specific areas. Several cities throughout the world have introduced either vehicle driving restrictions (e.g. Munich, Mexico City, Quito, Shanghai), or congestion pricing schemes (e.g. London, Milan, and Singapore); see Lehe (2019). A variant of such policies, mostly implemented in North America, are high-occupancy vehicle (HOV) lanes (see Caltrans, 2018, and Chapter 23 in this *Handbook*). These measures restrict access to vehicles based on occupancy, so that only vehicles with at least a minimum number of passengers are allowed access to specific lanes.

Economic efficiency arguments favour congestion pricing over driving restrictions, since the price mechanism inherent in the former allows flexibility and theoretically achieves a least-cost outcome. In contrast, the latter can be thought of as being akin to licences, resulting in a number of unintended consequences. The pricing component affects both distance driven and the vehicle stock, and in some cases might induce people to replace their vehicle earlier with a newer, more efficient vehicle with fewer driving restrictions. On the other hand, licence-related policies may well backfire. For instance, restrictions based on the last digit of the licence plate number (odd or even) have prompted households to keep older vehicles longer and in some cases decided to own two vehicles – one ending with an odd number and another ending with an even number – to circumvent the regulation. Given a fixed amount of the household budget, the additional vehicle purchased was often found to be older, with worse energy efficiency (Davis, 2008).

When implementing these policies, trade-offs between environmental goals must also be taken into account. For instance, diesel vehicles emit less CO_2 than gasoline vehicles, but more local pollutants such as PM_{10} and NO_x (Miravete et al., 2018). For this reason, even if the literature showed that driving restrictions based on emission rates of local pollutants are generally more effective, policymakers should also consider the presence of such trade-offs when choosing between different environmental measures.

Distributional effects of such policies depend on how the population is distributed in and around a city. Typically, driving restrictions and congestion charges are adopted in city centres and residents are granted free access, or discounts on the charge. Therefore, these policies tend to more heavily affect individuals living in suburbs and commuting to the city. If these tend to be low-income, they will suffer to a greater extent the effects of such policies. In a similar vein, if those policies are based on vehicle emission rates, low-income households who keep their older car for longer, or who cannot afford to replace their vehicle, would be disproportionally affected by the measures. In the particular case of LEZs, low-income individuals owning older vehicles will not be allowed into the LEZ at all. Banning the circulation of certain types of vehicles generates quite high social costs, and for this reason, it is fundamental to evaluate *ex ante* if the potential gains from lower pollution – in particular improvement in health outcomes – compensate for such costs (Börjesson et al., 2021).

4.3.4.2 Information programmes

The effectiveness of the monetary incentives mentioned so far can vary depending on the level of information available to consumers. In fact, there are two main informational hurdles that can prevent consumers from fully internalising the financial incentives towards energy-efficient and low-carbon choices. The first hurdle is that consumers are either unaware of the monetary incentives, or not completely informed about them. For instance, they might ignore that the circulation tax is lower for energy-efficient vehicles. If that is the case, the incentive is simply not taken into account by consumers in their choice of vehicle. The second hurdle is that, even when consumers are perfectly informed about the presence of monetary measures favouring energy-efficient choices, they are not able to include these incentives in their decision-making process. For instance, the calculation of the overall fuel costs of a vehicle requires combining information on the fuel price per litre (including the fuel tax), the fuel economy of the vehicle, yearly mileage, and the expected lifetime of the vehicle. If consumers lack the capability to perform these calculations, they might not fully internalize the various monetary incentives when making decisions on which vehicle to buy, or how much to drive.

Information measures can help overcome these hurdles in three ways: first, by making individuals aware of the presence of monetary incentives through informational campaigns (e.g. advertising or letters). Second, by directly providing a calculation of the monetary costs of each option – for instance, through an energy label that for each vehicle on sale illustrates the fuel costs per year for a typical mileage, or a website that compares different vehicles and directly calculates the circulation tax amount for each option. Third, by teaching consumers how to correctly calculate the overall costs of each option, and how to incorporate the various monetary incentives into such calculation.

4.3.4.3 Vehicle scrappage schemes

Vehicle scrappage schemes usually offer a rebate on the purchase of a new, energy-efficient vehicle if a buyer trades in her old vehicle, subject to satisfying some requirements, which can range from age to energy efficiency (Adda and Cooper, 2000; Mian and Sufi, 2012; Hoekstra et al., 2017). One reason why governments impose conditions on which vehicles can be traded in is the so-called free-riding problem; the short duration of the programme is such that consumers are likely to respond to incentives by anticipating the purchase of a low-emission vehicle and pocket the rebate. Thus, the environmental gains from the programme will be likely modest compared to its costs (Mian and Sufi, 2012).

Governments have often incentivized the early retirement of old, inefficient vehicles through vehicle scrappage schemes. For instance, several such programmes were introduced following the 2008 recession (e.g. in China, the EU, Japan, and the United States), both as an environmental policy instrument and as a temporary stimulus for the economy (Mian and Sufi, 2012). The effectiveness of these incentives as a measure to reduce vehicle carbon emissions is unclear, since the new vehicle fleet comprises a small share of the total vehicle fleet.

4.4 CONCLUDING REMARKS

This chapter has surveyed the policy instruments used in the passenger vehicle sector to tackle the externalities it creates. Given difficulties often associated with the implementation of "first-best" policies, policymakers worldwide have implemented a diverse number of policies, often in combination. Such a menu of policies is also motivated by the different externalities policymakers are aiming to address, from global pollutants such as CO_2, to local pollutants, and to congestion. Due to the different local contexts and approaches adopted by governments, in this chapter we offer some general findings on the effectiveness of the various policies from the literature, without focusing on evaluating specific situations.

While this chapter is focused on the reduction of carbon emissions, passenger car transport generates several other types of externalities, including some that are particularly relevant. In the EU congestion and accidents represent the most important types of external costs from passenger vehicle traffic, followed by climate and air pollution externalities (Van Essen et al., 2019). How this ranking of different types of externalities would change between different countries and with the evolution of the vehicle fleet is still an ongoing question.

An important factor influencing the environmental impact of passenger transport is the type of urban form. In general, the presence of urban sprawl can contribute to worsening environmental externalities, although whether a higher urban density is always desirable is still an open question (Gaigné et al., 2012). For a broader discussion of the relationship between urban form and transportation we refer the reader to Chapter 5 of this *Handbook*.

To achieve the goals of the Paris Agreement, carbon taxes – which would also affect the transport sector – should reach a level between 50 and 100 US$ per tonne of CO_2 and should be combined with other policies aimed to reduce carbon emissions. Because these pricing levels are higher than those currently existing, the political acceptability of these measures is a significant challenge. Successful carbon price schemes currently implemented have introduced some transfer schemes to compensate those actors who were affected the most or to make carbon pricing more palatable to voters (Klenert et al., 2018).

Technological developments in the transport sector in the coming years are likely to challenge the established view and use of many such policy instruments. Such developments range from the prevailing technology in transport to the business model under which the transport sector will operate, e.g. whether vehicles will be owned or just rented on an hourly basis or accessed via a subscription service. The impact of the diffusion of electric vehicles on carbon emissions, currently exempt from many of the measures described in this chapter, will be tied to the degree of decarbonization of the electricity mix. In sum, the developments are likely to impact the very externalities created by the sector, from pollution to utilization to vehicle size.

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