Policy Brief No. 2

Designing Policies to Green Road Transportation

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Key Points

- **Only a set of complementary policies can address traffic externalities. There is no silver bullet.**
- **The prevailing set of policies places too much emphasis on fuel efficiency and too little on curbing mileage.**
- **Fuel taxes and road pricing strongly affect driving.**
- **Progressive tax credits at the point of purchase can help overcome barriers in electric vehicle adoption.**
- **Recycling revenues from fuel and road pricing for public transport multiplies the impact of policies.**

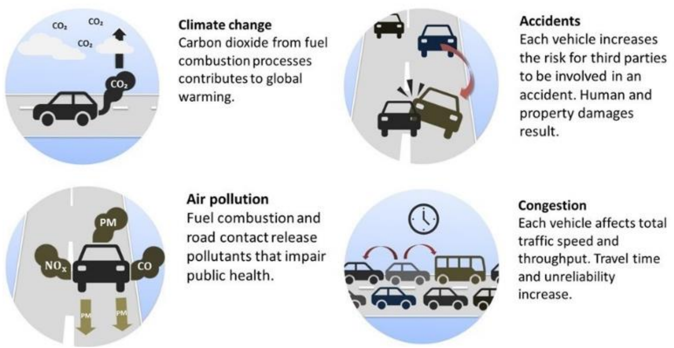
1. Externalities: The unintended side effects of road traffic

While undeniably beneficial for society, road transportation also has significant social costs that are ignored by private users when deciding if, where, how, and at what time to travel. Policymakers are mainly concerned about four sizeable externalities from road transportation:

1. **Climate change.** Road transportation causes carbon dioxide (CO_2) emissions. In Europe, transport is responsible for 26% of total CO_2, two thirds of which stem from cars and vans [1]. The social costs of carbon are borne globally.
2. **Road congestion.** Each vehicle on the road contributes to congestion and slows traffic. In heavy traffic, additional vehicles can reduce throughput. The social costs of congestion consist of increased travel time and decreased reliability of travel times.
3. **Local air pollution.** Fuel combustion results in emissions of carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM). Wheel-to-road contact, as well as brake, tire, and gear wear contribute to PM emissions. There is ample evidence that these pollutants cause harm to public health [2] [3] [4] [5] [6], even at low levels [7].
4. **Accidents.** Each vehicle on the road increases the probability of accidents. The social costs of this externality include loss of life, property damages and physical injuries resulting in medical expenditures.

Externalities reinforce another, e.g. congestion may increase air pollution and CO_2 emissions [2] [5] because stop-and-go traffic reduces fuel efficiency and increases travel times [8].

Here, we focus on the implications of these four externalities and identify effective policy instruments to address them. First-best solutions (Section 2) are compared to real-world current (Section 3) and emerging (Section 4) second-best policies. We explain their mechanisms, identify their goals and summarize empirical evidence. Other externalities such as noise, urban sprawl, road damages, or oil dependency [9] are also important but beyond the scope of this policy brief. We mainly focus on light-duty vehicles in an urban context.



2. Benchmark: First-best policies

The CO_2 emissions of a liter of fuel are fixed. Thus, a fuel tax is the optimal instrument to curb CO_2 emissions. However, it is a first-best policy choice only *if* consumers are far-sighted and accurately account for future fuel savings from improved fuel efficiency [10]. However, consumers are often myopic, and, hence, systematically underestimate fuel savings. Therefore, fuel-economy or CO_2 standards and vehicle taxes are necessary complements to fuel taxes for a *first best policy mix*. This set represents the most prominent real-world policies (Section 3).

Standards increase fuel efficiency by regulating the supply of vehicles and preventing myopic consumers from buying inefficient new vehicles. On the demand side, vehicle taxes penalize inefficiency and counteract short-sightedness by making efficient vehicles more attractive [10]. There is no clear consensus on the extent of myopia but most studies find at least a modest undervaluation of fuel savings [11] [12] [13] [14].

Fuel taxes are an efficient policy measure because fuel consumption perfectly correlates with CO_2 emissions. Because the relationships between fuel consumption, local pollution, congestion, and accident risk varies with vehicle characteristics, location, and time [15] [16] [17], addressing these externalities is more challenging. Viable policy options include road pricing and banning high-polluting vehicles (Section 4).

3. The three traditional policy pillars

3.1 Fuel taxes

Fuel taxes raise the price of fuel at the pump.

New vehicles become more efficient and shrink in size. Inefficient old vehicles are scrapped.

There is robust evidence that higher fuel prices increase the fuel efficiency of the vehicle fleet via two channels. First, consumers buy more efficient vehicles [18] [19]. Second, they choose smaller and lighter ones [10]. Fuel taxes are particularly efficient with frequent drivers [14] and reduce the sales of trucks and SUVs [20]. Third, fuel taxes accelerate the scrappage of older, less fuel-efficient vehicles while extending the lifetime of newer and more efficient ones [21] [22]. Changes in tax have a smaller effect on fuel economy in Europe than in the US [23].

Consumers drive less.

Fuel taxes decrease the distance travelled by car [10]. Empirical US-studies [24] [25] yield a fuel price elasticity of distance traveled between -0.10 and -0.30. Thus, a 10% increase in fuel prices reduces km driven by 1-3%. Estimates for Europe [26] [27] yield stronger elasticities between -0.30 and-0.45 which can be explained by higher availability of public transportation in this region [27] [28] [29]. Diesel car drivers are particularly responsive to fuel taxes [14] [27] [30]. Fuel taxes reduce pollution, congestion, and accidents proportionally to the decline in travel distance [10]. A fuel tax, however, can only recover a fraction of the incurred efficiency losses from these externalities [15]. Real fuel taxes in the EU-15 for gasoline and diesel remain constant since 2000 [31], leaving their full potential to curb externalities untapped.

3.2 Standards

Standards prescribe the minimum efficiency new vehicle fleets must achieve in terms of mean fuel consumption or emissions.

New cars get more efficient. Life of old inefficient cars extends.

Similar to fuel taxes, standards directly shift demand towards greater fuel economy [32] [33], even if consumers undervalue efficiency savings [10]. In the EU, the introduction of standards coincides with a 14% drop in CO_2 emissions. However, only 30% of the improvements in official emission ratings manifest on the road [33]. While fuel taxes incentivize scrapping, standards do not affect the operating costs of used vehicles. Since inefficient old and new vehicles are substitutes, the resale value and lifetime of used ones increases. This "Gruenspecht effect" reduces expected fuel savings by 13-16% [21]. Incentive programs for the scrapping of old vehicles may mitigate this adverse effect [34] [35] [36]. As standards ignore differences in vehicle lifetime mileage, they recover only 25-33% of the welfare loss from externalities [37].

Size-based standards often subsidize vehicle size.

Current standards in the EU, the US or Japan are attribute-based, linking efficiency targets to a vehicle's size or weight. Heavier vehicles face less stringent targets than lighter ones. This allows compliance burdens to spread more equally across manufacturers but may incentivize upsizing [38]. By accounting for historical vehicle dimensions at the manufacturer-level, European standards neutralize up-sizing incentives and instead accelerated technology, e.g. automatic engine shut-offs during stops [33].

Rebound effect: When driving costs fall, consumers drive more.

Efficiency standards reduce fuel consumption. Thus, the cost of driving declines and consumers are encouraged to drive more, which partly eliminates the initial gains from standards. A large body of literature estimates that this rebound effect [9] [10] [39] [40] reduces 5-30% of potential energy savings from efficiency improvements [41]. Note that the rebound and the Gruenspecht effect are additive. With the exception of CO_2 per km, standards at best fail to mitigate externalities and at worst exacerbate those scaling with driving [10].

3.3 Vehicle taxes

Vehicle taxes include purchase, registration & ownership taxes.

Vehicle taxes can address consumer myopia.

Empirical evidence confirms that vehicle taxes affect the composition of new vehicle sales in spite of consumer myopia [14]. Most EU countries impose registration or annual vehicle taxes that depend on CO_2 emissions. There is evidence that CO_2-based registration taxes in the EU reduce the average CO_2 emission intensity of new vehicles by 1.3% [42]. Registration taxes are more effective than annual taxes [43] [44] [45]. However, with more fuel efficient vehicles, drivers are likely to travel more (rebound effect) [44].

Lump sum tax credits support clean vehicle adoption.

Tax incentives must be salient to change behavior [46] [47]: Consumers respond more keenly to rebates and sales tax exemptions at the time of sale compared to complex income tax incentives, which have to be applied for and accrue later [43] [48]. Exploiting this consumer behavior may significantly accelerate the diffusion of new technologies such as electric vehicles (EV) [49] [50]. Evidence from the US suggests that a sales tax waiver may increase hybrid EV sales by 45% compared to a 3-5% increase from income tax credits of a similar magnitude [43]. However, tax rebate programs subsidize those who would have bought an EV anyway, which reduces the policy's cost effectiveness [51] [52]. This windfall effect is most prevalent in high-income households, who often have higher preferences for EVs. Lower-income consumers, however, only demand EVs in the presence of rebates. Progressive tax rebates granting higher credits to lower-income consumers may increase the number of additional EVs sold per Euro of rebate [48]. A combination of fuel tax increases and vehicle tax incentives is the most effective support for EV adoption [19].

Policy	Externality				Effect Mechanism				
	Climate change	Congestion	Air pollution	Accidents	Fuel economy (km/l)	Mileage (km)	Car attributes (size, weight)	Car stock (# vehicles)	Mode switch (# switches)
Fuel Tax *(with myopia)*	**+**	+	+	+	↑	**↓**	↓	↓	↑
Standards *(with rebound)*	+	–	–	–	**↑**	↑	↑/0	0	•
Vehicle Tax *(with rebound)*	+	–	–	–	**↑**	↑	0/↓	↑/0	•
Road Pricing *(Cordon Toll)*	+	**+**	+	+	•	↓	•	•	↑
Driving Bans *(Low Emission Zone)*	•	•	+	•	↑	•	•	•	•
Public Transit Subsidies	+	+	+	+	•	↓	•	↓	**↑**

Note: + and – indicate positive or negative effects. Arrows indicate increases and decreases in parameters. Bold symbols are for first-best policies and direct mechanisms. Dashed arrows indicate weak mechanisms while dots indicate insufficient credible evidence.

Effect of feebates on CO_2 emissions is ambiguous.

Recently, feebates have received particular attention. This policy grants tax rebates to buyers of fuel-efficient vehicles, while imposing fees on buyers of inefficient ones. This policy may promote low-emission vehicles without public spending. Research on the French "Bonus/Malus" feebate, however, suggests that real-world feebates emphasize rebates over fees [44]. As a result, the French policy not only shifts demand towards low-emission vehicles but can also involve a strong increase in total vehicle sales and, ultimately, CO_2 emissions. A simulation of hypothetical German feebates implies that welfare gains require total fees to exceed total rebates [53].

4. Emerging policies

4.1 Road pricing

Road pricing is a first-best policy to reduce congestion [16] [54]. The introduction of charges, that reflect the cost imposed on the system by individual drivers through lowering the speed of others, encourages drivers to use less congested roads, to not travel during rush hour, or to switch to other modes of travel such as public transit and ride sharing [55]. Electricity networks face similar congestion problems as road networks and are benefitting from congestion pricing for over a decade now [56].

Optimal design and current use.

A first-best road pricing policy charges drivers according to the local level of congestion at the time of travel. As this often proves infeasible, cities such as London, Milan, and Stockholm apply second-best solutions in the form of cordon tolls. These are time-invariant charges for driving within or into a defined area. In San Diego and Los Angeles, road access tolls vary with road conditions, while in Singapore and on San Francisco's Bay Bridge, tolls vary by time of day. Road pricing systems in New Zealand and Oregon rely on distance-based charges that are independent of location. Finally, road use for trucks is priced, inter alia, in Germany and Switzerland. Notably, parking fees may also disperse demand over time, reducing congestion [94].

Tolls effectively manage mode choice and time of travel.

There is strong evidence for the effectiveness of cordon tolls. In London, Stockholm, and Milan road traffic is 12-22% lower since the introduction of tolls, while the number of public transit trips is 4.5-30% higher [57]. Bus ridership is amplified even further as busses travel at higher speeds on less congested roads [58] [59]. The cordon tolls reduces congestion by shifting road demand to unpriced areas or times [60]. The effectiveness of tolls depends on the available level and quality of public transport [61]. While cordon tolls offer considerable efficiency gains [62] [63], more sophisticated dynamic pricing schemes accommodating peak times and local conditions are key to fully optimize road use [61] [64] [65].

Value pricing schemes target selected lanes. Users with high time costs have the opportunity to use less congested lanes for a fee. This option enhances efficiency if time preferences vary across drivers but it is also prone to displacing traffic to less congested roads instead of reducing it [64]. Empirically, the additional efficiency gains remain modest [55] [66] but it is possible to offset negative distributional effects [67] [68]. Studies of mileage taxes are scarce. The Swiss mileage tax for trucks reduces truck traffic by 4-6% in favor of rail [69]. In contrast, evidence for the German mileage truck toll on federal highways suggests a diversion of traffic to toll free roads [69].

Tolls reduce congestion, accidents, and pollution effectively.

Analyses for London, Stockholm, and Milan indicate that road pricing decreases congestion delays by 30-50%, accidents by 2-21% and vehicle emissions by 9-19% [57]. Several empirical studies also report significant air pollution reductions and health benefits caused by road charges. For instance, air pollution is 5-15% lower in the regulated area in Stockholm and there are significant reductions in childhood asthma incidents [7]. The 6-7% decrease in air pollution in Milan raises welfare by approximately $3B annually [60], while a temporary suspension of tolls for eight days in China may increase air pollution by 20% and health costs by at least $15M. [70].

Road pricing is a source of revenue.

It is possible to redistribute the revenues from road pricing [71], but targeting transfers is difficult [72]. Earmarking revenues for public transport is crucial for securing public support [58]. Road pricing may alleviate the funding gap in fuel tax revenues due to greater fuel economy and EV adoption.

4.2 Driving bans

Driving bans restrict car use at certain times or places. They aim to reduce air pollution and congestion.

Low emission zones reduce pollution.

Low emission zones (LEZs) limit access to vehicles that meet pollution standards. European cities adopt LEZs to reduce PM emissions and empirical evidence for Germany confirms reductions between 4% and 9% [73] [74]. Proximity to a LEZ makes consumers more likely to own a low-emission vehicle. The forced substitution away from old dirty cars may decrease the magnitude of the Gruenspecht effect. To secure access to LEZs, the number of commercially owned low-emission vehicles in Germany is up by 88% [73]. Yet, the reduction in air pollution has not conferred improvements in infant health [74].

Impact of plate-based driving bans differs across cities.

Some driving bans restrict the use of private vehicles to certain days based on license plate digits. Their effectiveness depends on the local context. Early evidence from major Latin American cities demonstrates ineffectiveness at reducing pollution and congestion [75] [76] [77]. By buying high-polluting, second vehicles for different license plates, drivers in Mexico City circumvent bans. Overall, the regulation unintentionally increases the size of the vehicle fleet and its emission intensity [75]. In contrast, similar driving bans in Beijing [78] [79] and Quito [80] reduce air pollution and congestion. In Beijing, air pollution is 21% lower and the analysis does not imply a shift towards driving at unregulated times [78]. The combination of high levels of compliance with high costs of additional vehicle ownership explains this success.

4.3 Public transport subsidies

Subsidizing public transport lowers its cost relative to private transport. It is the key for modal shifts.

Large ridership response to public transport service extension.

Empirical studies confirm that expanding public transportation infrastructure increases public ridership. Doubling the size of a metro network increases ridership by 60-70% [81]. Most new ridership is due to modal switches. The subway network extension in Copenhagen also reduces vehicle ownership by 2-3% [82]. Bus lanes and rapid transits (BRT) are effective and low-cost ways to improve service levels [59] [83].

Public transport is an important supplement to other policies.

Public transport availability increases the effectiveness of fuel taxes and road pricing to curb driving [27] [60] [61]. As low-income households often use public transport, subsidizing it redistributes income [59]. Research generally supports the efficiency of the current level of subsidies and the example of London shows that subsidies in excess of 50% of fares improve welfare [84]. Yet, their benefits may decline in the presence of other policies such as congestion pricing [59].

Public transport can curb externalities from vehicles.

New subway systems may reduce air pollution by 4-15% [85] [86]. Public transit strikes in Germany provide a counter-factual and temporarily increase PM pollution by 14% and hospital admissions for respiratory diseases in children by 11% [87]. More frequent rail services in Germany lower concentrations of CO and NO_x [88] but the literature also highlights the importance of context. Given the structure of cities across the US and Canada, public transit may lower air quality because the degree of substitution from vehicles to public transport is small [89] [90] [91]. The effect of public transport on congestion is substantial. Its absence increases average highway delays by 47% in Los Angeles [92], public transit strikes in Germany increase total vehicle hours by 11-13% [87] and evidence from Rotterdam values the congestion relief at 80% of the total public transit subsidy [93].

Cited references are available at [add link]

For more information

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