OECD Taxation Working Papers No. 44

Taxing vehicles, fuels, and road use: Opportunities for improving transport tax practice

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https://dx.doi.org/10.1787/e7f1d771-en

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Taxing vehicles, fuel, and road use: Opportunities for improving transport tax practice

ABSTRACT

This paper discusses the main external costs related to road transport and the design of taxes to manage them. It provides an overview of evolving tax practice in the European Union and the United States and identifies opportunities for better alignment of transport taxes with external costs. There is considerable scope for improving transport tax practice, notably by increasing the use of taxes based on road use. Distance charges offer great promise in delivering more efficient road transport. In heavily congested areas, targeted charges are a cost-effective way of reducing congestion.

Fiscal objectives provide an impetus for change as improving vehicle fuel efficiency and fleet penetration of alternative fuel vehicles erode traditional tax bases, particularly those relating to fossil fuel use. A gradual shift from an energy-based approach towards distance-based transport taxes has the potential to establish a stable tax base in the road transport sector in the long run.

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Introduction

Traditional structures of road transportation taxes in most countries focus on fuels and, to a lesser extent, vehicles. The central message of this paper is that there is considerable scope for beneficial change in this structure, by increasing the use of taxes based on road use, particularly distance charges and congestion charges. Distance charges can raise revenue at economic costs comparable to or lower than those of fuel taxes, and their appeal from this point of view will increase strongly when road transport decarbonises. Distance charges also offer great promise in delivering more efficient road transport, particularly if they can be differentiated to some degree according to vehicles' emission profiles and to exposure to pollution. The main external cost of transport in urban areas relates to congestion. Targeted congestion charges can cut congestion cost-effectively.

Fiscal objectives – of particular concern to finance ministers and administrators of stressed highway infrastructure budgets – provide an impetus for change as improving vehicle fuel efficiency and fleet penetration of alternative fuel vehicles (even if limited to date) erode traditional tax bases, particularly those relating to fossil fuel use. In the longer run, decarbonisation of transport (and other sectors) is necessary to fight climate change. In this context, several countries (e.g., France, India and Norway) are discussing or have announced bans on the sales of vehicles running on fossil fuels (sometimes including hybrids) starting in 2025 or by 2040. In addition, alternative business models and car-sharing could reduce car ownership and the tax base that it constitutes.

Traditional transport tax bases are under stress and could, in the case of fossil fuels, should decline strongly over time. In addition, the design of current tax, regulatory, and other transport management systems falls well short of addressing some of the worst negative side-effects of transportation, including greenhouse gas emissions, local air pollution, external costs of accidents and of infrastructure wear and tear, and urban congestion. Meanwhile, with developments in electronic metering technologies, fiscal instruments related to vehicle usage are becoming a practical, albeit politically challenging option. As the fossil fuel tax base erodes, a gradual shift from an energy-based approach towards distance-based transport taxes would establish a stable and relatively efficient tax base in the road transport sector in the long run. It also potentially represents a major step forward in using taxes to curb the main external costs of road transport.

This paper starts out by discussing the main principles for the design of more efficient road transport tax systems, in Section 2. It focuses on the nature and the size of externalities, drawing from overviews of recent cost estimates for the European Union, France, and the Netherlands (Section 2.1). Section 2.2 discusses the potential role of more novel fiscal policies, e.g., congestion charging, to align taxes better with the main marginal external costs. It also briefly investigates how current fuel taxes compare to the ideal level of fuel taxes that should be set if more sophisticated tax systems are out of reach.

Setting taxes in line with external costs is an important dimension of transport tax reform, but, as is explained in Section 2.3, other transport-related tax and pricing inefficiencies need remediation, e.g., improving the pricing of parking and removing tax preferences for company cars and commuting. Section 2.3 also discusses how questions related to inefficient land use interact with transport taxation, and considers interactions between transport taxation and the broader tax system.

Section 3 focuses on transport taxation practices to date, identifying patterns of change in the European Union (Section 3.1) and the United States (Section 3.2). The underlying causes of the changes are analysed, and the extent to which they align with the design principles of Section 2 is assessed. Section 4 sums up and concludes.

The main insights of the paper are as follows:

- Although estimates remain uncertain, it is safe to state that the external costs of road vehicle use are large. External costs of congestion in urban areas are particularly high. Per unit air pollution and climate costs are important as well, and the latter will rise in accordance with the social cost of carbon.
- Improved control, through prices, of some of the main transport externalities requires increased reliance on distance charges and congestion charges. The investment and operational costs of electronic charging mechanisms are declining rapidly, so that their applicability increases.
- Fuel taxes are not particularly effective at curbing external costs other than CO_2-emissions. Uniform distance charges can address external costs of road damage. Distance charges that differentiate by vehicle type can help address air pollution, and more strongly so if they are also differentiated by place. Congestion charges, even with limited differentiation over place and time, allow an approximation of marginal congestion costs and therefore yield potentially large benefits where congestion is severe.
- Increasing the use of distance charges and reducing the road-use component of fuel taxes can generate considerable efficiency gains. In the longer run, a gradual shift away from fossil fuel taxes will be required if decarbonisation objectives are achieved and revenues from the sector maintained or increased (whether or not these revenues are earmarked for funding road construction and maintenance). Policies that maintain relatively low prices for alternative transport energies to stimulate decarbonisation strengthen the desirability of shifting to road use as the main tax base for revenue-raising reasons.
- Distance charges provide an opportunity for also addressing congestion externalities when they can be differentiated, even to a small degree, according to congestion levels. Country-wide distance charges combined with local congestion charging systems can deliver such differentiation.
- There is no basis on externality grounds for the common practice of taxing road diesel favourably relative to gasoline on a per litre basis. Instead, there is a case for higher taxes per litre of diesel than per litre of gasoline. Recent trends towards relatively higher diesel taxes in several countries suggest that the problem of relatively low diesel taxes is declining.
- Ensuring that the price of parking reflects its costs more closely is potentially as important as internalising the marginal cost of congestion in urban transport prices. Removing or reducing the favourable tax treatment of company cars and the deductibility of commuting will also strongly contribute to more efficient transport and location choices.

- Revenue-raising considerations suggest that taxing car use at VAT plus marginal external cost presents a lower bound to fully efficient transport taxes. This is because driving and vehicles, and to a lesser extent fuel, are relatively inelastic tax bases. The rule of thumb of using excises and charges to align prices better with external costs is a cautious approach that is likely to result in considerable welfare gains.
- In the European Union, EU Directives constrain country policy, and this may have limited the potential adverse impacts of tax competition. The gradual adoption of distance charges for trucks has arguably improved the effectiveness of taxation in curbing external costs. However, limiting the use of distance charges to trucks is inefficient and strongly constrains their effectiveness as a bridge to congestion pricing. Extending the application of distance charges to passenger cars would be a next step towards more efficient transport pricing.
- The practice of transport tax reform in the European Union and in the United States often appears to be driven more by revenue considerations than by alignment of transport prices with external costs. There is considerable scope for such transport tax reform to also produce better alignment of taxes with external costs, resulting in more efficient usage of available infrastructure capacities and steering to some extent towards the development of less car-oriented transport practices.

1. Efficient tax structures for road transport

Section 2.1 defines the main externalities related to use of road vehicles, briefly discusses techniques for measuring them, and discusses recent estimates (an overview is provided in Annex 1). In Section 2.2, the appropriate mix of fuel, road use, and vehicle taxes for addressing the externalities effectively is considered from a conceptual viewpoint. It also discusses second-best fuel taxes: if for some reason the ideal tax mix is out of reach, fuel taxes may be the best available instrument to deal with the full range external costs, even if “best available” does not indicate “particularly good” in many cases. Section 2.3 takes a broader view of transport taxation and transport pricing, discussing, first, the need for improving the pricing of parking and removing tax preferences for company cars and commuting, and, second, how inefficient land use interacts with transport taxation; and, third, interactions between transport taxation and the broader tax system.

2. External costs of road transport

The list of potential negative side-effects, or external costs, from road transport activities is long. For example, (CGDD SEEIDD, 2013[1]) distinguishes between environmental externalities (climate change, local air pollution, water and soil pollution, noise, loss of biodiversity, inefficient land use, technology risks, visual intrusion, and vibrations), social externalities (accidents, health impacts, barrier effects, reduced quality of life) and economic externalities (wear and tear of infrastructure, and congestion).[1] This section

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[1] The same study mentions the possibility of some positive externalities, e.g., improved quality of life following upgraded transport infrastructure, and wider economic benefits (including, but not limited to, agglomeration effects). This paper does not consider wider economic benefits, not because they are unimportant, but because the principal role for transport taxes in stimulating them

focuses on the main externalities where quantification has been attempted, namely climate change, local air pollution, traffic congestion, accidents, noise, and road damage.[2]

2.1. CO_2 emissions and climate change

Combusting road fuel causes emissions of carbon dioxide (CO_2). Emissions are proportional to the volume of fuel used but differ between fuel types. For example, CO_2 emissions per litre of diesel are moderately higher than for gasoline (Small, Kenneth and Van Dender, 2007[2])). The resulting climate damage is mostly borne by future generations across the globe, because CO_2 stays in the atmosphere for more than a century and the climate system adjusts only gradually to rising atmospheric CO_2 concentrations.

As damages from CO_2 emissions are the same regardless of where emissions are released, strict application of the least-cost principle would seem to imply that emissions in different countries should be taxed at the same rate, but equity concerns and interactions with other taxes can lead to different results. A practical case might be made for lower prices in low-emitting, low-income countries e.g., (Gillingham and Keen, 2012[3])

One approach to valuing CO_2 damages is to quantify future risks using evidence on how emissions affects future atmospheric concentrations, the temperature and related climate impacts of higher concentrations, the economic impacts (damages to world agriculture, costs of protecting against rising sea levels, health effects, risks of large GDP losses from extreme climate scenarios, etc.), all discounted back to the present. Analyses performed by (IAWG, 2013[4]) , suggest a CO_2 damage value in the order of USD 40 per tonne of CO_2 for 2015, rising at around 2-5% a year in real terms. These types of estimates are the subject of intense debate see (Smith and Braathen, 2015[5]), for an in depth discussion).

Another approach determines optimal carbon price levels by deriving least-cost pricing trajectories that might ultimately be consistent with various climate stabilisation possibilities. Results are very sensitive to different assumptions (over future emissions baselines, the cost and availability of low-emission technologies, fuel prices, etc.).

French external cost estimates for transport (CGDD SEEIDD, 2013[1]) use a valuation for carbon, based on the least-cost-target-attainment method, of EUR 32 per tonne in 2010 (2008 prices), to rise by 5.8% per year from 2011 to 2030 (reaching EUR 100 per tonne in 2030) and then by 4% per year to reach EUR 200 per tonne in 2050. Dutch external cost estimates (Schroten et al., 2014[6]) are also based on a cost-effectiveness approach, but the central estimate for 2010 is higher with EUR 78 per tonne of CO_2, and EUR 44 as a low end estimate and EUR 155 as a high end estimate. Estimates for the European Union (Ricardo-AEA, 2014[7]), using sources similar to the Dutch estimates, arrive at

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runs precisely through the control of negative externalities to ensure that scarce transport network capacity is put to its most valuable use.

[2] Energy security is not considered either given the difficulty of pinning down the precise nature of the externality, the generally modest findings from studies attempting to quantify it e.g., (Brown and Huntington, 2013[89]) and the lessening of concerns with the recent decline in oil prices. For more in-depth discussions of automobile externalities see, for example, (De Borger, 2017[26]), (Litman, 2014[90]), (Parry, Ian W. H, Margaret Walls and Harrington, 2007[101]) and (Quinet, 2004[103]).

EUR 90 per tonne as the central estimate, with EUR 44 and EUR 168 as low and high end values (values for and prices of 2010).

A 2017 Report of the High-Level Commission on Carbon Prices (CPLC, 2017[8]) estimates that reaching the objectives of the Paris Agreement, i.e., keeping global average temperature increases well below 2 degrees Celsius, requires carbon prices of USD 40 to USD 80 per tCO_2 by 2020 and USD 50 to USD 100 per tCO_2 by 2030. It may be worth recalling that the Paris Agreement targets require deep to full decarbonisation of key sectors in the economy, short of breakthrough innovation with carbon capture and storage.

The estimated externals costs for climate change from greenhouse gas emissions in road transport vary due to the difference in input parameters and assumptions. The estimates for the European Union (Ricardo-AEA, 2014[7]) discussed here are expressed per vehicle-kilometre, to make them commensurable with other costs, even if the costs are fully proportional to fuel consumption and hence ideally internalised through fuel taxes.

The cost estimates amount to 1.5 to 3.3 Euro-cent *per vehicle-kilometre* for a gasoline car, with the range determined by EURO-class of the vehicle, engine size and road type (Ricardo-AEA, 2014[7]). Again on a per kilometre-basis, costs are a bit lower for diesel cars (1.1 to 3.3 Euro-cent per vehicle-kilometre) as they are on average sufficiently more fuel-efficient to compensate for the higher carbon content of diesel. The estimates for the Netherlands for a gasoline car range from 0.31 to 3.1 Euro-cent per vehicle-kilometre, with the range determined by the shadow price of carbon. The central value is 1.14 Euro-cent per vehicle-kilometre, which is at the lower end of the EU range. French estimates are lower, between 0.35 and 0.54 Euro-cent per passenger-kilometre depending on urban or rural driving conditions. Applying the EU carbon values to the French estimates would push these to 1.62 Euro-cent per passenger-kilometre, which is within the EU bracket of estimates.

2.2. Local air pollution and health damage

Fuel combustion produces various local air pollutants, especially fine particulates, which can be emitted directly, or formed indirectly from atmospheric reactions involving sulphur dioxide and nitrogen oxides. Diesel produces all three emissions sources while gasoline mainly the last, but in lower quantities. Fine particulates are small enough to penetrate the lungs and bloodstream and elevate the risks of various fatal diseases (e.g., heart and lung diseases; diesel exhaust is formally classified as carcinogenic), leading to loss of quality of life and to premature death see (OECD, 2014[9]).[3]

The health damages from emissions can be quantified in several steps. The first is to obtain a measure of population exposure to emissions, or equivalently the fraction of emissions that on average are inhaled by exposed populations. Next is to translate population exposure into mortality risks. Health damages can then be monetised using evidence on how people value mortality risks.[4] Finally, health damages can be expressed

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[3] Air pollutants cause a range of other impacts (e.g., impaired visibility, crop damage, nonfatal illness) but mortality impacts are easily the predominant source of environmental damage (NRC, 2009[99]). Other pollutants (ozone and carbon monoxide from fuel combustion) can have health effects, though on a smaller scale than those from fine particulates see (Hunt et al., 2015[91]).

[4] A meta-analysis of several hundred studies by (OECD, 2012[92]) puts the mortality value for the average OECD country at USD 3.3 million in 2005 USD.

per unit of fuel using data on emission rates per unit of fuel use by fuel type (e.g., gasoline and diesel). Alternatively, estimates can be disaggregated by region (e.g., rural, suburban and urban), or by vehicle type (e.g., engine size and pollution control equipment).

The external air pollution costs of diesel cars are in many circumstances more than twice as large as those of gasoline cars, and costs are particularly elevated for urban driving. The European Union estimates (Ricardo-AEA, 2014[7]) distinguish between EURO-classes of vehicles (i.e., different vintages of pollution regulation), engine size and region (urban, suburban, rural, and motorway). These estimates provide information on the situation where the standards apply in real driving, but provide only lower bounds when regulation levels of emissions are systematically exceeded.

Expressed per vehicle-kilometre[5], the external costs of a gasoline car driven in an urban area range from 0.4 to 1.1 Euro-cent per vehicle-kilometre, depending on engine size and EURO-class. For a diesel car in urban areas, the range is 0.7 to 3.7 Euro-cent. External pollution costs are lower for suburban, rural and motorway driving. In rural areas, for example, the range is 0.1 to 0.4 Euro-cent per vehicle-kilometre for gasoline cars and 0.2 to 0.8 Euro-cent for diesel cars. Available estimates for the Netherlands (Schroten et al., 2014[6]) do not distinguish between regions. The country range for gasoline cars is from 0.03 to 1.5 Euro-cent per vehicle-kilometre, with a central value of 0.34 Euro-cent. For diesel cars, the range is from 0.09 Euro-cent to 7.6 Euro-cent per vehicle-kilometre, with a central value of 0.98 Euro-cent. These central values are similar to those for the European Union. The French estimates (CGDD SEEIDD, 2013[1]) are well in line with the EU estimates as well, with urban driving of a gasoline (diesel) car generating an external pollution cost of 0.59 (1.43) Euro-cent per vehicle-kilometre, and costs of rural driving of 0.22 (0.54) Euro-cent.

Finally, external cost differences also depend on driving behaviour, and on-road emissions can differ strongly from regulated emissions. Obtaining closer resemblance of on-road emissions and test-cycle emissions is a matter of designing test-cycles that reflect on-road driving conditions reasonably well and of ensuring that engine- and pollution-control management systems operate in the same manner in all circumstances. Without these elements, emissions regulation and the taxes built on them cannot be very effective.

2.3. *Traffic congestion*

The basic definition of external costs of congestion is that car users account for the time they expect to spend on the road when deciding where and when to drive, but they do not account for the road space used by their vehicle, which adds to congestion, raising travel times and reducing travel time reliability for all road users.[6]

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[5] The unit is chosen for commensurability, in line with the literature. Air pollution costs depend strongly on vehicle characteristics and fuel type.

[6] It is sometimes argued that there is no congestion externality as road users as a group incur increased time costs and reduced reliability when congestion rises. However, the existence of a (Pareto-relevant) external cost is not related to who bears the burden of the external cost but to there not being an incentive for individual users to take the increase in costs caused by their decision to drive into account.

Marginal external congestion costs have been assessed in detail for a limited number of urban areas and road classes, using several pieces of information e.g., (Fosgerau and Van Dender, 2013[10]); (Small and Verhoef, 2007[11])Observed traffic flows on links in the road network can be used to estimate speeds. Also, direct speed satellite data on speeds is increasingly available. Traffic and speed flow relationships can be used to infer marginal delay – the delay one driver imposes on others. A rough rule of thumb averaged across urban centres derives a marginal delay of about 2.5 to 5 times the average delay (e.g. (Small and Verhoef, 2007[11]) pp. 69-83).

Finally, the value of travel time (VOT) can be used to convert marginal delays into marginal external congestion costs. Literature suggests these are around 60 percent of the market wage for travel under congested conditions (e.g., (Small and Verhoef, 2007[11]) pp. 52-53). Recent work suggests that congestion costs could be significantly (around 10 to 30 percent) higher when broader factors are taken into account like reduced reliability over travel times and disutilty from drivers deviating from their preferred travel times to avoid peak congestion (e.g., (Fosgerau et al., 2008[12]); (Peer, Koopmans and Verhoef, 2012[13]); (Kouwenhoven, 2016[14])). Substantial heterogeneity in VOTs across drivers – particularly the disproportionately large share of drivers with low VOTs who are most responsive to higher money costs of driving – implies that the average VOT of drivers left on the road (after the introduction of congestion charges) can increase significantly (e.g., (Fosgerau and Van Dender, 2013[10])).

The EU estimates (Ricardo-AEA, 2014[7]) of marginal external congestion costs are available at a fairly high level of disaggregation, distinguishing by region, road type, vehicle type and volume-capacity ratios. Values differ strongly, reflecting the obvious fact that congestion is highly specific to location and time of day. With low traffic loads (less than 75% of road capacity), the EU handbook finds marginal external congestion costs ranging from zero to 2.5 Euro-cent per vehicle-kilometre, depending on region and road type. With traffic loads near capacity (75% to 100%), marginal external costs are much higher, between 18 and 159.5 Euro-cent per vehicle-kilometre. When traffic volumes exceed capacity, costs are still higher, from 30.8 to 242.6 Euro-cent per vehicle-kilometre.

Using weights of traffic volumes for volume-capacity ratios in the United Kingdom (see Box 1), the range of marginal external congestion costs is from 1.9 to 18.5 Euro-cent per vehicle-kilometre (where the upper value is an average; as noted, in some situations, the external costs are an order of magnitude larger). This range is broadly similar to that reported in the Dutch study (Schroten et al., 2014[6]), which is from zero (when there is no congestion) to 30.8 Euro-cent per vehicle-kilometre (for urban roads in peak hours), with a central value of 6 Euro-cent per vehicle-kilometre (this is an average over all road types and times of day). This central value is less than half as high as the comparable value for the UK (12 GBP pence per vehicle-kilometre, see Box 1). The French estimates (CGDD SEEIDD, 2013[1]) are 16.8 Euro-cent per car-passenger-kilometre in urban settings, 2 Euro-cent in regional traffic, and 0.37 Euro-cent per passenger-kilometre of rural driving, a range which resembles that of the EU quite closely.

2.4. Traffic accidents

Even in the presence of numerous vehicle and road safety regulations (drunk driver penalties, air bag mandates, crash barriers, etc.), accidents will remain excessive as long as motorists are not charged for the risks their extra driving poses to others. An estimated 1.3 million people worldwide are killed in road accidents each year (World Health

Organization, 2013[15]), and many more are injured, but only some of these injuries (e.g., to pedestrians and cyclists) are viewed as external risks, while others (e.g., deaths to drivers in single-vehicle collisions), are viewed as internal risks. Liability insurance (which introduces a moral hazard problem) and, to a lesser extent, caps on damage awards, can contribute to excessive accident rates. Accidents also cause congestion, and this is part of the external cost.

Whether injury risks to other vehicle occupants in multi-vehicle collisions are external is a little unsettled. All else the same, extra driving by one motorist increases the likelihood of collisions for other drivers (as there is less road space between vehicles), but if people drive more carefully in heavier traffic, the average severity of accidents is reduced. As for the risk of medical costs and property damages from extra driving, these are mostly borne by third parties (insurance companies, governments) but to the extent drivers face some risk of liability or higher future insurance rates following a crash, a portion of them are internalised.

Recent estimates for the EU (Ricardo-AEA, 2014[7]) put marginal external costs of accidents at 0.3 Euro-cent per vehicle-kilometre for urban driving by car, and 0.2 and 0.1 Euro-cent for non-urban and motorway driving by car, respectively. The estimated values for France (CGDD SEEIDD, 2013[1]) are 4.8 Euro-cent per passenger-kilometre for urban driving by car, 1.5 Euro-cent for regional driving and 1.2 Euro-cent for rural driving. The estimates for the Netherlands (Schroten et al., 2014[6]) are 17.7 Euro-cent per kilometre for urban driving by car, 3 Euro-cent per vehicle-kilometre for regional driving, and 0.2 Euro-cent per vehicle-kilometre for rural driving.

Differences between estimates are large, particularly for urban driving. (Ricardo-AEA, 2014[7]) notes that the EU estimates in the updated handbook are much lower than those of the 2008 handbook, reflecting different assumptions about precisely what part of accident costs is external, and reflecting reduced accident risks over time as there were fewer accidents but larger traffic volumes).

2.5. Noise

Noise from transport causes discomfort and long exposure has adverse effects on health. Measuring and valuing the external effects of noise is not straightforward, requiring marginal noise emissions, noise dispersion, exposure-response relations, and economic valuation of the impacts. Estimates for the European Union (Ricardo-AEA, 2014[7])Table 28) range from near zero values for rural driving to EUR 0.36/km for a marginal kilometre by a heavy goods vehicle driven at night in thin traffic in an urban environment. A kilometre driven by car in dense traffic in an urban environment is estimated to entail an external noise cost of EUR 0.009 per kilometre.

2.6. Road damage

Yet another externality is wear and tear on the road network caused by traffic. It is almost entirely caused by heavy vehicles because road wear is a rapidly escalating function of a vehicle’s axle weight. The EU estimates of marginal infrastructure costs (actually average variable costs; (Ricardo-AEA, 2014[7]) of road use amount to 0.5 Euro-cent per vehicle-kilometre for cars across all road types, with lower values for motorways (0.1 Euro-cent per vehicle-kilometre) and higher values for other roads, including urban roads (0.8 Euro-cent per vehicle-kilometre).

The marginal costs of road wear and tear are much higher for trucks than for passenger cars due to higher axle-weights, with a cost of 5.2 Euro-cent per vehicle-kilometre for a truck of 18 to 26 tonnes with 3 axles across all road types. For motorways and other roads, the corresponding costs are 2.2 Euro-cent and 28.9 Euro-cent per vehicle-kilometre, respectively. The marginal cost estimates for cars in the Netherlands (Schroten et al., 2014[6]) are 0.2 Euro-cent per vehicle-kilometre on average across road types, 0.05 Euro-cent for rural roads, and 0.49 Euro-cent for urban driving. For France (CGDD SEEIDD, 2013[1]) , the estimates for cars are 0.58 Euro-cent per passenger-kilometre for urban and regional driving, and 0.37 Euro-cent per passenger-kilometre for rural driving.

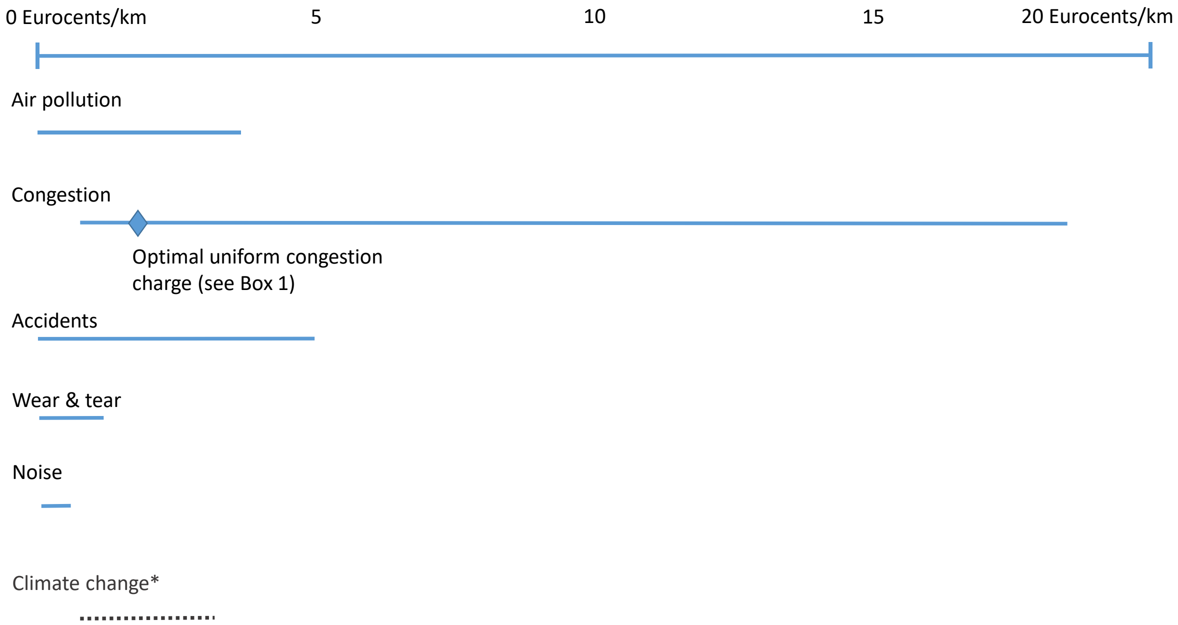
2.7. Summary of estimated ranges of external costs of passenger cars in the European Union

Figure 1 summarises the estimated ranges of the main external costs related to passenger car use in the European Union. The ranges themselves involve averaging, as indicated in the tables in Annex 1, so that not the full variation of marginal external costs is captured in the figure. No numbers are given for the range of the different external cost categories, to reflect the large uncertainty on the estimates. The top line indicates the range: marginal external cost estimates vary from zero to 20 Euro-cent per vehicle-kilometre, with the high end relevant only to congestion.

Marginal external congestion costs range from around zero to nearly 20 Euro-cent per vehicle-kilometre (with much higher values for small shares of traffic, as discussed in Box 1). Other external costs are in the zero to five cents per vehicle-kilometre range, or less. The diamond on the congestion cost line indicates the uniform per kilometre-charge that should be levied to reduce congestion best across all traffic levels. The estimate is based on data for the UK discussed in Box 1. This charge is low, around 2 cents per kilometre, reflecting the large share of traffic taking place under no or very low congestion levels. A fuel tax to reduce congestion should be even lower than this estimate, because fuel taxes also trigger improved fuel economy, which is an inefficient response to cutting congestion.

The figure also shows external costs from CO_2-emissions, but this is only to allow a comparison of orders of magnitudes of external cost categories. Tax policy for greenhouse gas emissions in transport involves fuel taxes, as emissions are proportional to fuel use. For the other external costs, distance charges make sense but the can sometimes be usefully combined with vehicle taxes or fuel taxes. This is discussed in the next section.

Figure 1. External cost estimates for passenger car use in the European Union, Euro-cent per vehicle-kilometre.



* For illustrative purposes only. The external cost is proportional to fuel consumption so is more naturally expressed per litre. The range shown covers fuel consumption between 5 and 10 litre per 100km and a social cost of carbon from EUR 60 to EUR 100 per tonne.

3. Aligning taxes with external costs

Taxes, which influence prices, are economically appealing instruments for reducing the negative side-effects of transport discussed in Section 2.1. Taxes can internalise external costs and so ensure their cost-effective reduction; see, e.g., (OECD, 2017[16]) for a general explanation of why prices and taxes are good environment policy instruments.

Ideally, each of the externalities described above requires its own fiscal instrument, carefully targeted at the source of the externality and set at a level to reflect external costs. Such tax design will promote all changes in economic behaviour for mitigating the externality for which benefits exceed economic costs. Other instruments (like air pollution emission rate standards for vehicles) are in general likely to be less cost-effective than price-based instruments, but have a role to the extent there are practical constraints on directly taxing the externality, or they can potentially contribute to other policy objectives.

This subsection discusses how taxes can be best aligned with marginal costs from transport. First, it considers distance-based taxes and congestion charges. Second, it discusses the main arguments in favour and against the use of vehicle taxes as a tool to internalise externalities. Finally, it reflects on the role of fuel taxes for the near and longer term.

3.1. The case for distance-based taxes and congestion charges

While fuel taxes are well suited to reflect external costs from CO_2 emissions, distance-based taxes have the potential to reflect effectively road damage and other infrastructure-related costs. If distance charges can be made to depend on vehicle characteristics, they can help address air pollution, and more so if they can also relate to population exposure to air pollution (e.g., by using population density at the place of driving as a proxy). Place-dependent charges also allow a degree of alignment with congestion levels, but time-varying charges will perform better in this regard.

3.1.1. CO_2 emissions

Unlike for other externalities, fuel taxes are the most efficient policy for promoting an efficient combination of behavioural responses that reduce carbon emissions (less driving, shifting to fuel efficient vehicles, etc.).[7] The efficient tax equals the CO_2 damage times the CO_2 emissions factors of each fuel, approximately 0.0024 and 0.0027 tons of CO_2 per litre for gasoline and diesel respectively. Using EUR 60 as damage value of one tonne of CO_2, the efficient tax for gasoline and diesel would equal EUR 0.14 and EUR 0.16 per litre, which is not that large when set against the potential for market-driven fuel price reductions, which exceeded EUR 0.4 per litre in recent years[8], or against prevailing fuel tax levels in many countries. With carbon values of EUR 100 per ton, the efficient charge for climate cost amounts to around EUR 0.25 per litre.

3.1.2. Local air pollution

Ideally local air pollution taxes would be based on tailpipe emissions per vehicle-kilometre, with the rate varying in proportion to local population exposure, topography, weather, interaction with other pollutants and ultimate pollution impact. This, however, is beyond technological and administrative reach. More feasible might be to tax estimated emissions damages based on each vehicle's emission rates per kilometre recorded at annual vehicle inspections, multiplied by the amount the vehicle is driven.

Alternatively, air pollution could be tackled through a combination of fuel taxes, distance charges and vehicle taxes. Distance charges will be more effective if they depend on vehicle emission characteristics and the place of driving. Vehicle taxes can help but do not vary with the amount and place of driving, so risk not being particularly cost-effective.

When used in isolation, fuel taxes are a blunt instrument for reducing air pollution emissions as they do not reward reductions in emissions per unit of fuel combustion (e.g., through adoption and maintenance of emission control technologies), nor do they vary with differences in population exposure to emissions across urban and rural areas. Fuel taxes can, however, reflect differences in average pollution profiles between fuel types,

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[7] In contrast to fuel taxes, fuel economy regulations promote only fuel-efficiency improvements in new vehicles (so affect the fleet average fuel economy only gradually) and by lowering fuel costs per kilometre they increase, rather than reduce, the amount of driving, though studies, for example, (Small, Kenneth and Van Dender, 2007[2]) suggest this 'rebound effect' is fairly modest. In principle, fuel economy standards might have a role when there are market failures other than mis-pricing that would otherwise cause under-investment in fuel efficient vehicles, but the existence and magnitude of such market failures is unsettled and fuel taxes may still be more efficient, depending on the size of the market failure relative to distance-related externalities (Parry, 2014[102]).

[8] Brent crude spot prices fell from USD 125 per barrel in 2012 to USD 50 per barrel in 2015 and one barrel is equivalent to 168 litres of gasoline. Carbon pricing has much more radical implications for the prices of coal which is far more carbon intensive and currently taxed at much lower rates than transport fuels see (OECD, 2013[108]) (2015[107]).

e.g., gasoline and diesel. In the case of gasoline and diesel, this calls for higher taxes on diesel than on gasoline, as air pollution from diesel tends to be higher than for gasoline for current vehicle stocks.[9]

Distance charges could include a component to reflect air pollution costs, particularly if they depend on vehicle type (as in practice often is the case for truck charges) and if they differ with where driving takes place, reflecting population exposure to some extent. Because congestion tends to correlate with higher exposure to air pollution, congestion charges could reflect not only the time-cost externality of congestion but also air pollution costs.

Vehicle taxes, imposed at the time of purchase of new vehicles or on a recurrent basis, can steer toward cleaner vehicles to the extent that other taxes fail to reflect fully the connection between technologies and emissions. There is evidence that vehicle taxes have strong effects on vehicle choice, so they are effective in that sense see, e.g., (OECD, 2016[17]). However, setting taxes at appropriate levels is difficult, and experience suggests vehicle taxes risk resulting in high abatement costs and high costs in terms of revenue forgone (see (D'Haultfoeuille, Givord and Boutin, 2013[18]).

The challenge is to determine the right mix of distance charges, fuel taxes and vehicle taxes. Uniform distance charges could reflect average urban pollution costs across fuels (around EUR 0.015 per kilometre in the European Union for fleets that consist of gasoline and diesel cars in equal proportion, see previous section). Differentiating distance charges by vehicle type will work better. Fuel taxes could reflect the different climate and pollution profiles of the fuels. The pollution component of the fuel tax then should be more than twice as high for diesel as for gasoline.

3.1.3. Congestion

Effectively reducing congestion requires per kilometre distance charges for vehicles driven on busy roads, with the charges aligned across roads and time of day with marginal external costs, meaning charges that progressively rise and fall during the course of the rush hours. This policy exploits all possibilities for drivers to alter behaviour in order to alleviate congestion, including flattening the distribution of trip departure times within rush hour periods, shifting from peak to off-peak travel, encouraging alternate modes (e.g., carpools, public transit, walking, cycling), reducing trip-making (e.g., via telecommuting or combining trips), shifting to less congested routes, changing job or residential locations, etc.

Box 1 illustrates, using figures for the United Kingdom, the dramatically larger economic welfare gains at stake from differentiating charges by congestion levels according to marginal external congestion costs, compared to a country-wide uniform charge. Such sophisticated pricing schemes have tended to be expensive, but they are becoming cheaper (see Box 2). Very fine-grained systems may be too complex from drivers' point of view, but simple systems, e.g. differentiation of distance charges between places and times where congestion often is high and where it is low, can result in appreciable

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[9] Across the fleet, diesel vehicles tend to pollute more than gasoline vehicles. Emissions regulation in the European Union tends towards a smaller gap between diesel and gasoline pollution for more recent vintages, but this takes time to work through the vehicle fleet, and only is effective to the extent that regulations are effectively enforced.

efficiency gains. The example discussed in Box 1 finds gains equal to more than 80% of what much more strongly differentiated charges can reach.

Congestion pricing schemes can be implemented at the nationwide or local level, or some hybrid of the two. Ideally, a top-down nationwide system involves recording annual kilometres driven by all motorists and levying charges on each kilometre that vary according to where and when driving occurs to reflect prevailing marginal external costs. The advantage of such a top-down system is its comprehensiveness – drivers are charged accordingly for every instance when they worsen congestion for other road users.

Administratively, congestion pricing could be implemented by requiring that all vehicles are equipped with technology which both informs motorists of the charges for their route and transmits real-time information on their driving behaviour to an independent collection agency which then bills motorists (perhaps via monthly credit card debits). This type of nationwide distance charges, adapted according to congestion conditions, was envisaged in the Netherlands but ultimately was not implemented. Existing distance charging systems fall well short of the ideal sketched here, being limited to some facilities or some vehicle types (trucks only) and with little variation according to congestion conditions.

In principle, local charging systems for individual urban centres could also charge by the kilometre, according to route within the road network and time of day, though current schemes are far more limited in scope, taking the form of charges for driving in the downtown area or on individual highways, or lanes of highways ("value-pricing"). The road-pricing system in Singapore is the closest approximation to an ideal local congestion-charging system. Cordon fees (where drivers pay when they enter a downtown area, as in London or Stockholm) or area licensing schemes (where drivers also pay for trips starting and terminating within the charging area) charge the same for trips irrespective of distance driven within the charging area, and fail to charge for driving outside of it. Nonetheless, if the location of the pricing boundary and the fee schedule are judiciously chosen, or better still, multiple cordons are used for larger cities,[10] these schemes can capture a significant portion of the welfare gains from more comprehensive pricing.[11]

As regards highway pricing, literature suggests that the welfare gains from differentiating tolls across lanes to allow drivers to sort themselves into different lanes according to their value of time are not much larger than for schemes with uniform tolls across lanes (e.g., (Verhoef, 2004[19]), (Parry, 2002[20]).[12] On the other hand, when just one, rather than all, lanes of a two-lane freeway are priced, this likely sacrifices more than half of the welfare gains (e.g., (Small, 2001[21])). In general, the direction and the magnitude of how network effects might affect second-best freeway tolls is highly case specific (e.g., (Verhoef, 2002[22]), and (Van Dender, 2004[23]). What is needed ideally to study these effects is a road network model with an economic component to capture changes in motorist welfare,

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[10] For some discussion of techniques for gauging the optimal placement of cordon tolls see (May, 2008[96]), (Sumalee, 2005[105]), (ITF, 2010[25])

[11] See for example, (May, 2004[97]), (Verhoef, 2002[22]).

[12] The difference between the efficient tolls across lanes is modest—although people in the high-toll lane have a higher VOT, the resulting increase in marginal external congestion costs for that lane are partly counteracted because there are fewer drivers on that lane, and less congestion.

though few of these models exist given the amount of time and data required to develop, calibrate, run, and update them.[13] A good transport network model, however, is indispensable for making good second-best road-pricing choices (Eliasson, 2010[24]).

Irrespective of its economic appeal, congestion pricing is challenging politically due to the reluctance of motorists to pay for roads they currently drive on for free. However, support for congestion pricing tends to increase after its introduction as users perceive the benefits or simply see it as a fact of life, so that charging systems tend to endure once in place even if they are entirely additional to existing transport taxes (see (ITF, 2010[25]) and (De Borger, 2017[26]), for a discussion of acceptance and policy design).

Political support may increase if nationwide schemes would partially and gradually substitute for some components of fuel taxes (see Section 3). Local schemes might be phased in by charging tolls on newly constructed lanes, or progressively replacing vehicle banning systems (e.g., allowing vehicles to pay on days they would otherwise be banned from restricted areas or allowing low-occupancy vehicles to pay to drive on high-occupancy vehicle lanes in the United States). Revenues might pay for better public transport (as is mostly the case in London), or for a range of benefits including environmental, 'liveability' and infrastructure benefits (the case of Stockholm), or more generally for mobility management and revenue-raising (as in Singapore). The projects to which revenues are allocated should be selected on the basis of social returns, in combination with considerations of political feasibility, rather than earmarking all revenues for a particular type of expenditure.

3.1.4. Accidents

In principle, the efficient tax for traffic accidents is levied on a kilometre basis, with rates scaled both to the driver risk (perhaps based on rating factors from insurance companies accounting for age, prior crash record, etc.), vehicle risks (e.g., as heavier vehicles generally pose higher risks to other vehicle occupants than lighter vehicles), and the time and place of driving, in a way that is similar (but not identical) to congestion pricing.

These fiscal instruments have yet to be introduced in any comprehensive way, but a promising alternative – already in use in some countries – is a market-driven transition to pay-as-you-drive (PAYD) insurance, where lump-sum annual insurance payments are replaced by payments in direct proportion to kilometres driven, with per kilometre charges scaled by the usual rating factors. Public opposition to PAYD should be muted as there is no new burden on the average motorist – in fact low-kilometre drivers have an incentive to switch to these schemes (e.g., (Bordhoff and Pascal, 2008[27]) as their annual payments decline (under current insurance they subsidise high mileage drivers).

Both fuel taxes and distance charges are blunt instruments to address accident externalities. Improvements in vehicle fuel efficiency (e.g., more efficient engines) induced by fuel taxes may not affect injury risks, and they do not impose higher penalties on riskier drivers (e.g., those with previous crash records). Distance taxes would not induce drivers to drive more carefully, choose safer routes, or drive under safer driving conditions.

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[13] Engineering models are more common, but there are not many economic models—examples include (Houde, 2007[93]) for Washington DC, (May, 2002[98]) and (Santos and Newbery, 2002[106])for UK cities.

3.1.5. *Road damage*

Road damage is most efficiently addressed through per-kilometre tolls on vehicles, scaled by their axle weight and ideally with rates higher for driving on more vulnerable road classes. Such a tax would encourage hauliers to seek vehicle fleets that carry goods efficiently over more axles, and over routes with hardier road surfaces, with less road damage e.g., (Small, Clifford and Evans, 1989[28]). They can also reduce the number of no-payload trips.

Fuel taxes are not an efficient instrument for addressing road damage as they charge for fuel rather than road use, and do not vary with a vehicle's axle weight or the vulnerability of the individual road surface to deterioration.

3.2. Vehicle taxes

In principle there is no external-cost-related basis for the increasingly common trend of relating vehicle taxes to emission rates or fuel efficiency when externalities (particularly carbon and local pollution) are efficiently priced, perhaps in combination with regulations for air pollutant emissions. Vehicle taxes are increasingly used to steer consumer choices towards the purchase of more fuel efficient and less polluting vehicles, but they can be very costly in terms of public revenue, and it is difficult to design systems so that they result in net benefits. This section reviews some of the argumentation on this matter, in the context of one-off taxes on vehicle sales and recurring annual payments for using vehicles.

A potential argument for relating vehicle sales taxes[14] to CO_2 emissions or fuel efficiency, even with CO_2 emissions appropriately priced, is the possibility of additional market failures due to consumers' discounting fuel efficiency benefits at rates well above market rates (e.g., (Allcott and Wozny, 2009[29]); (Hausman, 1979[30]); (Sanstad, Hanemann and Auffhammer, 2006[31]); (Train, 1985[32]). The issue is contentious, however, and some of more recent and sophisticated studies find evidence of only a limited degree of excessive discounting (e.g., (Busse, Knittel and Zettelmeyer, 2013[33]); (Sallee, 2014[34]): (Grigolon, Reynaert and Verboven, 2017[35])). These studies to the extent possible consider that findings of higher discount rates actually reflect alternative deployment of fuel economy potential. For example, technologies that could be used to save fuel have greater market value when used to enhance other vehicle attributes, e.g., acceleration. Ignoring this risks producing misleading findings of high implicit discount rates.

To the extent that vehicle sales taxes can play a role in an efficient taxation package, there are tax design concerns to be taken into consideration. The common approach of classifying vehicles into different emission rate bands and applying lower tax rates to lower emission classifications is problematic in at least two regards. First, it sets up a tension between fiscal and environmental objectives, namely the more successful the policy in shifting people to lower emission vehicles, the less revenue is raised. Second, it violates the principle of providing uniform incentives to reduce emissions and instead can create bunching of vehicle demand just below tax notches, with zero reward for further emissions reductions within a band.

Feebates can in principle address the shortcomings of vehicle sales taxes and charges by emission band but their design features matter. Feebates are fees or rebates applied to

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[14] See (OECD, 2009[95]), for an overview of the use of differentiated vehicle taxes.

vehicles in proportion to the difference between their CO_2 per kilometre and some pivot point of emissions, which typically rewards all reductions in CO_2 at the same rate (e.g., Small, 2009). If the pivot point is set equal to the average CO_2 per kilometre of the sales fleet (in a previous year and updated over time), the feebate will be approximately revenue neutral, regardless of the implicit price on CO_2. Fiscal objectives could then be met through a second instrument. However (D'Haultfoeuille, Givord and Boutin, 2013[18])show, on the basis of the experience with the French feebate ("bonus-malus system"), that careful policy design is needed as otherwise unexpected and unintended effects can occur (*in casu*, higher CO_2 emissions in the short run given increased acquisition of new vehicles with only marginally lower emissions).

Using recurring annual vehicle taxes to discourage use of vehicles with high air emission rates leads to similar conclusions. Again, all vehicles face the same reward for reducing pollution by an extra tonne under a feebate imposing annual taxes or subsidies in proportion to the difference between observed emission rates (recorded during periodic vehicle inspections) and some pivot point level. Illustrative calculations in (Parry et al., 2014[36])for a typical European country suggest that the average gasoline vehicle should be charged about EUR 200 per year more than its zero-emission counterpart and the average diesel vehicle EUR 1 000 more. Of course, vehicle taxes do not depend on actual vehicle use, which limits their effectiveness for dealing with marginal external costs.

3.3. *Summary – aligning taxes with marginal external costs*

Figure 2. External costs, drivers of external costs and tax instruments

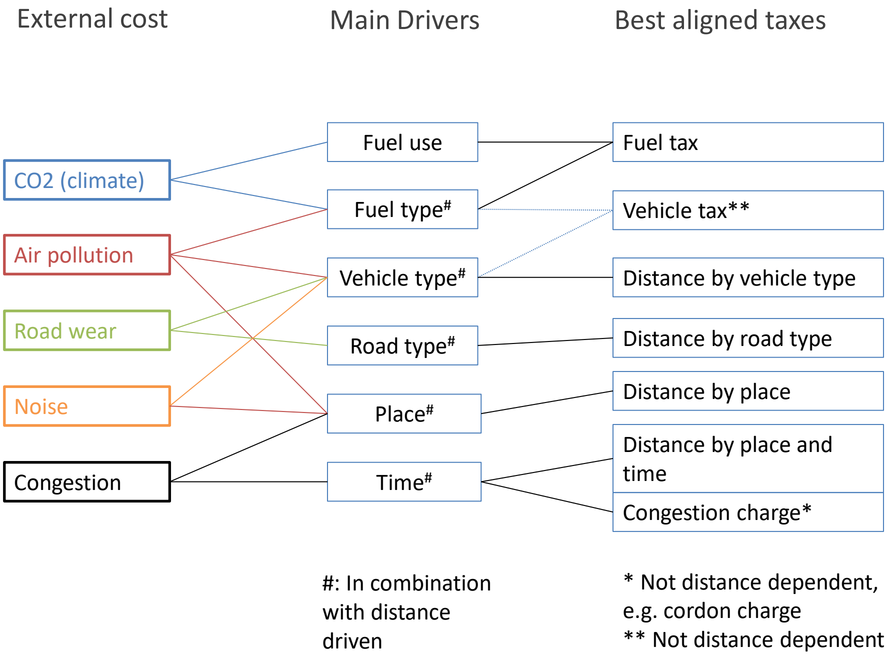

Figure 1 lists the main external costs of road use, links these costs to their principal (but not exclusive) determinants, and connects these drivers to the tax instrument or tax instruments best suited to provide incentives targeted towards these drivers. Emissions of CO_2 depend on fuel use and fuel type. A fuel tax can reflect these costs. Air pollution costs depend principally on fuel type, vehicle characteristics and exposure (place of emissions). This suggests using fuel taxes, vehicle taxes and place-dependent distance charges to reflect air pollution costs. This is complex and requires careful coordination of the various instruments.

Road wear and tear costs vary with the type of road and the type of vehicle. Distance charges can vary with these same determinants to reflect wear and tear costs accurately. Most electronic distance charging systems, which usually pertain to trucks only, feature such differentiation. Noise costs depend on vehicle type and the location of the noise emission, suggesting they can be approximated by the use of distance charges differentiated by place and vehicle type. A more sophisticated approach would also differentiate the noise charge by time.

Congestion differs by place and time, calling for distance charges that differ by place and time or for specific congestion charges that are not distance charges. Most currently operating congestion charges are not distance charges, but local cordon or zone charges (e.g. London, Milan, Stockholm, Singapore). Some systems differentiate charges by vehicle type (e.g., Singapore), others work with discounts and surcharges for low emission and high emission vehicles respectively (e.g., London), whereas others offer no such differentiation (e.g., Stockholm and Gothenburg).

3.4. *Fuel taxes for the near future*

Except for carbon emissions, the potential for fuel taxes to mitigate external costs from fuel use is quite limited. Introducing distance charges differentiated by vehicle type and location can deliver superior management of these costs.[15] In addition, distance charges are at least as attractive, and probably more attractive, than fuel taxes from a revenue-raising point of view, in the sense that the underlying tax base is less elastic (driving vs. fuel), see Section 2.3. If decarbonisation of transport energy actually materialises and taxes on low carbon energy remain low compared to current fuel taxes, for example because of broad climate policy, revenue stability is one more reason for gradually shifting to distance-based taxation.

However, instead of mainly becoming an instrument to internalise carbon costs, fuel taxes likely remain a core part of broad road transport taxation policy in the foreseeable future. Fuel taxes are by far the main tax instrument in car transport at present and it is an unlikely prospect for many that nationwide distance charging schemes, or congestion charging systems – despite their economic appeal – will be broadly applied in the near future.

If fuel taxes continue to be used, they should in principle be aligned with estimates of second-best taxes, as not doing so forgoes significant fiscal, emissions, health, and welfare benefits.[16] Therefore it is worth asking how prevailing fuel taxes compare to the levels that would be required for them to address the main external costs of car use as efficiently as possible.

Assuming, as before, that fuel excise taxes are not influenced by revenue raising considerations and that excise taxes should be aligned with external costs as closely as possible, the level of the fuel tax that is aligned with external costs as close as possible should include the full marginal external cost of carbon emissions and the marginal costs of driving-related external costs. Following (Parry and Small., 2005[37]) the literature has adopted the practice of halving the driving-related external costs for calculating the fuel tax, on the evidence that about half of the reduction of fuel use following fuel tax increases is the result of reduced driving and half is the result of improved fuel economy which should not be reflected in the tax.

Under these considerations, (Parry and Small., 2005[37]) find that fuel taxes in the United States are much lower than they should be, whereas in the United Kingdom they find that taxes are too high. (Parry et al., 2014[36]) come to similar results for the United Kingdom and the United States and find that fuel taxes are higher than indicated in some countries including several European countries, about right in others, and too low in several others. (Parry et al., 2014[36]) note that their marginal external cost estimates are to be seen as low end, so that their results should not be taken to imply that fuel taxes should be reduced where they currently exceed the external cost estimates.

On the basis of her external cost estimates, (Santos, 2017[38]) finds that gasoline taxes in Belgium, Denmark, Finland, France, Germany, the Netherlands, Portugal, Sweden and

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[15] This principle is reflected in the European Union’s draft proposals for amending the Directive on the charging of heavy goods vehicles, http://en.euractiv.eu/wp-content/uploads/sites/2/2017/05/EU-road-charging-proposal.pdf

[16] See (Parry et al., 2014[36]) Ch 5, for quantification of these benefits (aside from welfare) on a country-by-country basis.

the United Kingdom and are fairly close to covering external costs (in the sense described above), but they are too low for diesel. In all other countries, fuel taxes are too low to reflect marginal external costs. For trucks, the gap between marginal external costs and taxes is larger than for diesel cars. A study for Sweden (Transport analysis, 2015[39]) finds that external costs, excluding congestion, are more than covered by taxes for gasoline cars in rural areas but not in urban areas, because of higher air pollution costs in the latter. For diesel cars, external costs are internalised more or less in rural areas, but not in urban contexts.

While increasing fuel taxes makes sense in many cases, it deserves re-iterating that several external costs of road transport relate to road use, more strongly than to fuel use. Gains can be achieved from pricing systems that address these external costs directly than attempting to manage then through fuel taxes. Even simple distance charging systems that align taxes with country-wide average congestion costs (which Box 1 argues are very crude approximations to true congestion charges or even to minimally differentiated distance charges) outperform fuel taxes in reducing congestion externalities. If distance charges differ between vehicles on the basis of their pollution profiles, they offer great potential to address pollution costs better than fuel taxes, although there is a role for fuel taxes that differ between fuel types (e.g., gasoline and diesel).

Box 1. The (Large) Gains from Differentiated Congestion Charging – An Illustration

Congestion is highly time and place-specific, and the benefits from congestion charging rise as the charges are more aligned with specific conditions. In this box, data from the United Kingdom’s guidance for cost-benefit analysis (WebTAG databook 2014) are augmented with a very simple representation of the demand for car use to gain some insight into the relative benefits from uniform and differentiated congestion charges.

Table 2 shows UK-wide estimates of marginal external congestion costs in five “congestion bands” as defined by five brackets of volume to network capacity ratios. It also shows the estimated shares of total traffic falling in these congestion bands in 2015, and the marginal external congestion costs within these bands (calculated at the traffic levels that would obtain with optimal congestion charges).

As can be seen, a very large share of traffic, nearly three quarters, takes place under free-flow or weakly congested conditions (bands 1 and 2). External congestion costs are also seen to rise strongly with volume-capacity ratios, reaching very high levels in congestion bands 4 and 5, which together apply to circa 9% of traffic. The table shows average traffic and congestion conditions for Great Britain; breaking down data by regions within Great Britain would show stronger differentiation of external congestion costs, with a highest value of EUR 2.55 per kilometre for “A roads” in London.

Table 1. Traffic volumes and marginal external congestion costs by congestion band at surplus-maximising uniform and differentiated taxes, Great Britain, 2015 (EUR cent; MECC = marginal external congestion cost

				tax	% change in surplus	tax	% change in surplus	tax	% change in surplus
1	< 0.25	0.427	1.00	1.00	0.142	1.96	0.01	1.67	0.08
2	[0.25, 0.5]	0.31	2.42	2.42	0.139	1.96	0.13	1.67	0.12
3	[0.5, 0.75]	0.172	8.17	8.17	0.272	1.96	0.11	1.67	0.1
4	[0.75, 1]	0.065	65.25	65.25	0.539	1.96	0.03	74.17	0.57
5	>1	0.024	139.33	139.33	0.041	1.96	0.01	74.17	0.32
All bands		1	10.25		0.40		0.05		0.33

Source: UK Department for Transport, WebTAG data book May 2014 (columns 1-4) and own calculations (columns 5-10)

By how much would the economic benefits from car use increase if the costs of congestion were reduced through the use of per-kilometre charges? And how do these benefits depend on the degree of differentiation of such charges between congestion bands? In order to shed some light on these issues, a simple model of car travel markets is constructed, where average time costs of travel increase linearly with traffic volumes in a congestion band, and where the demand for travel declines linearly with the generalised price (the sum of time costs and per kilometre charges) of travel.

This simple linear structure is calibrated to the data for Great Britain shown in Table 2, assuming a generalised own price elasticity of travel demand of -0.35 in congestion band 1, rising to -0.15 in band 5 (in steps of -0.05) and zero cross-price elasticities between bands, and assuming a value of time of EUR 5 per hour in band 1 rising to EUR 30 per hour in band 5 (in steps of EUR 5).

The changes in economic benefits (‘surplus’) in each band are calculated for three scenarios:

- *Maximal differentiation* of charges, by setting the charge equal to the marginal external congestion costs in each band;
- *Uniform charges* across congestion bands, set at the level that generates the highest gain in surplus compared to the situation where there are no per kilometre charges;
- *Simple differentiation of charges* across congestion bands, set at the level that generates the highest gain in surplus compared to the situation where there are no per kilometre charges.*

Table 2 shows the changes in surplus in these scenarios, comparing to the situation with no per kilometre charges. The levels of change (e.g., 0.4% in the maximal differentiation scenario) in themselves are not of particular interest as they depend strongly on the chosen (linear) form of the cost and demand functions. However, the differences between scenarios allow meaningful interpretation. Some insights are as follows:

- A uniform kilometre charge across congestion bands, set at the welfare-maximising level, produces only 13% of the gain compared to the maximal differentiation scenario. This reflects the very large differences in congestion levels across congestion bands, which a single uniform charge is very poor at capturing.
- Simple differentiation of the kilometre charge between the “low congestion” bands (1 through 3) and the “high congestion” bands (4 and 5) allows capturing more than 80% of the gain from the maximally differentiated charges. This suggests that simple charging systems, that manage to set high charges (around EUR 0.9/km in the example) in highly congested areas, can yield substantial gains while being relatively easy to implement and understand.
- It is worth noting that the surplus-maximising uniform charge equals EUR 0.0196 per kilometre, which is less than a quarter of the weighted average external congestion cost of around EUR 0.10 per kilometre. This reflects the large weight of congestion bands 1 and 2 in total traffic: higher charges in these bands would lead to welfare losses. Implementing a charge of EUR 0.10 per kilometre would lead to a welfare loss in congestion bands 1 and 2 that is larger than the gains in the more congested bands, resulting in a net welfare loss (not shown in the table).
- If the revenue raised through the uniform congestion charge were to have a higher weight in total surplus than the direct consumer surplus from

travel, for example because driving is a tax base with relatively low economic costs, then higher uniform charges are justified. Given that a relatively large share of the tax base is formed by travel in low- or no congestion, even small positive weights on revenue will lead to larger welfare gains.

* The magnitudes of the elasticities and values of time in the calculations are differentiated around central values of -0.25 and EUR 10, respectively, to reflect that travel on average is more price elastic and values of time are lower where there is less congestion. Precise empirical evidence on the size of the differences is not available. Sensitivity analysis shows that reducing the degree of differentiation around the same average, leads to lower welfare gains from differentiated congestion charges in the less congested bands and higher gains where congestion is severe, and to lower welfare gains from uniform pricing (and sometimes losses in the low congestion bands). However, the share of the total gain that is obtained from uniform prices is not very sensitive to the degree of differentiation of time values and elasticities. Assuming that time values equal EUR 10 throughout and the elasticity is -0.25 everywhere, the gain from the optimal uniform charge (now 5.5 GBP pence) is 9% of the gain of the differentiated charges, as compared to 13% in Table 1.

Box 2. Costs of electronic tolling systems

Different technological solutions exist for implementing electronic tolling systems, including dedicated road-side communications (DRSC) and GPS-GSM-based systems. The choice between them depends on what objectives are set for a particular system and how these affect system requirements (geographical scope, number of tolling points, nature of the charge, etc.).

(ITF, 2010[25]), drawing upon expert opinion, reports that congestion charging schemes require costly investments and are expensive to operate, with operating costs generally outweighing start-up costs. Ensuring public support requires very high reliability and accommodating occasional users, and this increases costs. Costs are also affected by interoperability requirements, and since incentives for interoperability are weak for individual systems, higher level authorities may need to mandate it. Still according to the (ITF, 2010[25]), in Singapore, London and Stockholm, the costs of the system represent 15 to 30% of the gross charge income, and expert opinion is that the figure cannot be compressed to below around 10%. Of course, cost to revenue ratios provide limited information on system costs, dependent as they are on toll levels and traffic volumes.

(Walker, 2011[40]) finds cost to revenue ratios of 42% for London, 21% for Stockholm, and 20 to 30% for Singapore. (LogicaCMG, CapGemini and ID, 2005[41]) suggest a range of 50% to 57% for London. (Numrich,, Ruja and Voss, 2012[42]) report cost to revenue ratios of 6% to 20% for Norwegian tolling systems. For heavy goods tolling with satellite based systems in the EU, the estimated ratio is between 12% and 25%. The remuneration of the private partner implementing the truck tolling system in Germany amounted to around 20% of revenues from 2005 through 2007 but this has declined to 10 to 11% in 2010 and 2011; enforcement costs appear not to be included in this figure, however. (Walker, 2011[40]) finds a cost-revenue ratio between 12% and 25% for the German truck tolling system, and (LogicaCMG, CapGemini and ID, 2005[41]) puts it between 19% and 23%. Figures for Austria and Switzerland are lower, however, at 11% and 6% respectively according to (Walker, 2011[40]) and 9% to 12% and 7% to 9% according to (LogicaCMG, CapGemini and ID, 2005[41])

An in-depth study of the costs of tolling systems (Fleming, 2012[43]) argues that historical data for tolling systems in the United States, with cost-revenue ratios from 20% to 30% are not good indicators of the ratios for efficiently-run systems deploying the most recent technology. For such systems, cost-revenue ratios can be reduced to 5 to 8%, depending on the level of tolls. The same study provides cost-revenue estimates for gasoline taxes, arguing that they are well above the conventional wisdom value of 1% or less*, and could be as high as 5%. (Kirk and Levinson, 2016[44]) review a number of electronic tolling systems and find that administration and enforcement costs range from 5% to 13% of collected revenue.

The emerging message is that electronic tolls historically have been a relatively expensive way of raising revenue. However, efficiently run operations using the technology that is best adapted to the objectives of a tolling system and to the particular circumstances in which it is introduced, seem to be able to attain cost-revenue estimates in the 5 to 10% range. Costs can also be reduced by avoiding complexity (limiting the dependence of tolls on vehicle and user characteristics). Furthermore, as tolling becomes more widespread and interoperability is ensured, the share of occasional users for each tolling system will come down, and this too limits costs. Finally, simple distance charges do not require sophisticated electronic tolling technology, and therefore can be relatively cheap to implement.

In summary, the evidence suggests that at the lower bound of cost estimates, tolling becomes an appealing option in many circumstances, if fuel tax costs range between ca. 1% and 5% of revenue and fuel taxes are inferior from a revenue-raising point of view (driving is a less elastic tax base than fuel use) and from an externality-management point of view (as some of the main external costs are more closely linked to driving than to fuel use).

*Evidence reviewed in (van Essen et al., 2012[45]) puts the administration and compliance costs for fuel taxes in the Czech Republic at 0.64% of revenue, and at 6.5% for motor vehicle taxes (likely at least partly a consequence of the lower revenue from motor vehicle taxes). The same study reports evidence of administration costs of excise taxes in the United Kingdom of 0.45% of revenue (lower than for corporate income taxes – 2.7%, VAT – 4.8%, and personal income taxes – 4.9%).

4. Transport taxation and pricing in a broader context

This paper focusses on the role of taxes to curb external costs so as to contribute to more efficient road transport prices. But transport taxes need to be seen in a broader context. This section, first, points out that other sources of inefficient pricing of car use exist, and these too need to be addressed. Second, it discusses the interactions between transport prices and urban land use and, third, considers the linkages of transport taxes with the broader fiscal system.

4.1. Implicit subsidies and price misalignment[17]

Full alignment of prices with marginal social costs, which is the basic condition for efficient pricing, requires removing discrepancies between these costs and transport prices, other than non-internalised external costs. Some common sources of discrepancies derive from the tax treatment of company car use and of commuting, and the pricing and tax treatment of parking. These forms of inefficient pricing are discussed very briefly in the next paragraphs.

(Harding, 2014[45])] provides a detailed analysis of preferential tax treatment of company cars in 26 countries. In many of these countries, the share of company cars in the vehicle fleet is large and the tax preference significant in the sense that the imputed income from access to company cars is taxed at much lower rates than regular income, which tends to induce households to opt for car commuting and car use more often than would have been the case without the preferential treatment. In addition, fuel used in company cars is sometimes available for free, except for the tax on imputed income. This means users face low marginal costs of driving a car, also leading to excessive car use and choices for larger cars than would have been made in absence of the company car advantages. This

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[17] This section does not discuss fossil fuel subsidies, even if those still exist and result in lower transport fuel prices in a number of countries. (OECD, 2015[100]) and www.oecd.org/site/tadffss/ provide data on and analysis of this topic.

exacerbates the inefficiencies from misalignment of regular road transport taxes with marginal external costs. Removing preferential treatment of company cars therefore is a key component of tax reforms that aim for more efficient transport prices.

In several countries, the costs of car commuting are at least partly deductible from taxable household income. Although this does not in itself necessarily modify the marginal cost of a trip, infra-marginal effects likely induce households to opt for car commuting more often than would have been the case if car commuting costs would not have been deductible. (Harding, 2014[45]) and (Roy, 2014[46])provide estimates of the size of the implicit subsidy for car commuting and the potential negative side-effects on the environment and on other external costs of transport.

Low or zero prices for parking are a further, and often major, source of under-pricing of road transport, particularly for urban driving. In addition, regulations related to zoning and construction frequently lead to more ample supply of parking than likely would be provided in less regulated markets, contributing further to low urban trip costs. Employer-provided parking often is a form of untaxed or lower taxed income. (Shoup, 2011[47]) and (Inci, 2015[48]) provide in-depth overviews of the various inefficiencies related to parking and their effects.

Using a stylised model of urban transport with numerical illustrations for Brussels, (Proost and Van Dender, 2001[49]) that removing free parking is nearly as important to improving the efficiency of urban transport systems as aligning prices with external costs. Removing free parking by itself generates one third of the welfare improvement from full marginal social cost pricing, simply because parking costs constitute a large share of total car trip costs in urban environments but these costs are often not charged for.

Building on the same model, (Calthrop, Proost and Van Dender, 2000[50])find that removing free parking has particularly pronounced effects on modal split, a result also noted in the evidence reviewed in (Tikoudis et al., 2017[51]); (Calthrop, Proost and Van Dender, 2000[50]) also suggest that, while parking charges can help address congestion if more direct congestion charges are not feasible and *vice versa*, it is much more efficient to tackle both problems through separate instruments. There hence is clear evidence that parking supply and parking pricing are not minor issues and should not be ignored in policy packages aiming for more efficient car use in urban environments.

Besides car use, prices of other transport modes are often inefficient as well. These issues are not discussed in this paper. (Parry and Small, 2009[52]) and (Proost and Van Dender, 2008[53]) discuss pricing principles in road public transport and the interaction with road transport externalities more broadly. (Nash, 2005[54]) provides insight into the efficient structure of charges for rail transport, with applications to Europe. For a discussion of taxation of aviation and maritime transport, see (Keen, Parry and Strand, 2013[55]). The discussion in this paper largely abstracts from the impact that transport prices may have on households' and firms' location choices and the associated environmental outcomes, even if it is recognised that low prices can induce transport-intensive and car-oriented location choices in particular in the long run. There is a considerable literature that investigates interactions between policy, land use and its environmental impacts, which is reviewed and further developed in (Tikoudis et al., 2017[51]) and which is touched upon only briefly here.

Concerns about interactions between transport taxation and urban land use arise mainly from the potential impact of low transport prices on urban sprawl[18] and the associated negative effects (such as reduced biodiversity, higher emissions from transport fuel use and energy use in homes, reduced aesthetic value, higher costs of public infrastructure, etc.). Conversely, the exacerbating effect of urban sprawl on transport volumes and the external costs that come with them are often criticised as well. Urban areas are growing everywhere, both in the sense that they are home to an increasing share of populations and in the sense that they become larger. As urban areas tend to grow faster than urban populations, population densities fall over the long run and cities sprawl (Gordon and Cox, 2012[56]).

While sprawl is most often viewed pejoratively, it is sometimes also argued to have its upsides. For example, sprawl can be seen as an adaptation mechanism to cope with the congestion of transport networks and other shared infrastructure and public goods that come with rising agglomeration of economic activity. (Anas, 2010[57]) shows that commuting times are higher in more spread-out cities, but not *much* larger, because of higher congestion levels in denser cities: doubling city size increases commuting times by 10% on average. Also, average commuting times hardly rise over time and are virtually the same in the core and peripheries of large urban areas in the United States (Gordon and Cox, 2012[56]), Table 7). In this sense, "Sprawl is a friend. It keeps rising congestion in check." (Anas, 2010[57]). Such adaptation to sprawl obviously is not optimal when negative external costs remain un-internalised, but the economic performance of cities is nevertheless stronger with second-best adaptation than without adaptation. This matters as cities are increasingly the drivers of economic growth and development, through agglomeration economies.

A second reason why sprawl is not universally bad is that it caters to household preferences for dwelling types (single family detached housing), so contributes more to consumer welfare than other types of housing, all else equal. Of course, tastes can change over time, they differ within the population, and housing could be partly a positional good. Nevertheless, overall welfare may be reduced if external environmental costs of households' location decisions are not reflected in prices.

How do transport policies and infrastructure more broadly affect the use of urban land? Transport infrastructure and service supply strongly shape land-use patterns. Where road networks are more spread out and more connected, the transport costs associated with living further from workplaces decline. This means that, as incomes rise, households are inclined to own and use cars and to live in larger homes on larger lots of land. As sprawl continues and densities of demand per unit of land decline, public transport becomes less competitive, which drives up the costs of supplying high quality collective transport, so reinforcing car-dependency. These effects are so strong that sprawl is sometimes identified with car-oriented development e.g., (Gordon and Cox, 2012[56]).

Places where core transport networks were in place before motorisation took off (of which there are more in Europe), and where larger shares of infrastructure and service funding go to public transport, will sprawl less or at least more slowly, but rising incomes and expanding road networks will nevertheless induce sprawl. The pressure resulting from rising incomes towards more sprawled development is strong see (Bruegmann R.,

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[18] Urban sprawl is loosely defined as less dense and more fragmented land use. See (Tikoudis et al., 2017[51])for an in-depth discussion.

2005[58]) (Oueslati, W.; Alvanides, S. ; Garrod, G., 2015[59]), a useful reminder that sprawl is also the result of household choices and that less developed areas may be more prone to urban sprawl in the future.

Tax policies feature among the oft-quoted factors affecting land use outcomes. For example, where taxes on transport fuel and on household energy use in general are comparatively low, as is the case in the United States, adopting car-oriented lifestyles and living in larger houses is less expensive (Borck and Brueckner, 2016[60]). show that an optimal tax structure which reflects the external costs from energy use in transport and housing (but excluding congestion costs) may generate a more compact city with a lower level of emissions per capita.

Low vehicle taxes amplify car reliance, as do income tax deductibility of commuting expenses and generous company car provisions. In addition, several European countries and the United States provide favourable income tax treatment of home ownership, which reduces the cost of investment in housing compared to other assets, so tends to inflate the demand for housing. Mortgage guarantees, widespread in the United States, strengthen this bias. In sum, while the effect of each of these tax policies separately on land use may be limited and at any rate is constrained by land use policies (at least in cases where these are centralised, (see (Blöchliger et al., 2017[61])) , the combined impact of tax policies on land use is potentially large.

Evidence on the effect of transport taxes on housing prices in areas with longer commutes is mixed (Langer, A., Vikram M. and Clifford W., 2017[62]); (Molloy, 2013[63]); (Blake, 2016[64])). Results depend critically on the responsiveness of housing supply, and this strongly depends on geographical and regulatory features (Saiz, 2010[65]).

Location responses to relative price changes (e.g., via taxation) likely take a long time to materialise, because residential location choices are characterised by high switching costs. Depending on the share of income spent on commuting, households are very unlikely to move location only because of an increase in gasoline or other commuting costs. However, households that are intending to move are likely to consider changes in transportation costs in their location choice (cf. (Molloy, 2013[63])). If households in suburban areas move less often than households in city centres, the potential densification effect of cities as a response to transport taxes will be limited.

Tax policies affect land use but, conversely, what effects do land use and land use policies have on transport volumes? Will denser cities incentivise residents to more or less driving, and by how much? State-of-the art econometric work for the United States (e.g., (Brownstone, and Golob, 2009[66]); (Kim and Brownstone, 2013[67]); (Duranton G. and Turner, 2015[68]); (Bento, 2005[69]) – ; (Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70])see Annex 2 for a more detailed review) finds that urban form only weakly affects travel behaviour. This indicates that using land use policies to reduce the external costs from transport is likely to have only limited effects – at least in countries with relatively well developed transport infrastructure and services. Policies, including taxation, that target travel behaviour directly are likely to be more effective for managing the external costs from transportation.

To conclude, the evidence suggests that the transport tax principles laid out in this paper will have some effect on land use, but that nevertheless they can mainly be thought of as encouraging efficient transportation choices for given land-use and given infrastructure supply patterns, and providing signals for improved infrastructure and system design choices in the long run. Decisions on infrastructure supply, e.g., road network design and capacity (see (Small, and Chen Feng Ng, 2014[71])) and regulations, e.g., minimum parking requirements, appear to be stronger determinants of the degree of car-oriented development than pricing. These decisions are particularly important in countries where currently infrastructure is less developed. Land use considerations do not so much modify the nature of the principles for efficient urban transport taxation as further highlight their importance.

4.2. Fiscal considerations

A proper evaluation of any tax, including environmental ones, ought to consider linkages with the broader fiscal system. This section briefly discusses how fiscal considerations might affect the efficient level of transportation taxes and whether highway budgets should be funded from transport taxes or the general budget.

4.2.1. Another look at efficient tax levels

It is a core tax policy objective to raise revenues at the lowest overall cost or distortion to the economy. Basic principles from public finance on how to achieve this provide the following general guidance.

First, final goods consumed by households (including passenger vehicles and the fuels they use) may be legitimate bases of taxation on purely fiscal grounds, but intermediate inputs such as commercial trucks and their fuels are not. Taxing intermediate inputs at rates higher than those needed to reflect externalities would cause firms to use too little of the taxed input, and too much of other inputs, which would inefficiently drive up production costs. This principle is embodied in the normal procedures for value-added tax (VAT) systems where taxes paid on intermediate inputs are rebated. As for consumer goods, VAT (or general sales taxes) should be applied to prices that fully reflect marginal social costs, i.e., both supply and external costs: if excise taxes are used to reflect external costs, VAT should also be levied over the excise.

Second, when environmental impacts are internalised through specific taxes, then revenues from general consumer taxes should be mostly raised in ways that do not alter relative consumer prices (to avoid distorting the pattern of household consumption). This is the principle adopted in this paper: excise taxes can reflect external costs, which are additional to neutral revenue-raising taxes (VAT or general sales taxes). However, there are some subtleties to this simple rule of thumb.

The traditional Ramsey tax framework which focussed on distortions to the labour – leisure margin from labour and general consumption taxes, suggested that extra taxation of goods that are relative complements for leisure is potentially warranted, the more so the more inelastic their tax base. This is different from the neutrality principle of revenue-raising consumption taxes, as it says that goods that tend to be consumed together with leisure (untaxed, non-marketed activities) should be taxed relatively highly. One problem with this rule is to give it empirical content, as obtaining reliable estimates of the product-leisure cross-price elasticities needed to operationalise this principle was always challenging.[19]

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[19] One application to gasoline taxes in the United States (West and Roberton, 2004[94]) put the Ramsey tax well above the marginal external costs.

A second concern with the traditional Ramsey tax argument is that, since the mid-1990s, awareness has grown of the critical importance of capturing the full range of distortions created by broader taxes, not just excessive leisure but also, for example, excessive informality and spending on tax preferred goods like fringe benefits and housing, shifting between occupations, and labour migration (e.g., (Feldstein, 1995[72]); (1999[73]) The combined effect of all of these responses is captured in estimates of the responsiveness of the tax base to changes in tax rates. The implications for environmental taxes are that the efficiency gains from recycling revenues in broader tax reductions are substantially larger than implied by the traditional Ramsey tax framework and that net fiscal considerations can significantly increase the efficiency gains from environmental taxes.

In theory, this may warrant heavier taxation than implied by environmental considerations alone, especially in countries where broader tax bases are constrained by a lot of tax avoidance and evasion or where informality is widespread. Since fiscal objectives are generally met more efficiently by taxing immobile bases, this points towards relatively high taxes (compared to other consumption on average) on vehicles, to some extent driving, and to a lesser extent fuel (as the vehicle taxes cannot be avoided by using vehicles less intensively or using more fuel-efficient vehicles, and as driving is less elastic than fuel use).[20]

The discussion above suggests that neutral VAT combined with excise taxes can be seen as a lower bound to ideal transport taxes. In combination with arguments that under fully flexible income tax schedules, there is no reason in general to deviate from taxes equal to marginal external costs (Fosgerau and Van Dender, 2013[10]); (Jacobs and de Mooij, 2015[74]) and with the observation that current taxes are often well below marginal external costs, this supports the rule of thumb adopted in this paper that striving for better alignment of specific transport taxes with marginal external costs is a key guiding policy principle.

4.2.2. Earmarking

In most countries, revenues from road fuel taxes go to the general budget, with highway spending competing with health, education, social security and other programs for funds. However, in some cases (e.g., the United States), these revenues are earmarked for highway and transit projects. One problem with earmarking is that there is no necessary relationship between the efficient level of the tax (as described above) and the efficient level of spending on transportation.[21] If tax rates are set according to transportation spending they are likely wrong from an environmental perspective, while if rates are set from an environmental perspective, highway spending levels are likely inefficient under strict earmarking.

(OECD, 2017[16]) discusses the role of revenue raising and earmarking in environmental taxation in general, suggesting that earmarking becomes less politically expedient as higher tax levels and larger revenues are envisaged. However, transparency on and

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[20] One caveat here is that fuel taxes become more appealing on fiscal grounds if high vehicle taxes start to encourage people to purchase vehicles from other countries.

[21] In practice, in the United States currently specific transport taxes are lower than indicated by the principles set out in this paper, and they also generate insufficient revenue for highway spending, which has drawn from general revenue in the recent past.

political commitments to particular spending patterns can improve public support for tax reform strongly.

5. The slowly changing landscape of road transport taxation

The current practice of road transport taxation [22] varies with countries' and regions' specific economic, institutional and political conditions, and does not necessarily correspond very well with the design principles put forward in this paper – in particular those principles relating to the usage of taxes for environmental and mobility goals. As the discussion of the previous section suggests, there is not necessarily a strong trade-off between transport taxes that effectively curb negative external costs of road transport and transport taxes that contribute to revenue-raising and do so at relatively limited economic costs. Nevertheless, reforming transport tax systems may be difficult for example because of adverse distributional impacts, whether real or perceived.[23]

This section takes a look at changes in approaches to transport taxation in Europe and in the United States. It finds that the structure of transport taxes changes only slowly over time. In Europe, reliance on distance and congestion charges is rising, although fuel taxes continue to be the dominant source of revenue by far. In the United States, the use of fuel taxes as user charges has declined over time at the Federal level. This has led to a *de facto* shift towards general revenue funding of infrastructure. More recently, there is increased State initiative to raise revenue through a variety of instruments, perhaps signalling gradual devolution of transport taxation and funding to the State level, but with some dilution of the user charging principle.

The discussion below suggests that reform of transport taxation is mainly driven by revenue-raising concerns and potentially tax competition. Such reform often can and sometimes does lead to better management of the external costs of transport, for example when fuel taxes better reflect the costs of carbon emissions and of differences in air pollution among fuels, or when distance charges are implemented more widely. Better use of transport taxes for pursuing mobility and environmental goals appears to be more likely to result when stakeholders are ready to seize windows of opportunity for policy change created by revenue concerns.

6. Europe

Transport taxes in Europe have mainly taken the form of vehicle taxes and, in particular, fuel taxes. These taxes tend to be higher than in other parts of the world, and the revenues most often accrue to the general budget instead of being earmarked. Some countries also continue to use fees for access to the public road network over a limited period of time ('vignettes'). In addition, a number of European countries have a tradition of using barrier-based tolling systems on parts of the road network. In France, for example, tolls

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[22] See (De Borger, 2017[26]), for more in-depth treatment of some of the themes addressed in this section.

[23] Incidence of transport taxes is not discussed in this paper. (Flues and Thomas, 2015[109]) and (Sterner, 2012[104])show that fuel tax incidence differs between countries, that it more often is progressive where average incomes are lower, but not necessarily regressive when average incomes are high.

are levied on mostly interurban sections of concessionary highways. Portugal, Spain and Italy also levy highway tolls.

In the European Union, excise taxes on energy products (mineral oils, coal, natural gas and electricity) have been constrained since 2004 by the Energy Taxation Directive (2003/96/EC). The Directive stipulates minimum rates for excise duties for unleaded gasoline of EUR 359 per 1000 litres and EUR 330 per 1000 litres for diesel (gasoil) used in transport. The minimum rate on gasoil for other use than as a propellant is EUR 21 per 1000 litres. Excise rates actually charged differ between member states. For gasoline, they range from just over the minimum rate, to EUR 766 per 1000 litres in the Netherlands; for diesel actual rates are generally lower and closer to the minimum but reach EUR 674 in the United Kingdom.

Low diesel rates may indicate stronger tax competition for the diesel tax base, given the larger autonomy of trucks compared to passenger cars, than for gasoline or stronger concerns about competitiveness of trucking industries. In 2011, the European Commission discussed a revision of the Energy Taxation Directive, which distinguished a CO_2-related component and an energy-related component in the excise tax. Applying this principle would have implied a minimum rate on diesel of EUR 390 if the minimum rate on gasoline would have been EUR 359 per 1000 litres.[24] While this reform is not imminent, there is a tendency at the country level in recent years to increase diesel taxes more strongly than gasoline taxes (OECD, 2018[75]). This reduces or removes the relatively low taxes on diesel, which as noted above are not justifiable on climate or environmental grounds.

Charges for the use of road infrastructure by heavy goods vehicles are regulated at the European level in Directive 2011/76/EU, which amends earlier law on the topic.[25] The Directive puts constraints on member states' use of distance charges and vignettes for freight vehicles weighing 3.5 tonnes or more. Countries are allowed to require the use of vignettes, which give access to the principal road network for a given period of time, or introduce distance charges, but they cannot implement both instruments at the same time.

The European Union also requires that charges be non-discriminatory, and the level of tolls is constrained in that revenues should not exceed the costs of developing, constructing and operating the network. This implies an upper bound on average tolls, while allowing for differentiation of tolls in line with external costs of pollution, noise and congestion. In practice, however, differentiation is limited and refers to environmental characteristics only but not to congestion.[26] Policy preference is given to using revenues from vignettes or distance charges for developing sustainable transport, but no obligation exists.

Going forward, the European Commission has expressed the intention to reform transport taxation in ways that have the potential to greatly enhance the effectiveness of charging to reflect external costs, while maintaining revenues from the sector as the fuel tax base progressively erodes. For example, it encourages replacement of vignettes by distance charges which can align better with the principle of fair and efficient pricing of transport,

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[24] http://ec.europa.eu/taxation_customs/resources/documents/taxation/presentation_energy_en.pdf

[25] http://ec.europa.eu/transport/modes/road/road_charging/charging_hgv_en.htm

[26] The tolling system in the Czech republic sets higher charges on Friday afternoons, for heavy goods vehicles.

especially if distance charges also depend on vehicle pollution profiles (as is the case for most existing distance charges in the European Union). Because congestion charges are the most controversial element, the idea is to put an upper bound on the factor by which charges for road use in peak periods in congested areas can exceed charges when there is not a lot of congestion.

Also at the level of the member states, there is a gradual evolution towards distance charging on highways or major roads, particularly for trucks, since the early 2000s, although countries continue to rely strongly on fuel taxes. These more recently introduced tolling systems are electronic and do not use physical barriers, they are mostly limited to trucks (at least for now) and tolls depend on weight and emission profiles of vehicles. In several cases, the toll revenues are hypothecated for spending on transport infrastructure.

Switzerland introduced distance charges for trucks in 2001, abolishing the vignette at the same time but raising net tax levels considerably (see (OECD, 2005[76])for a discussion of the policy context). Austria followed suit in 2004 and Germany, after some delay, in 2005. The Czech Republic introduced electronic distance charges in 2007, Slovakia in 2010, Poland in 2011, Hungary in 2013 and Belgium in 2016.[27] Some countries, e.g., Belgium, are also working toward introduction of distance charges for passenger vehicles.

Limited social and political support can hinder reform of transport taxation. For example, intentions to introduce distance charges were abandoned in a more or less advanced stage of planning in at least two European countries. The Netherlands was preparing to introduce distance charges – and in a later stage congestion charges – for trucks and for cars in 2009 but ultimately decided against it (Jonkman and Takens, 2011[77]). In 2013, France decided not to introduce distance charges for trucks on non-tolled main roads despite a decision to do so and despite the necessary equipment being in place.

While distance charges can and to some extent do lead to more effective environmental and mobility management, their introduction is perhaps better understood as the result of tax competition among neighbouring countries. (Mandell and Proost, 2016[78])argue that truck tolling is ‘contagious’: a country that introduces a distance charge can generate extra revenue by reducing its tax on diesel to attract a larger tax base; neighbouring countries then have an incentive to reduce their diesel tax and introduce distance charges. The result is a gradual spread of distance charging and slower growth of diesel taxes.

It can be observed an increasing number of countries in Europe adopt distance charges (see Table 2) and more can be expected to do so in the future, possibly also for passenger cars. At the same time, countries that adopted distance charges do not appear to have reduced fuel taxes (see Table 3) in contrast to what the tax competition argument above suggests (but fuel taxes might have risen in the absence of distance charges). Diesel taxes apply to passenger cars and not to trucks alone, so the tax competition effect is mitigated by the revenue raising effect (as is also suggested by the increase of excise duties in two of the four countries with distance charges in Table 3) ; passenger cars can also cross borders but do so less frequently than trucks, and they carry less fuel on average.

Table 2 shows the level and the structure of taxes and charges on a truck making a trip of “representative” characteristics for a set of European countries, as well as the change in these taxes between 1998 and 2008. Total taxes consists of vehicle taxes (assigned to a

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[27] Although buses and coaches are included in Austria, the Czech Republic, Poland and Slovakia.

trip assuming 276 annual trips), fuel excise duties, vignette charges, tolls and distance charges. The countries are put in three groups: four countries that introduced electronic distance charging between 1998 and 2008 (Switzerland, Austria, Germany and Czech Republic)[28] four countries that have relied on barrier-based tolling mechanisms for highways for a longer period of time (France, Portugal, Italy and Spain), and seven countries that had not introduced tolls by 2008 (United Kingdom, Sweden, Denmark, Netherlands, Hungary, Belgium and Finland). Within groups, countries are ranked by declining level of charges in 2008.

Table 2. The impact of the introduction of electronic tolls on total charges and taxes: level, change and composition of charges and taxes for a “representative trip by truck” in selected EU countries and Switzerland.

"Representative trip”: vehicle charges distributed over 276 days, 128 litre diesel consumption, 400km trip of which 200km on toll roads in countries where tolling is common, carrying 40 tonnes (relevant for Switzerland where charges depend on weight).

	Electronic distance charge introduced in:	Ratio of taxes and charges per trip: 2008/1998	Charges and taxes per trip, 1998 (2010 prices)	Compostion of per trip charges and taxes			
				% vehicle charges	% fuel excise taxes	% vignette	% tolls and distance charges
Switzerland	2001	3.62	327.6	2.5	19.2	0	78.3
Austria	2004	1.29	127.6	5.3	37	0	57.7
Germany	2005	1.49	91.4	4.4	66.8	0	28.9
Czech Republic	2007	2.05	85.4	6	55.6	0	38.4
France		0.97	98.1	2.7	51.7	0	45.6
Portugal		1.82	87.9	3.5	53.3	0	43.2
Italy		0.88	79.9	4.3	66	0	29.7
Spain		0.83	78.8	4.8	49.8	0	45.4
United Kingdom		0.95	109	8.3	91.7	0	0
Sweden		1.13	66.1	12.9	80.4	6.7	0
Denmark		1.02	61.6	4.1	88.3	7.6	0
Netherlands		1.04	59.5	8.5	83.7	7.8	0
Hungary		0.37	58.9	18.9	76	5.1	0
Belgium		0.85	48.4	8.1	83.8	8.2	0
Finland		0.9	44.1	20	80	0	0

Source: own calculations based on ITF Road Taxation Database, http://internationaltransportforum.org/statistics/taxation/index.html
Note: Belgium, Hungary, Poland, Portugal and Slovakia have introduced electronic distance based charges, but are not yet included as such in the most recent available vintage of the ITF Road Taxation Database. See https://ec.europa.eu/transport/sites/transport/files/modes/road/road_charging/doc/hgv_charging.jpgfor the status of HGV road charging in the European Union.

Some observations from Table 2 are that:

a) The introduction of electronic distance charging has led to strong increases in per trip cost; the increase is particularly large in Switzerland, which is not constrained by EU legislation;

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[28] Poland introduced such charges in 2011 but is not included in the table due to lack of data.

b) With the exception of Portugal and to a smaller degree Sweden, charges and taxes (excluding network-wide distance charges) are not higher in real terms in 2008 than they were in 1998;

c) Charges and taxes are highest on average where there are network-wide distance charges and lowest on average where there are no such charges, except in the UK which has particularly high diesel excise duties as well as relatively high vehicle charges;

d) Diesel excise duties dominate the tax and charge burden across all countries considered, except in Austria and Switzerland where network-wide distance charges are high; in other countries that charge tolls or distance charges, excise duties nevertheless represent 50% to 66% of total charges, and where there are no tolls the share is 80% to 90%.

While Table 2 shows that electronic distance charges have led to higher overall taxes on road transport there is little evidence that they have also led to lower excise taxes. Table 3 shows the ratio of per litre diesel excise duty in 2008 and 2012 compared to 1998, for the same countries as in Table 2. Excise is lower in the more recent years in several countries with no distance charges, whereas they are similar or higher – particularly in 2012, perhaps because on fiscal consolidation grounds – in countries that introduced distance charges.

Table 3. Ratio of diesel excise duty in EU countries, 2008 over 1998 and 2012 over 1998

		2008 excise / 1998 excise	2012 excise / 1998 excise
Distance-based charges	Switzerland	0.94	1.21
	Austria	1.05	1.07
	Germany	1.26	1.2
	Czech Republic	1.03	1.52
Distance- based tolls	France	0.89	0.93
	Portugal	1.01	0.96
	Italy	0.83	0.83
	Spain	0.85	0.86
	United Kingdom	0.94	0.81
No distance-based component	Sweden	1.21	1.42
	Denmark	1.03	1.01
	Netherlands	1.05	1.11
	Hungary	0.6	0.61
	Belgium	0.86	1.09
	Finland	0.88	1.41

Source:: own calculations based on ITF Road Taxation Database, http://internationaltransportforum.org/statistics/taxation/index.html

Note: Belgium, Hungary, Poland, Portugal and Slovakia have introduced electronic distance based charges, but are not yet included as such in the most recent available vintage of the ITF Road Taxation Database. See https://ec.europa.eu/transport/sites/transport/files/modes/road/road_charging/doc/hgv_charging.jpg for the statues of HGV road charging in the European Union.

While tax competition is a plausible explanation for the gradual adoption of distance charging, it does not explain why such competition did not take place earlier, or at least was more muted, with vignettes. Perhaps the constraints of EU legislation are stricter for vignettes than for distance charges (as is suggested by the observation that net taxes tend to increase where vignettes are replaced by distance charges).[29] Also, tax competition may not be the only reason for the adoption of electronic-distance charging. The charges are also used for transport and environmental management reasons in many countries, and they are superior in this respect to blunt instruments like vignettes.

Regulating distance charges can make sense, if tax competition is the key driver of the introduction of distance charge, as there is no guarantee that unregulated shifts result in increased overall welfare (Mandell and Proost, 2016[78]).

Competition for tax revenue from transport is not limited to trucks, and it can therefore be expected that distance charging will gradually extend to passenger car traffic. Germany in fact is taking initiatives in this direction, although the toll is to take the form of a vignette (i.e., an annual charge independent of use) rather than an electronic distance charge. On the argumentation above, such a design choice may indicate a revenue interest more than a transport or environment interest.[30]

Notwithstanding debates and more or less advanced plans for new charging mechanisms in some countries, change in the broad approach to passenger car taxation in Europe has been limited. Some of these limited changes relate to congestion charges, reductions in the favourable tax treatment of company cars, and differentiated ownership or purchase taxes. Congestion charges have been introduced in a few cities, with London, Stockholm and Milan the best known examples. These systems have significant local impacts and generate net benefits by several accounts, e.g., (Santos and Gordon, 2006[79]), (Raux, 2005[80]) and (2012[81]), although less favourable accounts exist, e.g., (Prud'homme and Bocajero, 2005[82])).

The favourable tax treatment of company cars remains widespread (Harding, 2014[45]) but has been scaled back in some countries (e.g., the UK, where this has had a marked impact on commuting mode choice, see (Le Vine and Jones, 2012[83])) and is the subject of debate in some countries at present.

Vehicle ownership taxes are increasingly differentiated according to vehicles' CO_2 emissions rating, a practice that is known to affect purchase decisions but of which it is less clear that it generates net benefits. (Braathen, 2009[84]) (2011[85]) provides an overview of purchase and recurrent ownership taxes on vehicles, translating them into implicit tax rates per tonne of CO_2. These implicit tax rates are sometimes very high and are often higher for less fuel efficient vehicles, indicating that CO_2-abatement obtained through these taxes is relatively costly, and sometimes absolutely very costly. Differentiated ownership taxes may have other justifications than CO_2-abatement, however.

7. United States

Fuel taxes in the United States are lower than those observed in Europe. On 1 April 2015, average gasoline taxes at the state level in the United States equalled 48.85 cents per gallon, consisting of 20.70 cents (42.4%) state excise taxes, 9.76 cents (19.8%) other state

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[29] A referee concurs with this observation, noting that "Indeed, Directive 1999/62/EC limits the amounts chargeable in the form of vignettes (time-based charge) at a low level, while more and more EU Member States experienced degrading road quality and face the need for sustainable infrastructure financing."

[30] http://www.euractiv.com/sections/transport/berlin-paves-way-passenger-car-tolling-313223

taxes and 18.41 cents (37.7%) federal excise taxes. Diesel taxes totalled 54.1 cents per gallon, of which 19.13 cents (35.4%) state excise taxes, 10.57 cents (19.5%) other state taxes and 24.4 cents (45.1%) federal excise taxes.[31]

Revenues from the federal fuel tax are earmarked to the Highway Trust Fund (HTF), from which transport projects, and in more recent times also public transport projects, are funded. As the federal fuel tax has not been increased in nominal terms since 1993, while vehicle fuel economy has improved, earmarked revenues increasingly fall short of spending needs. No structural solutions to close the gap have been found, and instead annual *ad hoc* solutions to keep the HTF solvent have been introduced. These solutions have led to a *de facto* increased reliance on general revenues for transport funding in the United States.

More recently, there is increased initiative at the level of the states to generate more revenue for transport spending. States use a variety of measures, including higher fuel taxes, bonds, dedicated sales taxes, tolls, etc. It appears that the earmarking principle is retained at the state level, but that instruments other than fuel taxes are more frequently considered, implying a degree of dilution of the user charging principle. Some commentators argue that this could well be sound rebalancing of federal and state roles in revenue raising and spending decisions on transport, with the federal role more limited to projects of clear national significance (e.g., (Orski, 2015[86])).

In contrast to the European Union, the level and the distribution by state of the sum of state and federal taxes on gasoline and diesel is almost identical for gasoline and for diesel in the United States.[32] In Europe, taxes on diesel are close to the minimum stipulated in the EU Directive and less differentiated among countries than taxes on gasoline, which are partly shaped by tax competition between countries, particularly taxes on diesel due to its use for freight vehicles. Tax competition for diesel in the United States is mitigated by the International Fuel Tax Agreement (IFTA, http://www.iftach.org/) between the 48 contiguous states and ten Canadian provinces, which distributes fuel tax revenue between states on the basis of estimated fuel use by state and not by fuel purchased in each state.

For given fuel economy, the tax base from a state's point of view is distance, which is not – or much less – amenable to tax competition than fuel. Under IFTA, the purchase of fuel and the distance driven in each state are registered by vehicle, and the difference is determined by fuel taxes paid on purchases in a state and fuel taxes due based on distance for the average fuel economy (total fuel use divided by total distance). The per vehicle positions are aggregated by hauliers, who settle their position with their home state; states then use the IFTA clearing house mechanism to regularise positions at the state level.

The IFTA mechanism strongly reduces competition for tax revenue from diesel, which is almost exclusively used for trucks in the United States. Competition for revenue from gasoline is generally more limited as passenger cars have smaller tanks and are used predominantly for shorter trips, so are less able to benefit from lower rates in neighbouring states. US states do engage in tax exporting, however: (Levinson, 2001[87])

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[31] http://www.api.org/oil-and-natural-gas-overview/industry-economics/fuel-taxes

[32] On 1 July 2014, the median tax on both gasoline and diesel is 23.5 cents per gallon. The lowest taxing state charges 8 cents on both fuels; the first quartile value for gasoline is 19.4 cents for gasoline and 19.57 cents for diesel; the third quartile value is 27.88 cents for gasoline and 29 cents for diesel; the maximum tax is 41.8 cents per gallon for gasoline and 54.9 cents for diesel.

finds that states with higher shares of non-resident workers are more likely to levy tolls for the use of their main roads.

While the IFTA mechanism reduces incentives for states to engage in competition for diesel tax revenues, more in general the European institutional environment sets stronger EU level constraints on countries' ability to choose transport tax policies and rates than does the US federal level on US states' leeway in transport taxation. The energy tax and infrastructure directives prescribe the principles to be used for taxation and stipulate minimal or maximal rates.[33] The consequence appears to be that in the European Union there is rising homogeneity in approaches to transport taxation and in tax levels, even if differences remain large. In the United States, by contrast, the decline of the HTF and the apparent rise of state-level funding and spending leads to increasing heterogeneity of funding instruments and funding levels.

The EU Directives constrain countries, and in doing so reflect a view that taxes should be used to reflect social costs of transport choices. This is less the case in US policy, where tax preferences for environmentally less damaging choices are more common and environmental impacts more often are tackled by regulation. This is not to say that regulation and preferential tax treatment are not used in the EU (they are) but that they are embedded in a broad transportation tax policy of high taxes and higher taxes for more environmentally damaging choices, more so than in the United States.

Transport policy in the United States appears to be more specific, in the sense that mainly using fuel economy regulation to reduce fuel use can be seen as expressing a policy preference to reduce fuel use via better fuel economy rather than via less driving, whereas a high fuel tax is neutral *vis-à-vis* these options. Similarly, preferential tax treatment of electric vehicles can be seen as a preference for meeting the fuel economy constraint via alternative fuel choices rather than via improved fuel economy of conventional engines (a preference also seen in Europe). If there were in fact not such a preference, the question is why preferential tax treatment is needed if a fuel economy constraint is in place.

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[33] More generally, tax decisions at the EU level require unanimity.

Reforming road transport taxes – summing up

Transport taxes can deliver considerable benefits by ensuring that drivers take account of external costs of road vehicles when deciding how much, where and when to drive. These external costs of road vehicles appear to be large in quantitative terms..

To a large extent, current transport taxation takes the form of fuel taxation, but there is considerable scope to set better fuel taxes from an external cost perspective, and this will also raise more revenue in nearly all cases. In some countries, fuel taxes seem to adequately charge for external costs, at least on average and for gasoline cars, but they are well below their second-best corrective levels in most, and there is no basis on externality grounds for the common practice of taxing road diesel favourably relative to gasoline.

Distance charges and congestion charges, even if applied on a limited basis, address many of the major externalities from road transport more effectively than fuel taxes. Distance charges are particularly promising if they differ between vehicles according to their emission profiles and if they are higher where exposure to emissions is larger. A gradual introduction of distance charges for trucks is taking place in Europe. The charges can be expected to cover increasingly large areas and to include passenger cars as well as trucks, in the future. There is potential for more environmentally effective transportation tax systems to emerge, as long as tendencies to tax competition can be contained and charges are carefully designed, given the high investment and operational costs for electronic tolling mechanisms.

Revenue-raising considerations reinforce the case for transport taxes beyond external cost considerations, especially for distance-based and vehicle taxes that feature relatively immobile tax bases. Transport taxes can be used even where external costs from road use are very low, e.g., in non-urbanised areas where there is little congestion, to the extent that raising revenue from transport is not more economically costly than raising revenue through other taxes. Revenue interests also drive local initiatives to introduce congestion charging, implying that local governments will seek control of the revenue and this constrains how it can be used.

Fuel taxes are easy to administer so will be appealing in earlier stages of economic development (when they also often are progressive). Fuel taxes also play a role in more sophisticated transport taxation systems, but arguably should take on a less core role than they currently do, for non-climate reasons. Also, if decarbonisation of transport is a policy objective and revenue is to be maintained, gradual shifting away from fossil fuel taxes is crucial. The choice then is between taxing other transport energies or taxing mobility. Because alternative fuels may need encouragement instead of being taxed and because taxing mobility ultimately provides more synergies between revenue-raising and mobility management, increasingly taxing mobility is the superior option to taxing transport energy sources.

Annex A. : Range of estimates of marginal external costs of passenger car use, European Union

Table 1 provides an overview of the marginal external cost estimates of car use discussed in sections 2.1.1 through 2.1.5, based on the recent estimates for the EU, France and the Netherlands ((Ricardo-AEA, 2014[7]); (CGDD SEEIDD, 2013[1]), (Schroten et al., 2014[6]);). Given the broad similarity among these estimates, the table shows EU estimates (as these have the largest geographical coverage), and modified version of these estimates to account for differences in the estimated social cost of carbon (the French value is about three times smaller than the EU and the Dutch value) and in the external cost of accidents (where the 2014 EU value is much smaller than both the French and the Dutch estimates, and also much smaller than earlier EU estimates). Rather than showing averages, the sub-tables display combinations of key drivers of the external cost estimates. The low and high values for climate change and air pollution depend on the EURO class of the vehicle, the engine size and the road type.

Table A.1.A shows the EU range of cost estimates (i.e., with lower accident costs than in the Dutch and French studies, and with a higher carbon cost than the French study) for the low end value of congestion costs averaged over traffic loads. The costs are roughly between 5 and 10 Euro-cent per vehicle-kilometre. Climate and congestion costs dominate for gasoline cars, whereas for diesel cars local pollution costs are more than twice as large than for gasoline cars and also represent a major share of total marginal external costs. Table A.1.B highlights the dominance of congestion costs: taking the high end of congestion costs averaged of traffic loads, which means considering average congestion costs on road types and in regions most susceptible to congestion increases the share of congestion costs in total external costs to 70 to 80%. With mid-range values of average congestion costs, their share is around 50%.

Table A.1.C illustrates the large difference between, on the one hand, EU estimates and, on the other hand, French and Dutch estimates of external accident costs. Taking the higher Dutch and French values makes these costs the largest ones, for low end congestion cost estimates. The order of magnitude of external costs now is 10 to 15 Euro-cent per vehicle-kilometre, instead of 5 to 10 Euro-cent. The difference between the higher and lower cost estimates depends partly on evidence regarding relative accident frequencies, but also reflects larger conceptual and methodological uncertainty on the determination of which part of marginal accident costs is external. Table A.1.D shows the impact of a lower damage cost estimate of CO_2-emissions, with a moderate decrease in total external costs (4 to 8 Euro-cent instead of 5 to 10). Table A.1.E illustrates that external costs are lower in non-urban contexts (mainly because of lower accident and pollution costs), but urban external costs are not much higher at comparable congestion levels.

Ballpark ‘central’ figures, on a country level (i.e., not distinguishing between urban and rural driving) emerging from these estimates are 10 Euro-cent per vehicle-kilometre for non-congested driving, and 25 Euro-cent per vehicle-kilometre for driving under congested conditions. The latter figure, however, is not an ideal guide for tax design, because congestion costs vary strongly and fine-tuning of taxes to reflect this variation increases the benefits from congestion pricing considerably (see Section 2.1.6 and Box 1).

(Santos, 2017[38]) presents estimates of marginal external costs of car and truck use in the EU-27, for the year 2008, in 2010 prices. The sources for these estimates are partly, but not entirely, the same ones on which the EU estimates in Table 1 build. The marginal external cost of congestion, averaged across the EU-27, is EUR 0.07 per kilometre, compared to the estimate of EUR 0.10/km above. External costs of carbon emissions are lower than those in Table 1, at EUR 0.0051/km for gasoline cars and EUR 0.0047/km for diesel cars. However, when using a carbon cost estimate of EUR 60/tonne instead of the EUR 26.4/tonne used in Santos' calculations, the values increase to levels much closer to those of Table 1 (EUR 0.012/km and EUR 0.0011/km for gasoline and diesel cars, respectively). The estimates of marginal external costs of pollution in (Santos, 2017[38]) are EUR 0.0062/km for gasoline cars and EUR 0.0127 for diesel cars, in between the values for urban and rural regions reported for the two fuel types in Table 1. The study does not include wear& tear costs, but in contrast to Table 1 provides estimates of marginal external cost of noise. These are relatively small, but at EUR 0.0039/km not insignificant (for comparison, pollution costs from gasoline cars are estimated at EUR 0.0062/km).

Santos' marginal external accidents cost estimate is EUR 0.0264/km, close to the values for urban driving in the European Union in Table 1. (Santos, 2017[38]) notes that this estimates is high compared to other studies (e.g. (Parry et al., 2014[36])), and it also is high compared to the study used for Table 1). The difference can potentially be explained by differing assumptions about what share of marginal accident cost is external, with the sources used in (Santos, 2017[38]) assuming that all marginal accident risk is external and including production losses in the estimate.

Table 4. Marginal external cost estimates of car use, 2010, Euro-cent per vehicle-kilometre (prices of 2010)

	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	1.5	3.3	1.1	3.3	30.6	44.6	22.9	33.0
pollution	0.4	1.1	0.7	3.7	8.2	14.9	14.6	37.0
congestion	1.9	1.9	1.9	1.9	38.8	25.7	39.6	19.0
accidents	0.3	0.3	0.3	0.3	6.1	4.1	6.3	3.0
wear&tear	0.8	0.8	0.8	0.8	16.3	10.8	16.7	8.0
noise	1.2	3.0	1.2	3.0				
total	4.9	7.4	4.8	10	100.0	100.0	100.0	100.0

1.B: high end of average congestion cost, urban, high carbon cost, low accident cost

	Euro-cent per vehicle-kilometre				%			
	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	1.5	3.3	1.1	3.3	7.0	13.8	5.1	12.4
pollution	0.4	1.1	0.7	3.7	1.9	4.6	3.3	13.9
congestion	18.5	18.5	18.5	18.5	86.0	77.1	86.4	69.5
accidents	0.3	0.3	0.3	0.3	1.4	1.3	1.4	1.1
wear&tear	0.8	0.8	0.8	0.8	3.7	3.3	3.7	3.0
noise	1.2	3.0	1.2	3.0				
total	21.5	24	21.4	26.6	100.0	100.0	100.0	100.0

1.C: low end of average congestion cost, urban, high carbon cost, high accident cost

	Euro-cent per vehicle-kilometre				%			
	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	1.5	3.3	1.1	3.3	16.0	27.7	11.8	22.8
pollution	0.4	1.1	0.7	3.7	4.3	9.2	7.5	25.5
congestion	1.9	1.9	1.9	1.9	20.2	16.0	20.4	13.1
accidents	4.8	4.8	4.8	4.8	51.1	40.3	51.6	33.1
wear&tear	0.8	0.8	0.8	0.8	8.5	6.7	8.6	5.5
noise	1.2	3.0	1.2	3.0				
total	9.4	11.9	9.3	14.5	100.0	100.0	100.0	100.0

1.D: low end of average congestion cost, urban, low carbon cost, low accident cost

	Euro-cent per vehicle-kilometre				%			
	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	0.5	1.1	0.4	1.1	12.8	21.2	9.8	14.1
pollution	0.4	1.1	0.7	3.7	10.3	21.2	17.1	47.4
congestion	1.9	1.9	1.9	1.9	48.7	36.5	46.3	24.4
accidents	0.3	0.3	0.3	0.3	7.7	5.8	7.3	3.8
wear&tear	0.8	0.8	0.8	0.8	20.5	15.4	19.5	10.3
noise	1.2	3.0	1.2	3.0				
total	3.9	5.2	4.1	7.8	100.0	100.0	100.0	100.0

1.E: low end of average congestion cost, rural or non-urban, high carbon cost, low accident cost

	Euro-cent per vehicle-kilometre				%			
	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	1.5	3.3	1.1	3.3	40.0	56.4	31.9	52.8
pollution	0.1	0.4	0.2	0.8	2.7	6.8	5.8	12.8
congestion	1.9	1.9	1.9	1.9	50.7	32.5	55.1	30.4
accidents	0.15	0.15	0.15	0.15	4.0	2.6	4.3	2.4
wear&tear	0.1	0.1	0.1	0.1	2.7	1.7	2.9	1.6
noise	0.0	0.5	0.0	0.5				
total	3.75	5.85	3.45	6.25	100.0	100.0	100.0	100.0

1.F: high end of average congestion cost, urban, high carbon cost, high accident cost

	Euro-cent per vehicle-kilometre				%			
	gasoline		diesel		gasoline		diesel	
	low	high	low	high	low	high	low	high
climate change	1.5	3.3	1.1	3.3	5.8	11.6	4.2	10.6
pollution	0.4	1.1	0.7	3.7	1.5	3.9	2.7	11.9
congestion	18.5	18.5	18.5	18.5	71.2	64.9	71.4	59.5
accidents	4.8	4.8	4.8	4.8	18.5	16.8	18.5	15.4
wear&tear	0.8	0.8	0.8	0.8	3.1	2.8	3.1	2.6
noise	0.0	0.5	0.0	0.5				
total	26	28.5	25.9	31.1	100.0	100.0	100.0	100.0

Annex B. State-of-the-art econometric work on the impact of land use on transport volumes

Urban form may affect transportation volumes, though no consensus exists on the direction and size of this effect. Will denser cities incentivize residents to more or less driving? To what extent do residents adapt their travel behaviour in response to urban form? This section discusses five recent empirical contributions that analyse the link between urban form and travel. The reviewed studies come with convincing estimation strategies, although they of course have not addressed all potential methodological concerns.

The reviewed papers most often use a measure of density to represent urban form (see (Brownstone, and Golob, 2009[66]); (Kim and Brownstone, 2013[67]); (Duranton G. and Turner, 2015[68])). The geographical variation in densities allows ascertaining changes in travel behaviour across density levels while controlling for confounding factors that likely also impact travel behaviour. Density is said to be highly correlated with almost all measures of urban sprawl (cf (Kim and Brownstone, 2013[67])) and is thus a natural proxy for urban form. However, density is not the only aspect of urban land use that affects travel behaviour, therefore (Bento, 2005[69]) and (Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70])use more complex measures to represent urban form.

All reviewed analyses focus on the United States using cross-sectional data from the US National Household Travel Survey (NHTS). The NHTS gives detailed information on daily travel and transportation patterns of a representative sample of US households. Except Brownstone and (Brownstone, and Golob, 2009[66]) and (Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70])whose analysis is restricted to the state of California and the region of Southern California respectively, all reviewed studies consider the national US sample.

(Bento, 2005[69]) estimate the effect of urban form and public transport supply on household mode choice for commuting and on annual vehicle miles travelled (VMTs) in 114 urban areas of the United States. They estimate several discrete choice models using data from the 1990 NHTS, without explicitly addressing the problem of residential self-selection[34] (i.e., a phenomenon according to which households choose to reside in neighbourhoods with specific densities partly based on their travel preferences). They find that measures of urban form and public transport supply have small individual effects on travel demand. For

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[34] For example, if residents who inherently like driving the car (as opposed to other modes of transport) also prefer to live in less-dense suburbs (as opposed to dense city centres) the effect of density on driving might be overestimated. Meaning that a more extensive driving pattern in less-dense suburbs cannot be attributed entirely to the density level of the suburb but might result from the inherent driving preferences of suburb residents.

example, a 10% change in population centrality around the central business district lowers the probability of driving to work by 0.9 percentage points. Increasing the provision of rail and bus miles has small effects on the probability of driving as well. Annual VMT decrease slightly when a city becomes more circular and when rail miles increase. Conversely, a very small positive effect on VMTs is found when road density increases and the distribution of jobs and housing decreases.

When population centrality and public transport availability are increased jointly, the impact on VMT can be large. For example, VMT are estimated to decrease by 25% if a household moves from Atlanta to a city comparable to Boston in terms of public transport supply and urban form. This, however, is an extreme case, given the low density in Atlanta and the high density in Boston.

(Brownstone, and Golob, 2009[66]) apply a structural model to look into the effect of residential density on VMT and on fuel consumption in California, accounting for potential residential selection bias via specific assumptions. They use data from the 2001 NHTS and estimate recursively a household's choice of residential density, VMT and fuel usage, controlling for a number of socio-economic household characteristics but not including access to public transportation. Brownstone and Golob find that density affects fuel use via two channels. First, fuel use in less-dense areas is higher because cars in less-dense areas often are less fuel efficient than those in dense ones. Second, households living in less-dense areas tend to drive more and consume more fuel. In total, a household on average uses 65 gallons (i.e., 246 litres) more fuel per year (i.e., 5.5%) when living in an area where the density of housing units per square mile is smaller by 1000. The household is estimated to drive 1200 miles more (i.e., 4.8%) when density decreases by the same amount.

Increasing densities by 1000 housing units is challenging, as 1000 housing units per square mile equals 40% of the average density in the Californian sample used in the estimation. Actual policies that aim at increasing densities are likely to have much smaller effects than the ones estimated by (Brownstone, and Golob, 2009[66]).

In a follow up paper, (Kim and Brownstone, 2013[67]) apply the structural model developed in (Brownstone, and Golob, 2009[66]) to the US national sample using data from the 2001 NHTS and including metropolitan, urban and rural areas. The authors investigate the impact of residential density on VMT and fuel consumption. In contrast to the 2009 paper, Kim and Brownstone explicitly include a measure of public transport in their analysis. They find that density has very little impact on VMT. Otherwise identical households drive 1341 fewer miles (6.9%) and consume 65 gallons (i.e., 246 litres) less fuel (7.0%) if density at the census block level increases by 1000 housing units per square mile. The reduction in fuel consumption derives from the same two effects as in the 2009 contribution: households living in denser areas tend to drive fewer miles but also use more fuel efficient vehicles. A density of 1000 housing units per census block represents 50% of the sample average. Achieving an increase in density of that level again is not straightforward. Kim and Brownstone find much higher effects when residential density changes simultaneously with the urban or rural category in which a household lives. For example, at given densities, households living in a rural area drive an additional 2777 miles more (14%) compared to households living in an urban area.

(Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70]) extend the (Brownstone, and Golob, 2009[66])methodology and use a synthetic measure of urban form , including several land use variables such as population density, land use diversity, distance to employment centres, and a measure of access to transit services. Their contribution also differs from the previous ones in that the authors use exogenous variation in gas prices to identify the structural model. The authors use the 2008-09 data from the NHTS subsample of Southern California to analyse the effect of urban form on VMTs and fuel consumption, distinguishing between work trips and non-work trips. Their model shows that urban form has only small effects on VMT, and the effect is particularly small when work trips are considered. Similar to others, Dillon et al. find that vehicles are slightly more fuel-efficient in denser and less diverse areas. Finally, increases in gas prices affect a household's decision to drive for non-work purposes but have no effect on commuting choices related to work-trips. In the short run households drive 0.17% less when gas prices increase by 1%.

(Duranton G. and Turner, 2015[68]) use an instrumental variable approach to understand the causal effect of urban form on household VMT. Urban form is measured as a combination of residential and employment density within a 10 kilometre radius of the driver's home. (Duranton G. and Turner, 2015[68]) use the 2008-09 NHTS sample looking at all metropolitan areas in the United States. They find that densification has only small effects on individual driving behaviour. For example, a household that lives in an area of 10% higher density will drive 0.82% vehicle-kilometres less.

The authors emphasize that policies aiming at increasing densities are not cost effective. For example, 83% of the continental land area in the United States is populated at low densities (densities of the bottom density decile). Concentrating the population that lives in these areas into areas with an average density at the top density decile, would decrease total driving by only about 5%. The authors argue that a moderate gasoline tax increase would achieve a similar decrease in driving and that congestion pricing programs would have even larger effects.

In conclusion, using different econometric approaches, all reviewed contributions find only small or insignificant effects of urban form on travel behaviour. Three main results are important. First, the link between urban form and vehicle miles travelled by a household appears to be weak. A household travels only slightly fewer vehicle miles per year when living in areas of high densities e.g., (Brownstone, and Golob, 2009[66]); (Kim and Brownstone, 2013[67]). Effects are particularly small when work trips (as opposed to non-work trips) are considered (Dillon et al., 2015). Also measures of urban form other than density appear to have only limited influence on VMTs (Bento, 2005[69]); (Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70]); (Duranton G. and Turner, 2015[68]). However, in areas where with better access to public transport, effects on VMTs appear to be larger (Bento, 2005[69])). Second, the probability of driving to work by car (as opposed to using other modes of transport) decreases only mildly with urban density. Better provision of public transport changes this pattern only slightly (Bento, 2005[69]). Third, the link between urban form and fuel use materializes through at least two channels: households living in denser areas tend to drive fewer miles per year but also more fuel efficient vehicles (Brownstone, and Golob, 2009[66]); (Kim and Brownstone, 2013[67]); (Dillon, H.S., J.D. Saphores and M.G. Boarnet, 2015[70]).

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