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Urban Transport Policies and Net Zero Emissions in the European Union

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Abstract

This review discusses the role of road transport policies in achieving the European Union's ambitious zero-emission target for the transportation sector by 2050 and provides an overview of the empirical literature that studies the effectiveness of urban transport policies. The analysis is divided into two parts. First, we study policies that are relevant in the transitional phase from internal combustion engine vehicles to battery electric vehicles (BEVs), then we discuss policies that will remain relevant as we switch entirely to BEVs. In the best-case scenario, the transition can be driven by fuel taxes, but in case fuel taxes are not feasible or acceptable, a combination of penalties for buying polluting vehicles and subsidies for scrappage of such vehicles might be the best compromise. In the long run, road space will be increasingly at a premium, and to ensure its efficient use, increasingly sophisticated road-pricing policies will be needed.

1. INTRODUCTION

On March 28, 2023, the European Council formally approved a new law stipulating that all new cars and vans sold in Europe must be zero-carbon by 2035, which is essential given that the European Union has resolved that net carbon emissions from the entire block should be zero by 2050, while typical vehicle lifetime is at least 15 years. The law sets the context for all other transport regulation, but it does not obviate the need for it, because it solves neither the problem of carbon emissions during the intervening period nor other market failures linked to transport. These failures include congestion and noise pollution, and also positive externalities from agglomeration and knowledge spillovers. In this article, we review literature on urban transport policy in light of the European Union's zero-carbon legislation.

The problems of urban (as opposed to rural or national) transport policy are distinct and increasingly important given the zero-carbon transition. The transition solves the one transport-related problem that is identical in the rural and urban contexts—namely carbon emissions, which are uniformly mixing and therefore have the same social cost wherever they occur—while potentially aggravating problems, such as congestion, that are specific to urban areas. Furthermore, other trends justify a specific focus on urban problems, especially ongoing rapid urbanization. The global city population share has doubled from 25% in 1950 to more than 50% in 2020. By 2050, two-thirds of the population will be urban.

Our starting point is the observation that the externalities associated with urban transport are highly resistant to optimal policy. Carbon emissions are correctable in theory through Pigovian taxes on fuel, but the level of taxation commensurate with the zero-carbon goal is typically unpopular. Meanwhile, Pigovian taxes on local pollutants such as nitrogen oxides (NOx), and on individual vehicles' contribution to congestion and accident risk for others, are impossible to implement. It is therefore not enough to analyze market failures and suggest instruments such as Pigovian taxes to correct them. Instead, we must try to identify key changes to the allocation of resources that would be made in first best, and then find sets of policies that take us as far as possible in the right direction, while remaining acceptable on political economy and distributional grounds. We tackle this task in two steps. First, we use theory and stylized facts to identify the overall direction of the changes in allocation that are needed. Second, we then use the latest evidence from empirical studies of transport policies and their effects to help us identify alternative sets of policies, their strengths and weaknesses, and (where appropriate) the evidence needed to determine the best way forward. To help us systematize policy-induced changes in resource allocation and behavior, we decompose effects on pollution into three components: scale, technique, and composition.

We make a series of claims about appropriate policy for urban transport, the most important of which are listed below.

1. There is an important distinction between policies for the short and medium term and the long term. (*a*) In the short and medium term, the central policy aim should be to induce a smooth transition to zero-carbon transport and continued steep reductions in emissions of local pollutants. (*b*) In the long term, as battery electric vehicles (BEVs) increasingly dominate the car fleet, the primary task of policy will be to manage congestion and accident risks, while ensuring that transport systems deliver agglomeration benefits.
2. The primary mechanism to achieve the short- and medium-term changes will be technique effects, i.e., shifts out of internal combustion engine vehicles (ICEs) toward more energy-efficient and ultimately zero-emission vehicles. (*a*) In the best case, these changes can be driven by fuel taxes, but the level of such taxes needed to achieve the transition may not be politically feasible. (*b*) A combination of penalties for buying polluting vehicles and

subsidies for scrappage of such vehicles might be a reasonable substitute for higher fuel taxes. But subsidies for purchase of clean vehicles—although popular and effective in promoting sales—are likely to be inefficient because they promote excessive vehicle ownership and mileage and do little to get ICEs off the road. (*c*) Emission standards for local pollutants have, despite drawbacks in theory, been extraordinarily effective in improving urban air quality and boosting welfare. Further tightening of such standards—both over time for new vehicles and zonally for all vehicles—is called for during the transition to BEVs. As well as reflecting the increasing willingness to pay (WTP) for clean air and the falling costs facing manufacturers to achieve low emissions, such policies will also help to stimulate the transition to BEVs.

3. In the long term, road space will be increasingly at a premium. To ensure its efficient use, increasingly sophisticated road-pricing policies will be needed, along with improvements to public transport systems.

We focus on the climate neutrality ambition of the European Union and discuss urban transport policies in the context of this target. Our article is thus different from two recent reviews by Anderson & Sallee (2016) and Li et al. (2020) that discuss the efficiency of transport policies in other contexts. Anderson & Sallee (2016) compare the traditional fuel economy standard, where new vehicles have a minimum average fuel economy, to a feebate and to attribute-based standards. The authors focus on economic efficiency and carbon emissions and review the literature related to the United States. Li et al.'s (2020) review is more similar to ours. They review the literature related to transport policies that have been implemented in urban areas, distinguishing between command-and-control and market-based instruments, but they focus on policy tools that have been mainly applied in developing countries.

In the remainder of the review, we first discuss two perspectives on the effectiveness of urban transport policy (Section 2). Section 3 discusses policies that are relevant for the short and medium run and encourage the replacement of ICEs by BEVs. Section 4 describes the era when electric vehicles will become the norm and reviews a number of policies that will still retain their relevance in the long run. Section 5 concludes.

2. TWO PERSPECTIVES ON URBAN TRANSPORT POLICY

In this section, we discuss two perspectives on the effectiveness of urban transport policy. The first one focuses on the extent to which policies internalize externalities and correct market failures, whereas the second is a more pragmatic perspective in which we analyze, with the help of pollution decomposition, the effects the policy has on household and firm behavior and compare the resulting choices to a hypothetical first-best resource allocation. We argue that they must be used in tandem if policy analysis is to be helpful.

2.1. The Externality-Correction Perspective

In welfare economics, policy interventions should traditionally be justified by reference to the correction of market imperfections; according to what has become known as the Tinbergen rule, for each market failure we typically need a different policy instrument to achieve our target allocation (Arrow 1958). Therefore, when cars cause both carbon dioxide (CO_2) emissions and congestion, we need two instruments together; a Pigovian fuel tax alone will not do the job because damages from CO_2 emissions are the same whenever and wherever the car is driven, whereas congestion costs vary temporally and spatially.

If we know the size of the external effects to be corrected (such as the marginal damages of polluting emissions), and if we have a policy instrument that can ensure that the external effects are internalized (the emitter of pollution pays a charge equal to marginal damage), then we can achieve the first-best allocation using policy instruments, and we do not need to look beyond the welfare economic perspective. But in many cases—including urban transport—the situation is messier, as we explain by reference to three types of externality: global pollution damages from CO_2; local damages from tailpipe pollution, congestion, and accidents; and benefits from agglomeration, facilitated by urban transport.

The damage caused by CO_2 emissions is the simplest externality from transport: Because CO_2 is a global, uniformly mixing pollutant, damages per ton emitted are the same whatever the precise time and place of emission and irrespective of the quantity emitted. The problem, however, is that the level of the fuel tax needed to ensure a transition to zero-carbon transport on schedule may be too high to be acceptable on political economy and distributional grounds. Meanwhile, local damages create an immensely complex policy problem because these damages cannot be measured at the vehicle level, nor are they easily proxied by fuel use or vehicle miles traveled (VMT): Different vehicles emit vastly different quantities of local pollutants per unit of fuel burnt and per kilometer driven. Furthermore, the damages caused by such emissions vary substantially depending on both the location and time at which the emissions occur. Damages are of course higher where population densities are higher, and they are also higher under particular weather conditions such as during temperature inversions when pollutants are trapped at ground level. Similar problems are associated with congestion and accident risk. The waters are further muddied because, polluting emissions notwithstanding, we want to encourage transport because it facilitates positive agglomeration externalities, which are the advantages to both households and firms that arise from the fact that we live and work close to one another.

2.2. The Pollution Decomposition Perspective

If we cannot apply optimal policy instruments such as Pigovian taxes, we can ask what changes would result from hypothetical optimal policy and then look for (second-best) policy instruments that push the economy in the right direction. Focusing on urban transport, we can ask what changes would occur—lowering pollution—in an optimally regulated city. In principle, we can use pollution decomposition analysis to attribute such changes to a combination of three effects—scale, technique, and composition—as pioneered by Torvanger (1991) and developed by Levinson (2009). In this literature the focus is typically on the entire manufacturing sector within a national economy, but the approach can also help us to organize the analysis of changes within more limited sectors, such as urban transport.

For the sake of illustration, we focus on CO_2 emissions from passenger transport in a given city. Are emissions in the first-best allocation lower due to a reduction in passenger miles (irrespective of transport mode), i.e., through a scale effect? In that perhaps unlikely scenario, we need policy instruments that discourage travel. Or would the optimally regulated city have similar transport volumes and modes, but much more pollution-efficient vehicles such as BEVs? Then we have a powerful technique effect, and we need policies that drive efficiency. Or, finally, would the optimal solution involve a change of transport modes, away from private motor vehicles? Then we have a composition effect, and we need policies favoring the new modes. Congestion charges target scale and composition, fuel economy regulations such as corporate average fuel economy (CAFE) standards target technique, and subsidies to public transport target composition. Fuel taxes are a prime example of a policy that works through all three effects, while subsidies to low- (but not zero-) emission vehicles may have a positive technique effect but a negative scale effect, known as rebound.

Can we draw any general conclusions from the decomposition literature? In the manufacturing industry, the key to drastically improved environmental quality is generally a shift to radically cleaner technologies. Furthermore, Shapiro & Walker (2018) show that development and adoption of these cleaner technologies are driven by increasingly stringent regulation. Theoretical work such as that by Hart (2020), following Grossman & Krueger (1995) and Stokey (1998), shows that this is comprehensible in a framework where increasing income drives increasing WTP for environmental quality, which in turn pushes regulators to raise the marginal cost of pollution. Hart (2020) shows that the logical endpoint of this process is zero-emissions technology.

The transition to zero-emissions technology is of course at the heart of EU transport policy: The 2035 goal (all new vehicles being zero-carbon) cannot be achieved any other way. During the transition, hypothetical first-best policies would include increasing emissions taxes for CO_2 and local pollutants, mainly coming from ICEs, and the focus of second-best policy should be to try to replicate the allocation effects. But as the transition progresses, the relative importance of policies to deal with optimal use of road space, and accidents, will increase. The timescale for this shift will vary depending on the country, even within Europe, but ICEs are likely to dominate the roads for at least the next decade. In Norway, BEVs accounted for 82% of new car sales in June 2023,[1] but in Germany—Europe's biggest car market—they were just 19%, while in Italy they are stuck at around 2–3%. Projections for the European Union as a whole typically put the BEV fleet at approximately 30–40 million vehicles by 2030, whereas the total fleet will be around 300 million.[2]

3. POLICY INSTRUMENTS TARGETING INTERNAL COMBUSTION ENGINE VEHICLES

As explained above, in the short to medium term, policies should target ICEs: making them more fuel-efficient and cleaner, but also ensuring that they are replaced by electric vehicles, implying that BEVs must take over new car sales, but also that ICEs must be scrapped.[3] In theory, the best way to achieve this is through fuel taxes, but such taxes may be constrained by distributional and political economy considerations. The literature we analyze in this section shows that the social costs of alternative policies to achieve the same goal—a carefully designed combination of direct incentives affecting car purchase and scrappage—may be in the same ballpark. Regarding local pollutants, emissions standards—intensifying over time and varying spatially—are the sine qua non of policy alternatives. These standards may work against decarbonization in the early stages of a transition to zero-carbon (e.g., by discouraging the use of diesel motors), but in the long run, they complement the other regulations in hastening a transition to electric vehicles.

3.1. Fuel Taxes

By targeting the externality of CO_2 emissions, fuel taxes reach all parts of the market. They incentivize drivers to scale down their use of private transport, to shift to low- or zero-carbon vehicles

[1] All BEV sales data are from **https://www.insideevs.com**.

[2] See, e.g., **https://www.consultancy.eu/news/5766/europes-electric-vehicles-fleet-to-reach-40-million-by-2030** and **https://www.acea.auto/figure/size-distribution-of-the-eu-vehicle-fleet/**.

[3] Note that BEVs are also associated with pollution in the short to medium term, e.g., due to carbon emissions from electricity generation, which should also be considered when evaluating the overall environmental impact of BEVs before the electricity generation sector completely moves away from fossil fuels. Holland et al. (2022) show that, over the last decade, the marginal emissions from US electricity generation have increased because of a shift toward greater reliance on coal to meet marginal electricity use. Such shifts undermine the emissions reduction in the transportation sector when more BEVs are put on the road. Furthermore, BEVs are associated with damages from mining of lithium and cobalt, and in the long run there could be problems related to the scarcity of these nonrenewable inputs. Detailed discussion of these issues is beyond our scope, but see Nehiba (2024) for an analysis of damages from electricity used by BEVs, Maus & Werner (2024) on mining impacts, and Hart (2016) for an economic approach to analysis of nonrenewable resource scarcity.

(technique), and to shift to other zero-carbon forms of transport (composition). But high fuel taxes are frequently unpopular. Although there is fairly broad acceptance of levels currently seen in Europe, attempts to increase them have been met with stiff resistance, most famously in France with the *gilets jaunes* protests since 2018 (see, e.g., Lynas 2018). Here, we study what the literature can tell us about the effects of fuel taxes, especially on the adoption and use of low- and zero-carbon vehicles.

3.1.1. Vehicle miles traveled and congestion. How big is the effect of a fuel tax on VMT? We expect VMT to vary depending on the overall marginal cost of each kilometer driven, which depends on the sum of fuel costs, maintenance and depreciation costs, and the cost of time. If fuel is cheap, implying that fuel costs are a small part of overall costs, then changes in the fuel price will have little effect on VMT; this is what we see in the United States, where estimates of the elasticity of VMT to the fuel price are typically approximately −0.1 (Langer et al. 2017). On the other hand, in Europe where fuel costs comprise a large part of the total cost of driving, the elasticity of VMT to fuel prices is larger. Using data from the German Mobility Panel from 2004 to 2019, Alberini et al. (2022) show that the fuel price elasticity of VMT is approximately −0.37. Although not trivial, this elasticity shows that astronomically high taxes would be required to push carbon emissions from transport toward zero through scale effects alone. The same conclusion follows regarding the potential of fuel taxes to reduce traffic congestion and other externalities directly linked to VMT.

3.1.2. Efficiency of new vehicles and retirement of old vehicles. Given heterogeneity in fuel efficiency, fuel taxes should drive consumers toward more fuel-efficient vehicles. In Europe, our back-of-the-envelope calculations show that motorists spend ca. one-third as much on fuel as they do on purchasing new vehicles, which suggests that the incentive effects of fuel prices on vehicle choice should be significant. Suggestive evidence for these effects comes from differences in trends between the EU and US markets, given the much lower fuel prices in the latter. Klier & Linn (2016) examine the attributes of new cars sold in the United States and the eight largest markets in Europe from 2005 to 2010, finding that the percentage increase in fuel economy was almost double in Europe compared to the United States, while the increases in weight and horsepower were about the same. Overall, they show that new cars sold in the United States have much lower fuel economy and higher horsepower than those sold in Europe.

Crucially, fuel taxes incentivize both the purchase of new fuel-efficient vehicles and the scrappage of old and inefficient vehicles. Demand for efficient vehicles should in turn drive manufacturers to offer such models, which may be lighter and less powerful, or use different technology such as diesels or hybrids [hybrid electric vehicles (HEVs) or plug-in hybrid electric vehicles (PHEVs)]. Klier et al. (2020) provide evidence for such effects. Using US data (1997–2013), they show that an increase in fuel prices leads to a higher consumer WTP for fuel-saving technology, accelerating technology adoption.

However, if households fail to account fully for savings from buying fuel-efficient vehicles, then fuel taxes will not lead to efficient responses from households, and further policies may be justified. One possible reason for such undervaluation is if households are myopic with respect to future reductions in fuel costs. Another reason is that they have imperfect information or are rationally inattentive regarding savings from fuel efficiency (i.e., they discount excessively the future benefits of having a fuel-efficient car). Recent work investigating such effects includes that by Allcott & Knittel (2019), Gillingham et al. (2021), and Leard et al. (2023), but the overall picture remains unclear. Our main interest is on the effect of fuel taxes on new car demand, where Grigolon et al. (2018) show—explicitly accounting for heterogeneous vehicle usage patterns among households—that new car buyers facing higher fuel taxes fully (or almost fully) account for fuel savings from improved vehicle fuel efficiency.

Remarkably, there is increasing evidence that consumers may overreact to fuel taxes. The most important evidence for this is provided by Andersson (2019), who puts together data on total emissions from the transport sector in 25 OECD countries and then uses synthetic control to find the causal effect of price shocks such as the introduction of carbon taxes on transport fuel use in Sweden. Andersson thus measures the total effect of adaptations (scale, technique, and composition) but cannot measure the relative size of different effects. Nevertheless, he highlights the technique effect of a shift from petrol to diesel cars, the latter being more fuel-efficient. He finds not only that introducing a carbon tax on transport fuels in Sweden in the early 1990s led to an almost 11% reduction in CO_2 emissions related to transport services, but also that consumer sensitivity to an extra Swedish krona in fuel tax is much greater (3 ×) than sensitivity to an extra one added onto the underlying fuel price.

Another possible reason why fuel taxes may not live up to their theoretical billing would be if manufacturers with market power compensate consumers for fuel tax payments by reducing prices of new cars in the short run (Langer & Miller 2013). However, using European data during 1998–2011 and assuming constant marginal cost and price competition on the firm side, Grigolon et al. (2018) compute new equilibrium prices in the new market after tax changes. They show that the taxes have only a small impact on average new car prices.

3.1.3. Effects on local pollutants. Emissions of local pollutants from vehicles have declined spectacularly over recent decades. According to Jacobsen et al. (2023), emissions per VMT in the United States have declined by more than 99% since 1967, and lead—perhaps the most dangerous pollutant of all—has completely disappeared. These technique effects overwhelm the relatively modest scale effects of increased driving distance and any composition effects driven by increased car ownership.

Against this background, the relevance of fuel taxes is not through modest scale effects on VMT, but rather through their role in triggering technique effects as the car fleet is renewed. Perhaps counterintuitively, it seems that the most important effect of high fuel prices in Europe over the last 30 years has actually worsened local pollution problems. It has pushed a switch to diesel cars, which are more fuel efficient (and also carbon efficient) but dirtier in terms of local pollutants, especially NOx and particulates. It has been argued (see Miravete et al. 2018) that European regulators deliberately held back tough NOx regulations to favor the emerging diesel sector in the 1990s, a form of strategic trade policy. Today's fuel taxes may, on the other hand, make a significant contribution to lowering local pollution through earlier scrappage, especially as all new cars—not just BEVs but even diesels—now meet high emission standards for local pollutants. However, we are not aware of any direct evidence regarding the size of this effect.

3.2. Fuel Economy Regulations, Registration Taxes, and Feebates

We have argued that shifting cars onto cleaner technologies—better ICEs, and ultimately zero-emission BEVs—is the key to attaining both zero-carbon goals and further dramatic reductions in local air pollution. For CO_2, fuel taxes are clearly a good way to achieve this. But for politicians who are squeamish about increasing such taxes due to the distributional effects or political economy problems, might some other regulation directly targeting new car purchases do the job equally well, or almost equally well? An important policy of this type is fuel economy regulations such as CAFE standards. In this section, we discuss the effects of such regulations and alternatives such as registration taxes and feebates.

3.2.1. Efficiency of new vehicles.

If we have a goal for the overall economy level of new cars sold, fuel economy regulations can achieve it, but they cannot ensure that cars of different types are efficiently allocated. In the optimum, as achieved by fuel taxes under ideal circumstances, drivers with high mileage should buy the most fuel-efficient cars, as argued by Bento et al. (2012). They further suggest that not accounting for such sorting of new car buyers may lead to underestimated values of WTP for fuel efficiency in demand estimation.

3.2.2. Rebound effects: boosting vehicle miles traveled and slowing scrappage.

There are two potentially major drawbacks of fuel economy regulations when compared to fuel taxes: They may encourage greater mileage (compared to the effect of fuel taxes) and they may slow down the scrappage of inefficient vehicles. Both are a form of rebound effect—in the sense that they are unintended secondary effects that work in the opposite direction to the goal—although the latter is known as the Gruenspecht effect.

Regarding VMT, if regulations push the car fleet toward more fuel-efficient vehicles without raising the price of fuel, the cost of driving per kilometer will be lower than in the case with fuel taxes; hence, car owners will tend to drive more, making the regulations less effective (Bovenberg et al. 2008). De Borger et al. (2016) use detailed household-level panel data from Denmark between 2001 and 2011 to evaluate this rebound effect, finding that 7.5–10% of the fuel savings from improved vehicle fuel efficiency are consumed because of increased driving. Overall, there is a lack of clear evidence of significantly increased car usage from improved vehicle fuel efficiency in the EU context.

The failure of fuel economy regulations to encourage scrappage may be a bigger problem. Schemes such as CAFE standards make new gas guzzlers more expensive as manufacturers cross-subsidize fuel-efficient vehicles (Davis & Knittel 2019). This tends to raise the value of vehicles in the same category that are already in the fleet, hence delaying their scrappage and increasing mileage (Jacobsen & van Benthem 2015). Because these vehicles are likely to be even less efficient than those that might have replaced them, and emit more local pollutants, this is potentially a major drawback of fuel economy regulations compared to fuel taxes.

Regarding other aspects of the welfare consequences of the attribute-based EU regulation, Lin & Linn (2023) argue that regulating one vehicle attribute can affect virtually any other attribute because of demand and supply linkages across the attributes. Analyzing disaggregated data for the European market between 2005 and 2017, they find that the standard reduced fuel consumption and emissions but unintentionally reduced vehicle quality.

3.2.3. Gaming.

Recent literature suggests that weak enforcement of standards may allow manufacturers to cheat the system—gaming—causing emission reduction targets to be missed. For instance, based on a structural model of demand and supply, Reynaert (2021) finds that the 2015 EU-wide emission standard led to a 14% decrease in sales-weighted carbon emissions from new sales between 2007 and 2011. However, two-thirds of this decrease was due to firms gaming emission tests, while only one-third was due to actual technology adoption. He points out that standards rely on fuel economy tests that can be manipulated when compliance costs are high, and it is unclear whether emissions will actually decrease due to the policy.

To further investigate gaming of automobile carbon emission ratings in the same policy context, Reynaert & Sallee (2021) estimate the performance gap by comparing the laboratory ratings with direct measures of on-road fuel consumption constructed from a data set that tracks fuel consumption and kilometers traveled for a panel of more than 250,000 drivers over 12 years in the Netherlands. They show that gaming of fuel consumption ratings escalates after the introduction of regulations that target this rating. However, their calibrated simulations suggest that the pass-through of cost reduction from gaming substantially outweighs information distortions, so new car buyers benefit from gaming on the net—at the expense of society, which suffers from the climate externality—even when they misoptimize their product choices because of faulty information.

3.2.4. Feebates and differentiated registration taxes. An alternative to fuel economy regulations is feebate or bonus–malus schemes, that is, policies that combine extra taxes on the purchase of polluting vehicles with subsidies for cleaner vehicles. Special cases of feebate schemes are schemes with rebates for clean cars but no fees for dirty ones, and schemes with fees for dirty cars but no rebates for clean cars (i.e., differentiated registration taxes). A feebate scheme can replicate the effect of fuel economy regulations on new car prices, but the changes are achieved not through cross-subsidization by manufacturers, but more directly. However, if feebate schemes are relatively generous, they may lead to an overall increase in new car sales. Another problem highlighted by the experience of feebate schemes is that the environmental benefits of the subsidized vehicles may be doubtful, as with rebates for flexible-fuel cars (Huse 2018).

Employing the data from the Swedish new car market from 2004 and 2009, Huse & Lucinda (2014) estimate elasticities of demand at the product level to evaluate the effect of the Swedish Green Car Rebate on CO_2 emissions reductions. They show that transfers to consumers per unit of CO_2 emission reduction are more than five times the price of an EU emission permit. Moreover, costs are even higher because drivers of flexible-fuel vehicles—subsidized in the program—tend to put fossil fuel in the tank. Accordingly, Huse (2018) points out that policy makers should consider consumer preference over nonprice attributes when designing policies promoting emerging green technologies.

D'Haultfœuille et al. (2016) examine the evolution of CO_2 emissions of new vehicles sold in France between 2003 and 2008 to show that the average new vehicle CO_2 emissions fell by more than 10%. Estimating a nested logit demand model incorporating rich consumer heterogeneity, they find that 14% of the drop comes from the pure price effect of the 2008 French feebate scheme, in which the fee on the most polluting cars was €2,600, and the rebate was up to €1,000 for cars with low CO_2 emissions. Comparing the demand system before and after introducing the scheme, D'Haultfœuille et al. (2014) find that its environmental impact was negative because overly generous rebates increased the total new car sales of new cars by about 13%. This rebound effect, leading to both more cars and more driving, outweighed the benefit of the shift toward cleaner cars, although a modest decrease in the rebate would have decreased overall CO_2 emissions.

Focusing on the same French policy, Durrmeyer (2022) estimates a structural model of demand and supply to show that it increased annual welfare by approximately €115 million when accounting for the consumer surplus, car manufacturer profits, the budget cost of the policy for the government, and emissions costs. She shows that the net effect of increased car sales and the increase in vehicle efficiency was that average CO_2 emissions of new cars decreased by 1.6%. However, the increased sales of diesel cars increased the average emissions of particulate matter (PM) and NOx. Adamou et al. (2014) perform a related simulation study for Germany, testing the impact of various alternative feebate schemes. They find that revenue-neutral feebate designs do not improve welfare, but asymmetric schemes that make fees on high-emission cars larger than the rebates on low-emission cars are welfare-improving, although the environmental benefit remains modest.

Gerlagh et al. (2018) use data from EU 15 countries over 2001–2010 to study the effect of registration taxes that differ between fuel-efficient and fuel-intensive cars, exploiting variation in stringency across countries and time. They find that a 1% increase in the CO_2 sensitivity of vehicle registration taxes reduces the average CO_2 intensity of new vehicles by about 0.1%. This reduction is realized through increased sales of fuel-efficient petrol cars and the substitution toward diesel cars. Broadly similar results are found by Yan & Eskeland (2018) using Norwegian data and exploiting vehicle registration tax reforms. Focusing on the same Norwegian tax reforms, Ciccone & Soldani (2021) leverage differences in CO_2 emission intensity across different versions within a car model to show that consumers reacted more strongly to tax decreases (elasticity -1.99) than to increases ($+0.77$). Consistent with this, they show that the tax reform induced significant substitutions toward greener vehicles around the lower thresholds, where the tax on average decreased, and negligible substitutions around the highest threshold, where the tax on average increased.

Empirical work thus confirms the intuition that fees for dirty cars may be welfare enhancing, but rebates for clean ones probably are not. But Gillingham et al. (2022) show that even well-designed feebate schemes cannot compete with fuel taxes. Accounting for dynamic car holding and usage decisions of heterogeneous households, they develop a model in which various policies can be analyzed based on equilibria of both the primary market and the secondary market. They identify structural parameters using observed choice probabilities by consumer type and implied market shares of cars. Employing observations of the car holdings from all Danish households between 1997 and 2008, their model replicates the depreciation pattern of used cars and matches the pattern in car scrappage to the rigorous biannual safety inspection practice in Denmark. Their policy simulations show that it is possible to both raise tax revenues and consumer surplus and reduce CO_2 emissions by shifting taxation from the purchase of new cars to the use of cars, i.e., by lowering the new car registration tax and increasing the fuel tax.

3.3. Scrappage Schemes

We have shown that, in driving a transition to zero-carbon transport, well-designed fuel economy regulations or feebate schemes could potentially do the job of encouraging the purchase of low-carbon cars reasonably well, but such schemes, when compared to fuel taxation, will slow down scrappage of inefficient vehicles instead of encouraging it. Could scrappage schemes (such as the payments of subsidies to owners who scrap older vehicles) be a good complement to such regulations, while simultaneously having progressive distributional effects (as argued by Sallee 2023)?

Historically, scrappage schemes are typically introduced to encourage sales of new cars during economic downturns; there was a wave of such schemes after the financial crisis of 2008. Thus, the payment is conditional both on scrappage of an old car and purchase of a new one. Environmental benefits may be a spin-off or an explicit goal. In the latter case, there are normally requirements on the environmental friendliness of the new vehicle (e.g., its fuel efficiency) and sometimes also on the old vehicle (e.g., its minimum age). Schemes of the latter type are known in the literature as targeted schemes.

To understand the effects of scrappage schemes in seven European countries between 1998 and 2011, Grigolon et al. (2016) assemble a detailed monthly car sales and product attributes data set and exploit variations in the specific timing of the scrappage schemes across countries to identify causal effects. They find that both types of scrappage schemes—targeted and nontargeted—prevented reductions in total car sales during the financial crisis, and that the targeted schemes had significant environmental benefits.

Helm et al. (2023) focus on the nontargeted German scrappage scheme of 2009, in which a new car subsidy of €2,500 was paid if a car at least 9 years old was scrapped. They use vehicle registrations and data on pollutant concentrations to evaluate the effects on local pollution. Exploiting variations in the number of cars older than 9 years across districts, they show that the composition of vehicles changed toward a less-polluting fleet in response to the policy, and in terms of local air quality, the average reduction of NO_2 emissions was approximately 7% relative to 2008. Staying with the German scheme, Klößner & Pfeifer (2018) find no evidence of significant CO_2 emissions reductions, which is unsurprising, as there were no special requirements on the new vehicles. Applying the multivariate synthetic control method using time series to a country-level data set, they show that the generous incentive induced consumers to upgrade to larger vehicles, potentially more than offsetting the reduction of CO_2 emissions resulting from scrapping old cars.

3.4. Taxes on Car Ownership

Another way to reach high-carbon older cars (and encourage scrappage) is through differentiating annual taxes on car ownership [sometimes known as road taxes or vehicle excise duties (VED)]. Annual car ownership taxes are widely applied and increasingly differentiated according to the fuel efficiency of the vehicle. Such taxes, if they penalize more fuel-intensive vehicles heavily, could do a reasonable job of fixing incentives for both purchase and scrappage; i.e., they incentivize both the purchase of clean vehicles and the scrappage of dirty vehicles. However, at least one remaining problem in comparison to fuel taxes is that new-car-purchase and scrappage incentives are not aligned with the likely mileage of the buyer; in an optimal allocation, those with high annual mileage will invest most in efficient and low-pollution vehicles.

The literature shows modest reductions in CO_2 emissions from applying CO_2-differentiated annual vehicle taxes. For example, Cerruti et al. (2019) investigate the effects of the United Kingdom's annual VED, whose rate is a step function of a vehicle's CO_2 emission rate, on new vehicle registrations and their carbon emissions. They utilize monthly UK new car registration data over 2005–2010 and exploit variations in VED across vehicle emission rates and over time to obtain the estimate of the elasticity of new car registrations to taxes. They predict that the policy could reduce emissions from new vehicles by 1.64% compared with the preexisting tax. Similarly modest effects are found by Alberini & Bareit (2019) for the Swiss differentiated VED taxes and by Alberini & Horvath (2021) for the German equivalent.

The literature suggests that the ineffectiveness of annual vehicle taxes in emissions reductions might be rooted in the behavioral effects of the policy. For example, Huse & Koptyug (2022) employ consumer-level transaction data from a Swedish online auction platform of used cars to show that households severely undervalue annual recurrent vehicle taxes. By interacting tax policies with proxies for their salience and exploiting the temporal variation, they find that consumers react to the timing of the annual recurrent vehicle tax, and tax exemptions tend to depress consumer valuation of vehicle taxes. In light of their findings, Huse & Koptyug (2022) suggest that policy makers would improve consumer welfare and the effectiveness of policy instruments by increasing their salience.

3.5. Local Pollution Regulations

The contribution of urban transport to climate change is of course a critical concern for policy makers, but the health effects of local pollutants should most certainly not be forgotten, as highlighted by the Lancet Commission on pollution and health (Fuller et al. 2022). Most such pollutants come from ICEs, and according to the analysis of Parry et al. (2007), marginal damages of local pollution per VMT in urban areas are significantly higher than climate damages. Emissions per VMT have declined significantly since 2007, but on the other hand, WTP for clean air has risen and has been found to be higher than WTP for other externalities (Istamto et al. 2014).

The regulatory problem for local pollutants is complex. As pointed out by Jacobsen et al. (2023), emissions of local pollutants are untaxable because the measurement of emissions from each car is technologically infeasible. And because fuel use is very weakly correlated with local pollution, fuel taxes are an extraordinarily blunt instrument with which to tackle local pollution; they may even make things worse, for instance, by encouraging diesel vehicles. Taxation by VMT is also next to useless given a combination of heterogeneous emissions at the vehicle level (some cars emit far more than others) and heterogeneous damages both spatially and temporally (i.e., emissions at certain times and places are far more damaging than emissions at other times and places).

In a hypothetical first-best allocation, three adaptations would be key when compared to laissez faire. The main adaptation is simply the adoption of cleaner technologies in new cars. The second and third adaptations are to reduce the use of more polluting (typically older) cars in sensitive areas and at sensitive times. The obvious policy instruments to use to achieve these goals are different forms of command-and-control regulations such as new car standards and low emission zones (LEZs). We now discuss the evidence on the efficiency and effectiveness of such policies.

3.5.1. New car standards. New car standards refer to regulations and requirements that set specific criteria for new vehicles. One of the primary goals of new car standards is to regulate local pollutants from vehicles, such as NOx, carbon monoxide, and PM. These regulations set a maximum emission rate per kilometer for every vehicle. Currently, in the European Union, every new car has to meet the Euro 6 standard, which implies that new cars cannot emit more than 80 mg/km of NOx gases, while a petrol car cannot emit more than 60 mg/km. The standards have tightened dramatically; for instance, under Euro 3, binding until December 2005, the maximum for NOx from diesel vehicles was 500 mg/km.

There are few quantitative studies on the effect of new car standards on local pollution levels, but Jacobsen et al. (2023) show that pollution per VMT in the United States has declined by more than 99% over the last half-century, mostly thanks to pollution standards. The steep decrease in emissions from new vehicles means that there is large heterogeneity in the car fleet, and at the same time, there is significant heterogeneity in damages depending on the time and place of emissions. This motivates the use of zoning policies, which, as we discuss in the next section, restrict or ban polluting vehicles in sensitive areas.

3.5.2. LEZs and other spatial and temporal standards. Since the 1970s, policy makers have used a variety of zoning policies that impose restrictions on driving. Initially these were intended to reduce congestion and later to promote the use of clean vehicles and restrict the use of polluting ones. Examples include car plate number restrictions, and more recently, LEZs and zero-emission zones (ZEZs), which are increasingly enforced in European cities. Zoning policies can reduce pollution by promoting the use of cleaner vehicles (technique effect) and encouraging the switch to other modes of travel (composition effect). Overall, most studies on LEZs focus on the impact of this policy on the concentrations of local pollutants. More research is needed to understand whether LEZs promote the switch to cleaner vehicles and the faster renewal of the car fleet.

One of the first attempts to reduce congestion and improve air quality was made by implementing car plate number restrictions, or odd–even schemes, in various cities around the world (e.g., in Athens in 1979). This measure was later introduced in big cities in Asia (Beijing, New Delhi) and Latin America (Mexico City, Bogotá, São Paulo, Santiago), but its effectiveness has been questioned. It was successful in early stages due to easy implementation and low cost (Soto et al. 2023), but it does not usually lead to significant reductions in pollution levels. In many cases, it has encouraged the purchase of a second car, which is usually secondhand and more polluting (Davis 2008, Bonilla 2019, Basso et al. 2021).

The most widespread zoning policy in the European Union is currently the creation of LEZs, where the most polluting vehicles are regulated. There are also ZEZs, where only zero-emission vehicles such as BEVs are allowed. LEZs and ZEZs have been created in cities in Germany, the Netherlands, France, Belgium, England, Denmark, Sweden, Norway, Hungary, and Italy.

As of 2023, Germany has 52 LEZs, comprising more than 70 cities. Earlier efforts to assess the effectiveness of LEZs suggest that the environmental and health benefits significantly outweigh the costs associated with upgrading the vehicle fleet. For example, Wolff (2014) estimates the impact of LEZs on PM10 (PM 10 μm or less in diameter) concentrations using panel data of daily pollution and weather conditions in Germany from 2005 to 2008, finding that on average, LEZs decrease PM10 concentration by ~9%. A more recent study on German LEZs (Gehrsitz 2017) uses a difference-in-differences design and finds that LEZs decreased fine particulate concentration by 4%, while in the case of more restrictive LEZs, the reductions were larger (up to 8%). However, those reductions did not lead to significant improvements in infant health. Lower levels of air pollution in urban areas, but also reductions in circulatory and chronic lower respiratory diseases after the introduction of LEZs in Germany, are found by Pestel & Wozny (2021).

Studying the implementation of LEZs in Amsterdam, Panteliadis et al. (2014) show that traffic-related air pollution concentrations (NO_2, NOx, PM10) were reduced by 5–6%. Using a unique panel data set on congestion and PM2.5 levels in European urban areas during 2008–2016, Bernardo et al. (2021) find that LEZs are particularly effective in highly polluted areas, when they are implemented in a wider area of the city, or when there are very strict vehicle restrictions. Ellison et al. (2013) assess the impact of LEZs in London both on vehicle registrations and usage and on air pollution and find that the rate of fleet turnover for the dirty vehicles increased substantially after the introduction of the zone but returned to the national average in subsequent years. Moreover, PM concentrations decreased by approximately 2.5–3% in targeted areas and 1% in the areas outside the zone. No significant impact was found in NOx concentrations. Using cost-benefit analysis to evaluate the impact of LEZs in the inner city of Stockholm, Börjesson et al. (2021) find that the costs outweigh the benefits, where the social costs consist mainly of adaptation costs for drivers of banned vehicles, whereas the benefits consist mainly of the health benefits associated with air quality improvements.

Even though there is clear evidence showing that concentrations of air pollutants have declined due to LEZs—but still in many cases remain above the safe limits set by the World Health Organization—and that LEZs reduce air pollution–related health outcomes (Chamberlain et al. 2023), there is some resistance to the introduction of new ones, or the further increase in the strictness of the regulations. There is also much resistance to the expansion of the ultralow emission zone in London, while many German cities and municipalities are planning to abolish the environmental zone regulations because, according to the experts, the air quality has significantly improved.

4. POLICY INSTRUMENTS IN A ZERO-CARBON ECONOMY

When electric vehicles become the norm, some externalities—such as tailpipe emissions of CO_2 and local pollutants—will disappear, while others—such as congestion—will remain. Certain urban transport policies will thus retain their relevance in the long run and contribute to the sustainable evolution of urban mobility. Examples include congestion charges and electronic metering. At the same time, advances in digital technology and the implementation of hybrid working schemes, which allow employees to (partly) work from home, will change the structure of cities and the frequency of commuting. Here, we discuss how cities will change in response to those forces and in the presence of clean vehicles and which policy instruments will still be needed in the BEV era.

4.1. Agglomeration Policies

The dynamics of urban development, transportation, and work patterns are closely linked. Indeed, high traffic–induced pollution, often found in urban areas, deters households from locating there (Verhoef & Nijkamp 2004, Schindler et al. 2017). This influences the optimal city structures by impeding the formation of monocentric cities (Denant-Boemont et al. 2018, Kyriakopoulou &

Picard 2021). This is bad news, because agglomeration yields benefits for both the firms—in the form of knowledge spillovers, access to potential markets, and access to a specialized labor pool—and the households who enjoy a larger number of amenities. To foster agglomeration, we should internalize the associated externalities and create incentives for firms to cluster together (Fujita & Ogawa 1982, Lucas & Rossi-Hansberg 2002).

The shift to BEVs promises a cleaner urban environment and significant reductions in air pollution. This transition will weaken the dispersal effect of pollution, allowing other factors like agglomeration benefits to play a more important role in shaping urban areas. This will encourage the formation of more specialized, monocentric cities, as well as the implementation of policies that promote the clustering of firms in pure business centers (Regnier & Legras 2018).

The post-COVID-19 era has added another force into play, namely the shift to remote work (Barrero et al. 2021). This change will have an impact on the size and structure of cities, with more employees choosing to relocate to the outskirts of big cities or even to other cheaper cities (Glaeser & Cutler 2021, Kyriakopoulou & Picard 2023). While remote work will reduce daily commutes, it can lead to longer trips and eventually increase the overall VMT for both work-related and personal activities.

In the long run, urban planning and transportation policies will need to adapt to a new balance of agglomeration forces, including reaping the benefits of agglomeration and accommodating changing working patterns. With air pollution being less of a concern, policy makers can also focus on other transport-related issues, such as investments in public transportation infrastructure or traffic congestion.

4.2. Road Pricing

Road pricing (also known as road tolls or congestion charges) has been implemented in many European cities over the past two decades. When combined with fuel taxes, it can achieve much greater socioeconomic efficiency. Well-designed road-pricing policies discourage drivers from using their cars when the marginal damage of driving is high; hence, it can allocate limited road space to the highest-valued users to reduce traffic congestion, which also helps reduce local pollution. Road pricing targets primarily composition effects, shifting drivers to other modes of transport. However, if there is differentiated pricing based on the vehicle characteristics—such as the Norwegian congestion charges, where electric cars are either exempted or subject to lower pricing—road pricing can also promote the switch to cleaner vehicles (technique).

An increasing body of research examines the effects of road pricing on car ownership and usage, pollution levels, and public health. In 2003, London was the first city in Europe to introduce road pricing for driving within the central district. Green et al. (2016, 2020) investigate the impact, finding reductions in travel times, traffic accidents, and air pollution stemming from vehicles caught in traffic congestion. Applying an instrumental variable approach and exploiting variation in traffic flow induced by the London congestion charge zone, Tang & Van Ommeren (2022) also find significant reductions in traffic flow (9.4%) and accidents, including fatalities.

Gibson & Carnovale (2015) exploit an unanticipated suspension of Milan's congestion charge in July 2012 to evaluate the drivers' responses to road pricing, finding that drivers shift trips both spatially and temporally to avoid the charge. Nevertheless, the policy reduced air pollution and generated large welfare benefits. Examining Norwegian policies that impose different driving costs depending on the time of the day and vehicle type, Isaksen & Johansen (2021) show that such a design improves urban air quality, lowers traffic volume, and induces the adoption of BEVs among congestion charge–paying commuters. Exploring the impacts of congestion charge designs that vary with the type of vehicles on the composition of passenger vehicle fleets, Mannberg et al.

(2014) find that an exemption for alternative-fuel cars from the Stockholm congestion charge through 2008 increases ethanol car purchases, although the effect fades over time. Finally, using a triple difference approach to evaluate the impact of the Gothenburg congestion charge on car ownership and usage, Kyriakopoulou et al. (2021) find that the charge reduces the car ownership probability by half a percentage point, but there is no significant reduction in the car usage of households who keep their cars. This result is in line with that of Börjesson & Kristoffersson (2015) and Eliasson et al. (2009), who show that the Gothenburg congestion charge led to a small reduction in traffic volume, and the adjustment was slower in Gothenburg than in Stockholm (where the congestion charge was implemented earlier).

Although the primary objective of congestion charges is to alleviate traffic congestion during peak hours, it is also anticipated that improvements in congestion levels will lead to reductions in the concentrations of local pollutants. In this context, Simeonova et al. (2021) study the congestion charge in Stockholm by combining variation in congestion fees with data on pollution concentrations and administrative data on inpatient and outpatient health visits. Comparing the outcomes in Stockholm with outcomes in other Swedish cities that did not implement this policy, they demonstrate that the Stockholm congestion charge reduced ambient air pollution by 5–15% and the rate of acute asthma attacks among young children. Similarly, using a difference-in-differences approach, Conte Keivabu & Rüttenauer (2022) find that more stringent traffic regulations implemented in Central London from late 2015 contribute to a substantial decrease in both pollution and school absences for low-income students.

Examining individuals' transportation decisions and congestion is crucial for analyzing road traffic reduction. However, this is a challenging task because it requires knowing how road traffic equilibrium is modified after individuals make their transportation decisions. Using a wide range of data, Durrmeyer & Martinez (2023) develop and calibrate a structural model that characterizes equilibrium traffic conditions in a metropolitan area, considering both individual and geographical heterogeneity. Their model includes transportation mode and departure time choices by individuals with heterogeneous but fixed travel patterns and area-specific congestion technologies affecting driving speeds. Comparing road tolls to driving restrictions during peak hours, their policy simulations show that driving restrictions are less detrimental to individuals than uniform tolls but generate less tax revenue. They find that benefits from reduced emissions offset only 2.4% to 4.5% of surplus losses, which range from €0.7 to €1.5 million per trip at the aggregate level. They also find that personalized tolls yield greater welfare gains and emissions reductions than variable tolls but still reduce aggregate consumer surplus. After evaluating the role of access to public transport, public transport efficiency, and cost for surplus losses, the authors argue that connecting the part of the population that lacks access to public transportation and improving public transport speed are the best ancillary instruments to reduce policy surplus losses.

4.3. Electronic Metering

Smart electronic devices (e.g., Global Positioning System or GPS) can be used to impose a vehicle-, time-, and space-differentiated taxation to car drivers. This taxation system is more sophisticated than congestion charges because it can take into account factors such as the vehicle used, time of travel, specific location, or route taken. It can also track mileage and driving behavior, such as speed and acceleration. It can be used to encourage more efficient use of roadways, reduce congestion during peak hours, and incentivize the use of environmentally friendly vehicles. In that sense, electronic metering can internalize many of the externalities associated with road transportation and is closer than other instruments to the optimal policy.

Even though many countries are examining the implementation of electronic metering for vehicles entering the city centers, this type of policy has not yet been applied to private cars. But a simpler version, namely a VMT tax—a policy charging drivers based on how many miles they have traveled—has been implemented for heavy vehicles in various places in Europe, the United States, and New Zealand. This policy can be used as an alternative to fuel taxation, the revenues of which are constantly decreasing due to the increased popularity of electric vehicles and the higher efficiency of internal combustion engines.

As VMT taxes have not been implemented for private vehicles, there is no empirical evidence on their efficiency. A recent study by Langer et al. (2017) develops a model of drivers' short-run demand for automobile travel measured in vehicle miles that takes into account the heterogeneity of the drivers and their vehicles and estimates drivers' responses to changes in the marginal cost of driving a mile with the vehicles they currently own. This approach allows them to compare the impact of the fuel and VMT taxes by assuming that each one of them can raise the same amount of money per year, but VMT taxes can be different for urban and rural driving. This empirical exercise using US data shows that the implementation of a VMT tax is more efficient and is better than the fuel tax at affecting the behavior of the drivers who create the greatest externalities.

5. CONCLUSIONS

Economic theory, supported by many of the empirical studies discussed above, is unequivocal in its conclusion that fuel taxes should be the cornerstone of policy to drive a transition to zero-carbon transport. The public resistance to such taxes epitomized by the French *gilets jaunes* movement shows that we either need to work on alternatives or find ways to win over public opinion. Policy makers have largely plumped for the former and have, among other things, financed giveaways to buyers of new, cleaner vehicles. These have done little to reduce carbon emissions because dirty vehicles have remained on the road and are also regressive because new car buyers are typically high-income households. Policy makers should look more to scrappage subsidies than new car subsidies and impose higher taxes on car ownership of polluting vehicles. Getting polluting cars off the road should be a focal point of climate transport policy.

Beyond climate policies, it is essential to address other externalities stemming from the use of passenger cars through appropriate policy measures. These externalities include local pollutants, congestion, accidents, and the potential impediment of agglomeration benefits in polluted areas. Command-and-control policies, such as LEZ or ZEZ regulations, have been successful in reducing local pollution and should be more widely implemented during the transition to BEVs. Moreover, recognizing that congestion and accidents will remain relevant even in the era of BEVs, the use of differentiated policies such as time- and vehicle-specific charges, along with more sophisticated electronic metering, can significantly reduce their magnitude.

Implementing environmental transport policies, such as fuel taxes, congestion charges, and promoting the switch to BEVs, is a crucial step in mitigating the impact of transportation on the environment and achieving the net zero emission target. However, it is important to recognize that these policies include challenges, such as high costs and distributional impacts. For example, fuel taxes and congestion charges impact low-income households more significantly as a proportion of their income. Researchers and policy makers should pay more attention to finding strategies that are both economically efficient and acceptable on political economy and distributional grounds, such as measures in which revenues are allocated toward funding policies that mitigate negative distributive impacts. This may involve implementing measures to protect vulnerable groups or offsetting the financial burden through targeted subsidies or rebates.

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