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The Efficient Combination of Taxes on Fuel and Vehicles

Abstract

A tax on fuel combined with tax-exemptions or subsidies for purchase of fuel-efficient vehicles is implemented in many countries to reduce greenhouse gas emissions and other negative externalities from road traffic. This study, however, shows that a tax on fuel should be combined with heavier taxation of fuel-efficient vehicles to curb externalities from road traffic. The tax on fuel is implemented to curb externalities linked to both consumption of fuel and road use. The heavier tax on fuel-efficient vehicles prevents that motorists avoid the road user charge on fuel by purchasing fuel-efficient vehicles.

JEL-Codes: H200, H210, H230, Q580, R480.

Keywords: transportation, optimal taxation, environmental taxation, global warming.

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1. Introduction

Road transport is essential to maintain a good flow of goods, services and people. Road transport also generates costly negative externalities connected to CO2 emissions, local air pollution, accidents, congestion and noise. Many countries have implemented taxes on fuel to curb externalities linked to both fuel and mileage. The gain of reduced externalities per liter fuel is however diminished as households avoid the mileage-related tax by purchasing more fuel-efficient vehicles. Parry and Small (2005) claim that the optimal mileage-related tax rate component on fuel is halved due to such avoidance. Differentiated taxes on high- and low-emission vehicles are however excluded from the model framework in Parry and Small (2005). The aim of this study is to shed light on the second-best optimal uniform tax on fuel combined with differentiated taxes on vehicles to curb externalities linked to both consumption of fuel and road use. The study shows that the optimal mileage- related tax rate component on fuel should not be reduced as such avoidance should be neutralized by a higher tax on fuel-efficient vehicles. Many countries have, in contrast, introduced tax exemptions or subsidies for fuel-efficient vehicles.

Parry and Small (2005) calculate the optimal uniform tax rate on petrol, and shows that the optimal tax rate on petrol in the United States was more than twice as large as the current rate, while that for the United Kingdom was about half its current rate. Their significant methodological contribution have inspired a range of other studies to calculate optimal tax rates on fuel in other countries, see e.g. Anton-Sarabia and Hernandez-Trillo (2014), Lin and Zeng (2014). Anderson and Auffhammer (2014) estimate higher accident-related externalities, and suggest that UK gas taxes are closer to optimal levels compared to US taxes. Several objections can however be made to the methodology in these studies. First, differentiated taxes on purchase of vehicles are as mentioned not considered even though Innes (1996), Fullerton and West (2002, 2010) and De Borger (2001) shows that restrictions on taxes on use of vehicles imply that taxes on purchase of vehicles are desirable. Indeed, subsidizing substitutes of polluting goods might be desirable when the government is unable to tax emissions directly, see Sandmo (1976). Second, their optimal tax rate on petrol includes a Ramsey tax component. A general set of assumptions however excludes the Ramsey tax component from a welfare maximizing tax system according to Atkinson and Stiglitz (1976)[2]. Indeed, Jacobs and de Mooij (2015) show that a Pigouvian tax on polluting goods is part of a welfare maximizing tax system

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[2] Taxation of consumer goods designed to redistribute income is also rejected.

within a Mirrlees economy framework[3]. Third, tax theory adopted by Parry and Small (2005) is unable to generate one unique optimal tax rate on polluting goods according to Fullerton (1997). The explanation is that the tax rate on polluting goods is increased by a uniform tax increase on consumer goods. The impact on the allocation of private and public sector goods of this tax increase can however be neutralized by a proportional revenue neutral reduction in taxation of income. Hence, welfare is preserved even though the tax rate on polluting goods is increased.

The optimal design of taxes on both fuel and vehicles in the pioneering contributions of Innes (1996) and Fullerton and West (2002) provides the theoretical foundation for results derived within the present study. Innes (1996) do not quantify optimal tax wedges on fuel or vehicles, but the main insight is that second-best optimal vehicle taxes approximately equals the social cost of a vehicle's predicted emissions, less the portion of costs that are internalized by the gasoline tax. Fullerton and West (2002) extends the analysis, and show that vehicles with bigger engines, and hence, higher fuel consumption should be subsidized as a tax on fuel which equals the marginal damage per gallon of fuel more than completely internalize the impact of engine size. Fullerton and West (2010) extends the analysis in Fullerton and West (2002) with vehicle age, and simulates different scenarios. They find that the three-part instrument involving a gas tax, an engine size subsidy, and a new-car subsidy maximize welfare. The welfare gain of implementing the engine size subsidy however does not significantly increase welfare. The insightful analysis in Fullerton and West (2002, 2010) however leave several questions unanswered. First, the welfare gain of reduced externalities per gallon of fuel is diminished as households avoid the mileage-related tax by purchasing more fuel-efficient vehicles. It is not clear whether the optimal tax on fuel in Fullerton and West (2002) should be adjusted for such avoidance. Second, a tax on fuel which equals the marginal damage of CO2-emissions will perfectly internalizes CO2-emissions due to a bigger engine. Hence, it is not clear whether CO2-emission-intensive vehicles should be subsidized. Third, several empirical studies find that households have rational expectations when purchasing vehicles, see Sallee et al (2016) and Busse et al (2013). Some studies however find support for partly myopic behavior, see Grigolon etc. (2014)

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[3] Results in the literature differ on the issue of whether environmental taxes should deviate from the Pigouvian rate due to tax revenue requirements. The optimal tax rate in Parry and Small (2005) is lower due to tax revenue requirements. Jaeger (2011), however, finds that the need for tax revenues contributes to increase the optimal environmental tax wedge above the Pigouvian tax rate. The optimal CO2 tax also exceeds the quota price when the government purchase quotas and the marginal cost of public funds exceed one according to Bjertnæs et. al. (2013). The second-best optimal tax rate on fuel is lowered due to tax revenue considerations with an emerging electric vehicle market, see Tscharaktschiew (2015). A lower tax on fuel reduces the incentive to switch to lower taxed electric vehicles, which ultimately expands other distorting taxes to satisfy the government budget constraint.

and Allcott and Wozny (2014). Myopic behavior is not considered by Innes (1996) or Fullerton and West (2002, 2010).

These objections to Parry and Small (2005) concerning omitted taxation of vehicles and Ramsey tax components, and issues in Fullerton and West (2002, 2010) concerning the impact of tax avoidance and myopic behavior is resolved in this study by calculating taxes on fuel and vehicles designed to curb externalities from road transport. A partial model framework of the transport sector is employed where heterogeneous households choose type of vehicle and driving distance. The government chooses taxes to maximize an individualistic welfare function. Tax revenue collected is transferred to households without distorting the economy. Hence, optimal taxes are obtained by balancing the efficiency cost of taxation against the welfare gain of reduced externalities. This optimum condition is consistent with the optimum condition for environmental goods in Jacobs and de Mooij (2015). The Pigouvian solution is however excluded when policy instruments are restricted to a uniform tax on fuel combined with differentiated taxes on vehicles. Optimal taxes are then compared with current taxes in selected countries.

The study shows that the optimal tax on fuel equals the marginal damage of CO2 emissions plus the weighted average marginal damage of mileage-related costs of road transport in the case with rational expectations[4]. The CO2-tax on fuel provides correct incentives for mileage. The road user charge on fuel exceeds mileage-related externalities for vehicles with higher than average fuel consumption per mile. The road user charge is lower than the mileage-related externalities for fuel-efficient vehicles. Distortions in mileage due to such differences are however optimal in a second-best solution where policy tools are restricted.

Taxes on fuel are fully accounted for by households with rational expectations who purchase a vehicle. Hence, the CO2-tax on fuel provides correct incentives for choice of vehicle in this case. The choice of vehicle is however distorted by the mileage-related tax on fuel as taxes deviate from externalities. An optimal additional tax on fuel-efficient vehicles which neutralizes these differences between road user charges on fuel and mileage-related externalities imply that households face correct costs of externalities when choosing vehicle. Hence, avoidance of road user charges on fuel

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[4] This result is consistent with the result in Diamond (1973). The optimal road user charge on fuel is however reduced below the marginal cost of mileage- related externalities when economic driving is considered, see Bjertnæs (2017). The tax is reduced to prevent costs of road tax avoidance due to economic driving.

by purchasing fuel-efficient vehicles should be neutralized by a tax on fuel-efficient vehicles in this case.

Myopic behavior implies that households underestimate the benefits of purchasing fuel-efficient vehicles. It is optimal to correct for such behavior by reducing the tax on fuel-efficient vehicles. The study illustrate the impact of myopic behavior by calculating the optimal tax wedge between different Volkswagen Passat models, and shows that the optimal tax on low emission models exceeds the tax on high emission models, also in the case with myopic behavior. Jansen and Denis (1999) conclude that the desired policy mix to reduce CO2-emissions consists of a tax on fuel combined with differentiated purchase taxes to correct for myopic behavior. A mileage-tax is however introduced into their model simulations to reduce mileage-related emissions.

The optimal tax on fuel designed to curb externalities is compared with current tax wedges between fuel and non-polluting goods to prevent shortcomings due to the lack of a unique optimal tax rate on polluting goods[5]. The comparison uncovers substantial room for improvements. The current US tax wedge, 37.3 cents per gallon, is way below the optimal tax wedge, 2.36 dollars per gallon. The current UK and German tax wedge is also lower than the optimal tax wedge. The Norwegian tax wedge, however, is higher. The road user charge is to a large extent levied on fuel within all these countries. Hence, it is optimal to tax fuel-efficient vehicles more heavily to neutralize avoidance of the road user charge on fuel. Substantial tax exemptions for purchase of these vehicles are in contrast introduced in all countries except for the US where the tax wedge is modest.

The lack of road user charges for electric vehicles implies that the optimal additional tax on electric vehicles equals the life time value of mileage-related externalities for electric vehicles when other market imperfections are absent. Substantial differences in mileage-related costs between geographic regions call for geographic tax differentiation between regions. Implementation of geographic tax differentiation favor a yearly vehicle tax as differentiated taxes on purchase is more likely to be hampered by evasion. Tax exemptions and/or subsidies for purchase of electric vehicles

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[5] The optimal tax rate on petrol in Parry and Small (2005) equals the optimal tax wedge between petrol and non-polluting goods as the tax rate on non-polluting goods is set equal to zero. This tax wedge is however compared with current tax rates on petrol, and not current tax wedges between petrol and non-polluting goods.

are in contrast introduced in all selected countries, although some US states have introduced annual road user fees for electric vehicles.

Allowing for vehicle specific taxes on fuel or a GPS-based tax on driving removes the problem with avoidance of road user charges on fuel. The study shows that the tax wedge between high- and low-emission vehicles should be zero in the absence of other market imperfections in these cases. Both these solutions lead to a more efficient allocation of vehicles and driving distance compared to the second-best solution presented above. Such systems are on the other hand more costly to administer.

2. The model framework

2.1 Households

Households choose driving distance and type of vehicle with different fuel economy. Household $i's$ utility, u_i, net of externalities is given by the quasilinear utility function

(1) $u_i = u(km_i) + b_i + c_i$, with a fuel-intensive vehicle and $u_i = u(km_i) + c_i$ with a fuel-efficient vehicle. $u' > 0$ and $u'' < 0$.

The utility is determined by driving distance measured in kilometer, km_i, consumer goods, c_i, and the utility connected to owning a fuel-intensive vehicle instead of a fuel-efficient vehicle, b_i. This utility parameter differs between households as transport needs and requirements differ between households. Some households may prefer the fuel-efficient vehicle, i.e. their utility parameter, b_i, is negative. Some road trips are more important/ necessary to households than other road trips. This feature is captured by the utility function for driving distance. The household budget constraint is

(2) $c_i = y + k - (p_l + t_l) f_j km_i - t_{car,j} - p_{car,j}$, where $j = high, low$ indicates vehicle with high and low fuel consumption per kilometer.

Income, y, and transfers, k, are fixed for households. The cost of using the vehicle is given by the price of fuel, p_l, the tax on fuel, t_l, the theoretical fuel economy measured in liters per kilometer,

f_j, and driving distance in kilometer, km_i. Vehicle maintenance and capital depreciation is excluded from the operating costs of vehicles to simplify the model framework. A tax designed to correct for negative externalities is however not influenced by such operating costs when externalities are not influenced by such operating costs[6]. The cost of purchasing a vehicle is determined by the producer price, $p_{car,j}$, plus the tax, $t_{car,j}$. The tax on purchase of fuel-intensive vehicles, $t_{car,high}$, equals t_{car}. The tax on purchase of fuel-efficient vehicles equals zero. Note that theoretical fuel-efficiency equals actual fuel-efficiency within the model framework even though deviations and even cheating is observed in the real world. Utility maximization with respect to km_i imply that

(3) $u'_{km_i} = (p_l + t_l) f_j$.

Or,

(4) $km_i = d_j(t_l)$, where $j = high, low$ indicates each type of vehicle.

Hence, driving is restricted to trips where the benefit exceeds the costs. Demand for driving distance is identical for individuals with identical vehicles. The indirect utility function net of externalities for each household, i, with each type of vehicle is found by implementing equation (2) into equation (1), and then implementing equation (4).

(5) $v_{i,high} = u(d_{high}(t_l)) + b_i + y + k - (p_l + t_l) f_{high} d_{high}(t_l) - t_{car} - p_{car,high}$,

and $v_{i,low} = u(d_{low}(t_l)) + y + k - (p_l + t_l) f_{low} d_{low}(t_l) - p_{car,low}$.

Each households' utility connected to owning a high emission vehicle instead of a low emission vehicle, b_i, differ across households. Assume that households are ranked from high to low according to their utility parameter, b_i, and that the N first households have chosen the high emission vehicle. Assume that their accumulated utility connected to owning a high-emission vehicle instead of a low-emission vehicle, BA, is given by the expression

(6) $BA = b_{\max} N - \frac{1}{2} a N^2$,

where $a > 0$ and no restrictions are imposed on $b_{\max}$. Households choose the type of vehicle that maximizes utility. Households therefor choose the high-emission vehicle to the point where

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[6] Maintenance could e.g. be preserved by maintenance control.

household number N is indifferent between types of vehicles. This equilibrium conditions, equation (7), is satisfied as the utility parameter, b_i, is decreasing as N is increasing.

$$(7)\quad u(d_{high}(t_l))+b_{\max}-aN+y+k-(p_l+t_l)f_{high}d_{high}(t_l)-t_{car}-p_{car,high}$$
$$=u(d_{low}(t_l))+y+k-(p_l+t_l)f_{low}d_{low}(t_l)-p_{car,low},$$

Households with a higher willingness to pay for owning a fuel intensive vehicle is going to choose a fuel intensive vehicle. Households with a lower willingness to pay for owning a fuel intensive vehicle will choose a fuel-efficient vehicle. Equation (7) determines the number of households which choose the high-emission vehicle as a function of taxes on fuel and vehicles as well as exogenous parameters and producer prices. This equation is presented as equation (8) to simplify notations.

$$(8)\quad N=N(t_l,t_{car}).$$

The total number of households is $\overline{N}$. Hence, the number of households that choose the low emission vehicle amounts to

$$(9)\quad N_{low}=\overline{N}-N$$

2.2 Costs of road traffic

The social cost of driving consists of damage from CO2 emission and damage from mileage-related externalities. The damage from CO2 emission, S_{CO2}, is determined by the number of liter fuel multiplied by the cost of CO2 emissions per liter fuel, p_{CO2}.

$$(10)\; S_{CO2}=p_{CO2}Nf_{high}d_{high}(t_l)+p_{CO2}(\overline{N}-N)f_{low}d_{low}(t_l).$$

A share of the current lifetime emission from vehicles originates from production of vehicles and energy, se Hawkins et al. (2012). CO2-emission from production of energy and vehicles are however excluded from the model framework. This assumption is relevant when all polluters pay for their own emissions. The assumption is also relevant when such emissions are included in an emission trading system like EU ETS, and hence, are neutralized by adjustments in other sources of emissions.

The cost of mileage-related damage, S_d, is determined by the total number of kilometer driven multiplied by the cost of mileage-related damage per kilometer, p_d.

(11) $S_d = p_d N d_{high}(t_l) + p_d (\overline{N} - N) d_{low}(t_l)$

The cost of traffic congestion and damage due to accidents is dominating, while costs of local pollution are more modest. These costs are influenced by a range of factors like e.g. drinking and driving, reckless driving and speeding. It is assumed that the present level of drinking and driving, reckless driving and speeding is preserved by current traffic laws and regulations.

2.3 The government

The government chooses the uniform tax rate on fuel and the tax on purchase of fuel-intensive vehicles to maximize welfare. Tax revenue collected is transferred to households. Each household receive a lump-sum transfers, k. The transfer is chosen to balance the government budget constraint. The government budget constraint is

(12) $\overline{N}k = N t_l f_{high} d_{high}(t_l) + N t_{car} + (\overline{N} - N) t_l f_{low} d_{low}(t_l)$.

The welfare function is given by the sum of indirect utility functions, equation (5), minus social costs of traffic, equation (10) and (11), with the government budget constraint, equation (12), and the condition determining the allocation of vehicles, equation (8), incorporated. The government chooses taxes to maximize this welfare function. The problem is

(13)

$$\underset{t_l, t_{car}}{Maks} \quad \overline{N}y + N(t_l, t_{car}) u(d_{high}(t_l)) + b_{\max} N(t_l, t_{CO2}) - \frac{1}{2} a N(t_l, t_{CO2})^2$$

$$+ (\overline{N} - N(t_l, t_{CO2})) u(d_{low}(t_l)) \; - N(t_l, t_{car}) \left[p_{car,high} + p_l f_{high} d_{high}(t_l) \right]$$

$$- (\overline{N} - N(t_l, t_{car})) \left[p_{car,low} + p_l f_{low} d_{low}(t_l) \right] \; - p_{CO2} N(t_l, t_{car}) f_{high} d_{high}(t_l)$$

$$- p_{CO2} (\overline{N} - N(t_l, t_{car})) f_{low} d_{low}(t_l) \; - p_d N(t_l, t_{car}) d_{high}(t_l)$$

$$- p_d (\overline{N} - N(t_l, t_{car})) d_{low}(t_l)$$

Note that choice of transfers, k, is excluded from the optimization problem as the government budget constraint is implemented into the welfare function. The first order conditions imply that

$$(14)\; u(d_{high}(t_l)) + b_{\max} - aN - p_{car,high} - p_l f_{high} d_{high}(t_l) - p_{CO2} f_{high} d_{high}(t_l) - p_d d_{high}(t_l)$$
$$= u(d_{low}(t_l)) - p_{car,low} - p_l f_{low} d_{low}(t_l) - p_{CO2} f_{low} d_{low}(t_l) - p_d d_{low}(t_l),$$

see appendix A. Second order conditions are presented in appendix B. Equation (14) shows that the benefit minus private and social costs of one additional high-emission vehicle equals the benefit minus private and social costs of one additional low-emission vehicle within a welfare maximizing solution. This solution is implemented by setting the tax on fuel equal to

$$(15)\; t_l^* = p_{CO2} + \frac{\left(N d_{high}{}'_{t_l} + (\overline{N} - N) d_{low}{}'_{t_l}\right) p_d}{N d_{high}{}'_{t_l} f_{high} + (\overline{N} - N) d_{low}{}'_{t_l} f_{low}}.$$

The CO2-tax component on fuel, the first term on the right hand side of equation (15), equals the social cost of CO2-emissions for both types of vehicles. The road user charge on fuel, the second term on the right hand side of equation (15), equals the reduction in mileage-related damage due to a marginal tax increase on fuel (the numerator), divided by the reduction in fuel consumption due to a marginal tax increase on fuel (the denominator). Hence, the road user charge on fuel equals the reduction in mileage-related damage per liter reduced fuel consumption due to a marginal tax increase on fuel. This road user charge on fuel exceeds mileage-related externalities for fuel-intensive vehicles. The road user charge on fuel is lower than mileage-related externalities for fuel-efficient vehicles. The welfare maximizing tax on fuel-intensive vehicles equals

$$(16)\; t_{car}^* = \frac{\frac{\overline{N} - N}{\overline{N}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{high}(t_l *)$$
$$+ \frac{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{low}(t_l *).$$

Both terms on the right side are negative. Hence, there should be heavier taxes on fuel-efficient vehicles compared to fuel-intensive vehicles. The interpretation of these tax formulas are clarified by the following comparison. Assume that the tax on purchase of vehicles with poor fuel economy is set equal to the difference in mileage-related external costs for high and low-emission vehicles minus the difference in the road user charge on fuel for high and low-emission vehicles. i.e.

$$(17)\, t_{car} = p_d d_{high}(t_l) - P_d d_{low}(t_l)$$

$$- \frac{\left(\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} + \frac{\overline{N} - N}{\overline{N}} \right)}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d f_{high} d_{high}(t_l)$$

$$+ \frac{\left(\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} + \frac{\overline{N} - N}{\overline{N}} \right)}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d f_{low} d_{low}(t_l)\,.$$

A comparison with equation (16) shows that this equation is identical with the optimal tax on fuel intensive vehicles. The difference in road user charge on fuel for high- and low-emission vehicles that deviate from the difference in mileage-related damage for high- and low-emission vehicles is completely neutralized by the subsidy for fuel-intensive vehicles, or equivalently, the additional tax on fuel-efficient vehicles. These taxes on fuel and vehicles mimic the cost of externalities connected to each type of vehicle. Hence, household's choice of vehicles implements the socially desirable allocation of vehicles given by equation (14).

The model framework excludes road transport within production sectors. Tax formulas designed to correct for externalities from the household sector are however relevant if externalities from road transport within production sectors are identical with externalities from the household sector.

2.4 A fixed stock of vehicles

The share of newly purchased vehicles relative to the stock of vehicles is small because the life expectancy of vehicles is close to 20 years. The government maximization problem is altered to illuminate on this issue. The tax on purchase of vehicles does not influence driving distance within the current model framework when it is assumed that the stock of vehicles is fixed. Hence, the short run government maximization problem is reduced to choose the tax rate on fuel that maximizes welfare in this case. The problem is

(18)

$$\underset{t_l}{Maks} \ \bar{N}y + Nu(d_{high}(t_l)) + b_{\max} N - \frac{1}{2} aN^2 + (\bar{N} - N)u(d_{low}(t_l))$$

$$- N\left[p_{car,high} + p_l f_{high} d_{high}(t_l)\right] - (\bar{N} - N)\left[p_{car,low} + p_l f_{low} d_{low}(t_l)\right]$$

$$- p_{CO2} N f_{high} d_{high}(t_l) - p_{CO2} (\bar{N} - N) f_{low} d_{low}(t_l) - p_d N d_{high}(t_l)$$

$$- p_d (\bar{N} - N) d_{low}(t_l) .$$

The first order condition is identical with the first order condition that determines t_l in appendix A. The second order condition is presented in appendix C.

$$(19) \quad t_l^{**} = p_{CO2} + \frac{\left(N d_{high}{}'_{t_l} + (\bar{N} - N) d_{low}{}'_{t_l}\right) p_d}{N d_{high}{}'_{t_l} \, f_{high} + (\bar{N} - N) d_{low}{}'_{t_l} \, f_{low}}$$

Hence, the expression for the optimal tax formula on fuel is identical with the expression for the optimal tax formula on fuel in the case where households choose vehicle, equation (15). This shows that it is sub-optimal to lower the tax on fuel when households avoid the road user charge on fuel by purchasing fuel-efficient vehicles.

2.5 Myopic behavior

Empirical estimates by Allcott and Wozny (2014) show that vehicle prices move as if consumers are indifferent between 1 dollar in discounted future gas costs and 0.76 dollar in vehicle purchase price. Such myopic behavior is incorporated into the model framework in the present study by assuming that households value future discounted gains and costs of driving at 70 percent of actual values when choosing vehicle. This leads to a modified equilibrium condition where a household is indifferent between high- and low-emission vehicles, equation (20). The allocation of vehicles is affected by myopic behavior as future benefits of fuel-efficient vehicles are not fully taken into consideration when vehicles are purchased. Choice of driving distance is not affected because willingness to pay for driving and operating costs of driving take place in the same periods.

(20) $$0{,}7u(d_{high}(t_l))+b_{\max}-aN+y+k-0{,}7(p_l+t_l)f_{high}d_{high}(t_l)-t_{car}-p_{car,high}$$

$$=0{,}7u(d_{low}(t_l))+y+k-0{,}7(p_l+t_l)f_{low}d_{low}(t_l)-p_{car,low}$$

Actual future gains and costs are inflicted upon households even though they attach a lower value to future outcomes due to myopic behavior. The perfect-foresight government therefore maximizes an individualistic welfare function where actual future gains and costs are incorporated. The maximization problem of the government is found by replacing equation (7) with equation (20) in problem (13). First order conditions which determine the tax on fuel is identical with conditions in problem (13).

(21) $$t_l^{***}=p_{CO2}+\frac{\left(Nd_{high}{}'_{t_l}+(\bar{N}-N)d_{low}{}'_{t_l}\right)p_d}{Nd_{high}{}'_{t_l}\,f_{high}+(\bar{N}-N)d_{low}{}'_{t_l}\,f_{low}}$$

Hence, the optimal tax formula on fuel should not be modified due to myopic behavior. First order conditions also imply that equation (14) is satisfied. The optimal tax on purchase of fuel-intensive vehicles however is modified according to equation (20), see appendix E.

(22)

$$t_{car}^{***}=\frac{\frac{\bar{N}-N}{\bar{N}}\left[f_{low}-f_{high}\right]}{\frac{N}{\bar{N}}\frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}f_{high}+\frac{\bar{N}-N}{\bar{N}}f_{low}}p_d d_{high}(t_l*)+\frac{\frac{N}{\bar{N}}\frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}\left[f_{low}-f_{high}\right]}{\frac{N}{\bar{N}}\frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}f_{high}+\frac{\bar{N}-N}{\bar{N}}f_{low}}p_d d_{low}(t_l*)$$

$$+0{,}3[u(d_{low}(t_l^{***}))-(p_l+t_l^{***})f_{low}d_{low}(t_l^{***})\;-(u(d_{high}(t_l^{***}))-(p_l+t_l^{***})f_{high}d_{high}(t_l^{***}))]$$

The first two terms on the right hand side are both negative, and identical with the terms in equation (16). The explanation is identical with the explanation in the case with rational expectation. The last term is positive. The explanation is that households underestimate rewards of a fuel-efficient vehicle. An additional tax on purchase of vehicles with higher fuel consumption contributes to correct for the mistakes due to myopic behavior. Which of the two effects is greatest will determine whether the additional tax on purchase of fuel-intensive vehicles is positive or negative.

2.6 Electric vehicles

A user charge on electric vehicles is desirable to correct for mileage-related externalities. This section however analyzes optimal taxation of fuel and purchase of electric vehicles when the use of electric vehicles is not taxed. The problem is analyzed within the present model framework by replacing low-emission vehicle with electric vehicle, and by assuming that the private cost of using an electric vehicle is zero. Hence, driving distance for electric vehicles is determined by the condition, $u'_{km_{low}} = 0$. CO2-emissions from production of electricity and electric vehicles are excluded.

The maximization problem of the government is found by inserting $f_{low} = 0$, and by assuming that $d_{low}(t_l)$ is fixed in the perfect foresight problem in (13). First order conditions imply that

$$(23)\; u'_{km_{high}} = p_l f_{high} + p_{CO2} f_{high} + p_d$$

Implementing equation (23) into equation (3) gives

$$(24)\; t_l^{****} = p_{CO2} + \frac{p_d}{f_{high}}.$$

Hence, the optimal tax wedge between fuel and other consumer goods equals the marginal damage of CO2 emissions plus the mileage-related marginal damage of road transport. The first order condition with respect to t_{car} combined with equation (24) and (7) imply that

$$(25)\; t_{car}^{****} = -p_d km_{low}.$$

Equation (25) shows that the optimal additional tax on purchase of electric vehicles equals mileage-related external costs connected to electric vehicles. The absence of a road user charge for electric vehicles should thus be neutralized with an equivalent tax on electric vehicles. The cost of CO2-emissions and local external damage from driving a fossil fuel vehicle is incorporated into the price of fuel. Hence, costs of externalities connected with both types of vehicles are considered when households with rational expectations choose between fossil fuel vehicles and electric vehicles.

The simple tax formula leads to strong implications. The optimal additional tax on EVs in equation (25) should not be lowered due to an increase in the marginal damage of CO2 emissions. The tax on CO2 emissions is levied on fuel consumption, equation (24), and the size does not affect the optimal additional tax on purchase of electric cars. The optimal additional tax on purchase of EVs in equation (25) should not be lowered due to range anxiety or other preferences for buying fossil fuel cars rather than electric cars. The producer / import prices of cars are not included in equation (25). Hence, tax exemptions for electric cars should not be offered to compensate for higher import prices of electric cars. The additional tax on purchase of EVs is equivalent to an additional yearly tax on EVs within the model framework. Substantial differences in mileage-related costs between geographic regions call for geographic tax differentiation between regions. Implementation of geographic tax differentiation favor a yearly vehicle tax as differentiated taxes on purchase is more likely to be hampered by evasion.

2.7 Other tax instruments

The impact of introducing other policy instruments is analyzed by calculating the first-best solution and then evaluating which policy packages that is able to implement the first-best solution. The first best solution is found by maximizing the objective function in problem (13) w.r.t. the allocation of vehicles N and driving distance for each vehice, km_{high} and km_{low}. The First order conditions w.r.t N imply that

$$
\begin{aligned}
(26)\; & u(km_{high}) + b_{\max} - aN - p_{car,high} - p_l f_{high} km_{high} - p_{CO2} f_{high} km_{high} - p_d km_{high} = u(km_{low}) \\
& - p_{car,low} - p_l f_{low} km_{low} - p_{CO2} f_{low} km_{low} - p_d km_{low} .,
\end{aligned}
$$

The left hand side of equation (26) equals the utility of an extra high emission vehicle minus the costs of a high-emission vehicle minus damage caused by a high-emission vehicle. This equals the right hand side, which equals the utility of an extra low-emission vehicle minus costs connected to a low-emission vehicle minus damage caused by a low-emission vehicle. The first order conditions also imply that

$$(27)\; u'_{km_{high}} = p_l f_{high} + p_{CO2} f_{high} + p_d$$

and

$$(28)\; u'_{km_{low}} = p_l f_{low} + p_{CO2} f_{low} + p_d \,.$$

The left hand side of equation (27) and (28) equals the willingness to pay for one additional kilometer for each type of vehicle. This equals the right hand side, which equals the price of fuel multiplied with consumption of fuel per kilometer plus the cost of carbon multiplied with consumption of fuel per kilometer plus mileage-related damage of driving one kilometer.

The government is able to implement the first-best solution when the tax on fuel can be differentiated between vehicles with different fuel economy. Assuming rational expectations imply that the first-best solution is implemented by choosing a zero tax wedge between vehicles with different fuel economy, combined with tax rates on fuel which equals

$$(29)\; t_{l,j} = p_{CO2} + \frac{p_d}{f_j}$$

where $j = high, low$. The proof consist of incorporating these tax rates into equation (3) and (7), and comparing with the first-best solution given by equation (26), (27) and (28). Note that the tax on fuel is higher for fuel-efficient vehicles in this case. Hence, the result in Montage (2015) is confirmed. The government is also able to implement the first-best solution with uniform tax rates on fuel and on driving distance based on GPS-monitoring. A tax on fuel which equals the marginal damage of CO2-emissions, a tax on driving distance which equals the marginal damage of mileage-related externalities, combined with a zero tax wedge between vehicles with different fuel economy generates the first-best solution. Note that a user charge on electric vehicles is implemented in this case. Both these solutions lead to a more efficient allocation of vehicles and driving distance compared to the second-best solution presented above. A GPS-based system is however costly to administer, is likely to impose information processing costs on motorists and represents undesirable surveillance, see Parry et al. (2007). A tax on fuel which is differentiated between vehicles is unable to differentiate between geographic locations or peak and off-peak periods, and may lead to costly monitoring to implement such taxes.

3. Optimal versus current taxation of fuel and vehicles

This section compares the optimal tax wedge between fuel and other consumer goods with tax wedges implemented in selected countries. The section also compares tax wedges between high- and low emission vehicles in selected countries with illustrations of optimal tax wedges between high- and low emission vehicles.

3.1 Optimal tax estimates

Optimal tax formulas presented are determined by both endogenous and exogenous parameters of the model. It is assumed that parameter values and functional forms are calibrated to fit specific solutions of the model. Several simplifying assumptions are adopted. First, it is assumed that the utility function is shaped so that the reduction in mileage due to a tax increase on fuel is identical for households with high- and low emission vehicles in optimum, i.e. , $d_{high}{}'_{t_l} = d_{low}{}'_{t_l}$. This simplifying assumption implies that the optimal tax formula on fuel equals

$$(30)\; t_l^* = p_{CO2} + \frac{p_d}{\frac{N}{\overline{N}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}}.$$

Second, it is assumed that parameters are chosen so that the stock of high- and low-emission vehicles is identical. The optimal tax wedge between fuel and other consumer goods, presented in equation (30), equals the marginal damage of CO2 emissions plus the average mileage-related marginal damage of road traffic from fossil fuel vehicles in this case.

Norway and other countries participating in the non-ETS quota system have agreed upon substantial GHG reductions within the non-ETS sectors, where transport is dominating. Access to flexible mechanisms and quota trading among participants to ensure cost effectiveness imply that emission targets can be reached by purchasing quotas, see European Commission (2016). The emission quota price therefore represents the marginal cost of carbon emissions for countries within this emission trading system. Future quota prices are highly uncertain, but it is desirable with a quota price which equals the social cost of carbon. Note however that countries which are not obligated by climate treaties may end up with a marginal cost of CO2 emissions.

The marginal damage of CO2 emissions, or social cost of carbon, is estimated by more than 100 peer-reviewed studies according to the report from the Intergovernmental Panel on Climate Change, IPCC (2007). The average cost estimate is $ 43 per ton CO2. A cost estimate of 50 dollars is common as some resent estimates are higher. Consumption of one liter of petrol generates 2.32 kg CO2, which amounts to approximately 0,44 dollars per gallon of petrol. This cost estimate is adopted for the US and the UK. An exchange rate of 8 NOK/ dollar implies a cost of about 0.93 NOK / liter petrol[7]. A cost

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[7] Consumption of one liter of diesel generates 2.66 kg CO2, and a cost of about 1.06 NOK / liter diesel.

of 0.19 Euros / liter petrol is chosen for the German case to implement identical estimates as in Tscharaktschiew (2015), see table 1.

Table 1: Costs and road user charges per unit of fuel, 2016.

	The cost of CO2-emissions	Average mileage-related costs	Optimal tax wedge, fuel vs. goods	Current tax wedge, fuel vs. goods	Current Fees, toll road	Current road user charge, Tax plus fees
USA, dollars per gallon petrol	0,44	1,92	2,36	0,28	0,09	0,37
UK, dollars per gallon petrol	0,44	2,92	3,36	2,69	0	2,69
Germany, Euros per liter petrol	0,19	1,11	1,30	0,65	0	0,65
Norway, NOK per liter petrol	0,93	4,78	5,71	5,96	2,22*	8,18
Norway, NOK per liter diesel	1,06	6,53	7,59	4,56	2,22*	6,78

*In 2015.

The average mileage-related marginal damage connected to road transport for the US and UK amounts to 1.92 and 2.92 dollars per gallon of petrol, respectively according to Parry and Small (2005). The cost of traffic congestion and damage due to accidents is dominating, while costs of local pollution are more modest. Anderson and Auffhammer (2014) shows that accident-related externalities are connected to the weight of vehicles. Internalizing such externalities by a weight-varying mileage tax or a 0.97-2.17 dollar per gallon gas tax is similar for most vehicles. Hence, this higher fuel-related externality could be implemented by increasing the tax on fuel according to equation (30).

Cost estimates in the case of Germany amounts to 1.11 Euros per liter petrol, which is identical with estimates in Tscharaktschiew (2015). Norwegian estimates are given by Thune-Larsen et al. (2016), which find that the cost of local damage due to road traffic on average amounts to 4.78 NOK/ liter petrol and 6.53 NOK/ liter diesel.

The optimal tax wedge between fuel-intensive and fuel-efficient vehicles in the case with rational expectations is given by equation (16). This equation is employed to illustrate optimal tax wedges between the following Volkswagen Passat 2017-models: the 1.6 TDI, the 2.0 TDI DSG 4MOTION, the GTE plug-in hybrid. Data on fuel economy, emission, power, weight and lifetime driving distance are presented in appendix F. The illustration also assume that each model have the same market share. The optimal additional tax on the 1.6-model equals 2942 dollars compared to the 2.0-model. The optimal additional tax on the GTE also amounts to 2942 dollars.

The optimal tax wedge between purchases of high- and low-emission vehicles in the case with myopic behavior is given by equation (22). The optimal tax wedge equals the tax wedge with rational expectations plus 30 percent of the difference between the accumulated willingness to pay for driving distance minus operating costs for high- and low-emission vehicles. Thirty percent of the difference between accumulated willingness to pay for driving distance minus fuel costs for high- and low-emission vehicles amounts to approximately 820 dollars, see Appendix F. Hence, the optimal additional tax on the 1.6-model equals 2122 dollars compared to the 2.0-model in this case. The optimal additional tax on the GTE also amounts to 2122 dollars in this case.

The optimal additional tax on electric vehicles is given by equation (25). The mileage-related cost per gallon of petrol amounts to 1.92 dollars/ gallon, see table 1. The average miles per gallon for light duty vehicles in 2013 amount to 21.6 according to the Bureau of Transportation Statistics. Hence, the mileage- related cost amounts to approximately 5.5 cents per kilometer. The average number of miles per driver per year in 2014 is 13.476 according to the US department of transport (FHWA). Assuming that these numbers are relevant for electric vehicles imply that the optimal additional yearly tax on electric vehicles amounts to 1.193 dollars. The alternative is to introduce an additional tax on purchase of electric vehicles according to equation (25). This tax is found by calculating the present value of additional yearly taxes over the life time of an electric vehicle. This amounts to 14.643 dollars with a 5 percent interest rate and a vehicle life expectancy of 18 years. The optimal additional yearly tax on electric vehicles in Norway is given by mileage-related damage per kilometer, 0.54 NOK / km according to Thune-Larsen et. al. (2016), multiplied by driving distance of approximately 14.000 km. This amounts to an additional yearly tax of approximately 7.000 NOK (875

Dollars). The alternative is an additional tax on purchase of electric vehicles of approximately 86.000 NOK when these taxes are distributed over the life cycle and discounted by a 5 percent interest rate.

The optimal tax wedge between purchases of fossil fuel vehicles and electric vehicles in the case with myopic behavior equals the tax wedge with rational expectations plus 30 percent of the difference between the accumulated willingness to pay for driving distance minus operating costs for fossil fuel vehicles and electric vehicles. Thirty percent of the difference between accumulated willingness to pay for driving distance minus fuel costs for fossil fuel vehicles and electric vehicles is estimated to approximately 4.439 dollars, see appendix F. Assumptions regarding life time driving distance and discounting is required to calculate the per vehicle adjustment. The optimal additional tax on purchase of electric cars in Norway is lowered to approximately 63.000 NOK in the case with myopic behavior.

Externalities connected with technological development of electric vehicles combined with a desire to protect domestic car industry by capturing the emerging market for electric vehicles may warrant subsidies for purchase of electric vehicles within large markets like Germany and the US. It is however challenging to quantify the externality per vehicle sold. Small car-importing countries like Norway are however less likely to influence the development strategies of multinational car companies. The global market share is too small, and the empirical insight from other industries show that learning-by-exporting is non-existent according to Keller (2004).

Externalities associated with the development of a network of charging stations could justify tax exemptions for purchase of EVs, see Greaker and Midttømme (2016). Investment- subsidies for charging stations, however, seem to be a more fine-tuned policy tool for such externalities. The financial burden on the government budget is also likely to be more modest. Such subsidies constitute a fraction of the lost tax revenue associated with tax exemptions for electric cars in Norway according Bjertnæs (2016). Direct subsidies for investments in charging stations thus appear to be less expensive. Additional adverse impacts of subsidies for electric vehicles, such as increased car use and less public transport, should also be expected, see Holtsmark and Skonhoft (2014) and Aasness and Odeck (2015).

3.2 The USA

The tax wedge between fuel and other goods is given by the tax per gallon of fuel minus sales taxes connected to spending the money on other goods. The average US tax on petrol amounts to 45.7 cents per gallon in 2017 according to the US Energy Information Administration. The average combined sales tax (8.4 percent according to Thomson Reuters, 2015) of spending one gallon petrol worth of money on other goods amounts to approximately 17.8 cents. Hence, the tax wedge between fuel and other goods amounts to 27.9 cents per gallon of petrol.

Taxes on driving also include fees on toll roads. Revenue from fees collected by US toll agencies in 2013 amounts to 13 billion dollars according to IBTTA (2015). The total vehicle miles traveled (moving 12-month) amounts to approximately 3.000 billion in 2013 according to USFHA (2017). Hence, average toll paid per miles traveled equals 0.43 cents. The average fuel efficiency measured in miles per gallon of petrol for light duty vehicles in 2013 was 21.6 according to the Bureau of Transportation Statistics. Hence, average toll per gallon of fuel consumed amounts to 9.36 cents. The total road user charge between fuel and other goods amounts to 37.3 cents for petrol. The optimal tax wedge between petrol and other goods equals 2.36 dollars per gallon, see table 1.

A substantial share of the road user charge is levied on fuel in the US. Hence, it is desirable to tax purchase of fuel-efficient vehicles more heavily to neutralize tax avoidance according to equation (16) and (22). The current US tax on purchase of vehicles differs between states and counties. Sales tax and registration fees on purchase of vehicles are common in most states. Local governments collect an additional sales tax. Registration and documentation fees are also common. These taxes and fees generate a marginal tax wedge between fuel-intensive and fuel-efficient vehicles.

The Corporate Average Fuel Economy (CAFE) standard in the US stimulates purchase of fuel-efficient vehicles relative to fuel-intensive vehicles, see Goldberg (1998). Goldberg (1998) argues that this standard acts as a firm specific tax on fuel-intensive vehicles relative to fuel-efficient vehicles. The impact on consumer prices is however modest. Hence, taxes and the CAFE-standard is not designed to neutralize tax avoidance of the road user charge on fuel in the US.

Fees on toll roads for electric vehicles differ between states in the US. The road user charge for electric vehicles is however marginal. Hence, it is optimal to tax purchase of electric vehicles more heavily compared to fossil fuel vehicles according to equation (25). Tax credits and rebates on purchase of electric vehicles are in contrast introduced in the US market. The federal tax credit per new electric vehicle range from 2.500 to 7.500 dollars according to the US department of energy. Many states offer additional benefits, including support for charging stations. California e.g. offer an additional 7.000 dollars cash rebate for low income households who purchase an electric vehicle. Some states have however replaced subsidies with additional annual fees ranging from 50 to 300 dollars for electric vehicles to compensate for the lack of a road user charge.

3.3 The UK

The tax wedge between petrol and other consumer goods in the UK amounts to the fuel tax of 0.5795 pounds per liter petrol, or 2.69 dollars per gallon, se UK (2017). The additional value added tax is levied on most goods, and hence, do not influence the tax wedge. There is toll on selected roads and bridges as well as the London (and Durham) congestion charge. Revenue from these road user charges divided by total vehicle miles amounts to only 0.002 pounds per vehicle miles in 2007, se uk (2009). Vehicles above 12 ton pay a road user charge in the UK. This fee is however paid together with vehicle excise duty, and hence, is not based on driving distance. The current tax wedge between petrol and other goods, 2.69 dollars per gallon, is below the optimal tax wedge, 3.36 dollars per gallon of petrol, see table 1.

The tax on fuel amounts to almost 100 percent of the road user charge in the UK, and there is no road user charge for electric vehicles. Hence, it is desirable to tax purchase of fuel-efficient vehicles more heavily to neutralize avoidance of the road user charge on fuel. The current tax design however deviates substantially as the current tax increases with the theoretical CO2-emission per kilometer, see UK (2015). A 4.000 pound subsidy on purchase of electric cars with sufficient range is also introduced according to the UK government web site gov.com. Hence, current UK tax rebates and subsidies for purchase of electric cars deviate substantially from the optimal additional tax on purchase of electric cars according to equation (25).

3.4 Germany

The tax wedge between petrol and other consumer goods amounts to 0.65 Euros per liter petrol in Germany. The additional value added tax is levied on most goods, and hence, do not influence the tax wedge. Vehicles above 7.5 ton pay a road user charge based on driving distance in Germany. Such vehicles are mainly propelled by diesel. Germany and the European Commission have reached an agreement on a road charge scheme for lighter vehicles. This road charge is based on annual fees combined with short-term allowances to facilitate temporary needs. The current tax wedge between petrol and other goods, 0.65 Euros per liter, constitutes approximately half of the optimal tax wedge, 1.30 Euros per liter of petrol.

The tax on fuel amounts to almost 100 percent of the road user charge for petrol cars in Germany. Hence, it is optimal to tax purchase of fuel-efficient vehicles more heavily to neutralize avoidance of the road user charge on fuel. The current tax design however deviates substantially as there are additional taxes on purchase of vehicles with higher theoretical fuel consumption per kilometer, see VDIK (2017).

A 4.000 Euro subsidy on purchase of electric vehicles, and a 3.000 Euro subsidy on purchase of plug-in hybrid vehicles are introduced in Germany to achieve the goal of 1 million electric vehicles on German roads within 2020. Leading automakers have agreed to finance 50 percent of this subsidy scheme. Premium cars like Tesla model S and X are not eligible for the subsidy as the price of these cars exceeds the 60.000 Euro price limit. Electric cars are also partly exempt from the vehicle tax in Germany. Hence, current German tax rebates and subsidies for purchase of electric cars deviate substantially from the optimal additional tax on purchase of electric cars given by equation (25). The rebates are however designed to protect the domestic car industry and to promote development of clean transport technology.

3.5 Norway

The tax wedge between fuel and other consumer goods in Norway includes a tax of 5.96 and 4.56 NOK per liter petrol and diesel, respectively. The additional value added tax is levied on most goods, and hence, do not influence the tax wedge. Revenue from toll roads amounts to 9.3 billion NOK in 2015 according to the State Road Administration. The total consumption of fuel for road use amounts to 4.18 billion liters in Norway in 2015. Hence, this amounts to 2.22 NOK / liter fuel. The current total tax wedge between petrol and other goods in 2016, 8.18 NOK per liter, exceeds the optimal tax wedge of 5.71 NOK per liter. The current total tax wedge between diesel and other goods, 6.78 NOK per liter, is lower than the optimal tax wedge of 7.59 NOK per liter.

A substantial share of the road user charge is levied on fuel in Norway. Hence, it is desirable to tax purchase of fuel-efficient vehicles more heavily to neutralize road user charge avoidance. The current tax design however deviates substantially as there are additional taxes on purchase of vehicles with higher theoretical fuel consumption per kilometer. The current vehicle tax on purchase of the Volkswagen Passat 1.6 TDI model is 58.849 NOK (7.350 dollars) below the tax on the 2.0-model within the Norwegian tax system. The optimal vehicle tax on the 1.6-model is 17-24.000 NOK (2.122-2.942 dollars) above the 2.0-model. The current vehicle tax on purchase of the GTE model is 124.570 NOK below the tax on the 2.0-model. The optimal vehicle tax on the GTE model is 17-24.000 NOK above the 2.0-model.

The average Norwegian tax on purchase of petrol/ diesel cars in 2014 amounts to 135.000 NOK when the value added tax is included according to Bjertnæs (2016). The annual vehicle tax amounts to approximately 3000 NOK for petrol/ diesel cars. Hence, the optimal yearly tax on electric cars which is consistent with equation (25) amounts to approximately 10.000 NOK when the average tax on purchase of electric cars amounts to 135.000 NOK. The optimal average tax on purchase of electric vehicles in the absence of a yearly tax on cars amounts to approximately 221.000 NOK. The optimal average tax on purchase of electric cars is lowered to approximately 198.000 NOK in the case with myopic behavior. Purchase of battery electric cars is in contrast exempt from all taxes in Norway. The yearly tax only amount to 455 NOK for electric cars, and the tax on electricity only amounts to approximately 500 NOK. EV owners also enjoy implicit subsidies in the form of permission to drive in bus lanes, free parking and charging in public spaces and free toll roads.

4. Conclusion

Many countries have implemented taxes on fuel to curb externalities linked to both fuel (CO2 emissions) and road use (local air pollution, accidents, congestion and noise). The gain of reduced externalities per liter fuel is however diminished as households avoid the mileage-related tax by purchasing more fuel-efficient vehicles. Parry and Small (2005) claims that the optimal tax rate component on fuel designed to curb mileage-related externalities is halved due to such tax avoidance, and conclude that the optimal tax rate on petrol in the United States was more than twice as large as the current rate, while that for the United Kingdom was about half its current rate. This study shows that both the US and the UK tax wedge between fuel and other consumer goods is lower than the optimal tax wedge, as the mileage-related tax rate component on fuel should not be reduced due to such tax avoidance. Such avoidance should be neutralized by a higher tax on fuel-efficient vehicles. Many countries have, in contrast, introduced tax exemptions or subsidies for fuel-efficient vehicles.

The study also shows that the lack of road user charges for electric cars implies that the optimal additional tax on electric cars equals their lifetime value of mileage-related externalities when other market imperfections are absent. Substantial tax exemptions and or subsidies for purchase of electric vehicles are in contrast introduced in several countries. This optimal additional tax is reduced in the presence of myopic behavior. A desire to protect the domestic car industry and to promote development of clean transport technology may also justify some subsidies for purchase of electric vehicles, especially within large car-producing countries like Germany and the US. The case for subsidies is less convincing for small car-importing countries like Norway, with no car industry, limited possibilities to influence the future transport technology, and subsidies for charging stations to harvest potential network-effects.

Some limitations should be considered when results are interpreted. The simple one-period model framework adopted, where households with specific preferences for driving and type of vehicle chose driving distance and type of vehicle, suggest that results are limited to specific settings. The model framework excludes other choices, like e.g. economic driving, and other externalities, like e.g. the rat race for status. Optimal tax formulas are however mainly determined by the damage fuel and vehicles inflict upon society. Such damage is determined by empirical estimates. Hence, taxes are mainly determined by these estimates. Note that the optimal vehicle tax is based on theoretical emissions per mile. Several car manufacturers have however been caught manipulating emissions per mile-tests. Improved testing may contribute to reduce this problem.

The problem with avoidance of road user charges on fuel is removed if such charges are replaced with GPS-based road user charges designed to trace externalities. A GPS-based system is however more costly to administer, is likely to impose information processing costs and undesirable surveillance, see Parry et al. (2007). A road user charge based on odometer readings or pay-as-you-drive insurance does not differentiate between locations or peak and off-peak periods, and is exposed to evasion. Congestion charges and toll roads allow for peak-load pricing, but are costly to administer, and leads to undesirable traffic planning designed to avoid toll stations, see Parry (2002). A tax on fuel which differentiates between various characteristics of vehicles, so that the tax equals the marginal damage of driving, provides optimal incentives for mileage, economical driving style and choice of vehicle, see Fullerton and West (2002) and Montag (2015). Such taxes however do not differentiate between geographic locations or peak and off-peak periods, and may lead to costly monitoring to prevent that high-tax fuel vehicles use low-tax fuel. The choice of policy tools to curb externalities from road transport is complex. New improved technology may however remove hurdles for tools like GPS-based pricing.

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Appendix A

First order equations w.r.t.

$$t_{car}: -\frac{1}{a}u(d_{high}(t_l)) - \frac{1}{a}b_{\max} + N(t_l, t_{car}) + \frac{1}{a}u(km_{low}(t_l))$$

$$+\frac{1}{a}\left[p_{car,high} + p_l f_{high} d_{high}(t_l)\right] - \frac{1}{a}\left[p_{car,low} + p_l f_{low} d_{low}(t_l)\right]$$

$$+\frac{1}{a}p_{CO2} f_{high} d_{high}(t_l) - \frac{1}{a}p_{CO2} f_{low} d_{low}(t_l)$$

$$+\frac{1}{a}p_d d_{high}(t_l) - \frac{1}{a}p_d d_{low}(t_l) = 0$$

Note that $\frac{\partial N}{\partial t_{car}} = \frac{1}{-a}$ according to equation (7). Multiply with $-a$ implies that

$$u(d_{high}(t_l)) + b_{\max} - aN(t_l, t_{car}) - p_{car,high} - p_l f_{high} d_{high}(t_l)$$

$$- p_{CO2} f_{high} d_{high}(t_l) - p_d d_{high}(t_l)$$

$$= u(d_{low}(t_l) - p_{car,low} - p_l f_{low} d_{low}(t_l) - p_{CO2} f_{low} d_{low}(t_l) - p_d d_{low}(t_l) .$$

First order equations w.r.t. t_l:

$$\frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a} [u(km_{high}(t_l)) + b_{\max} - aN(t_l, t_{car}) - u(d_{low}(t_l)$$

$$- p_{car,high} - p_l f_{high} d_{high}(t_l) + p_{car,low} + p_l f_{low} d_{low}(t_l)$$

$$- p_{CO2} f_{high} d_{high}(t_l) + p_{CO2} f_{low} d_{low}(t_l) - p_d d_{high}(t_l) + p_d d_{low}(t_l)]$$

$$+ N(.)u'_{km}\, d_{high}{'}_{t_l} - N(.)p_l f_{high} d_{high}{'}_{t_l} - N(.)p_{CO2} f_{high} d_{high}{'}_{t_l} - N(.)p_d d_{high}{'}_{t_l}$$

$$+ (\bar{N} - N(.))u'_{km}\, d_{low}{'}_{t_l} - (\bar{N} - N(.))p_l f_{low} d_{low}{'}_{t_l} - (\bar{N} - N(.))p_{CO2} f_{low} d_{low}{'}_{t_l}$$

$$-(\bar{N} - N(.))p_d d_{low}{'}_{t_l} = 0$$

Note that equation (7) implies that $\frac{\partial N}{\partial t_l} = \frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a}$. The first order equation w.r.t. t_{car} implies that parameters in the first bracket equals zero. Hence, these conditions imply that

$$\frac{N}{\bar{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} u'(km_{high}) + \frac{\bar{N} - N}{\bar{N}} u'(km_{low})$$

$$= \frac{N}{\bar{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} p_l f_{high} + \frac{\bar{N} - N}{\bar{N}} p_l f_{low}$$

$$+ \frac{N}{\bar{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} p_{CO2} f_{high} + \frac{\bar{N} - N}{\bar{N}} p_{CO2} f_{low}$$

$$+ \frac{N}{\bar{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} p_d + \frac{\bar{N} - N}{\bar{N}} p_d .$$

Multiplying equation (3) with $\frac{N}{\overline{N}}$ and $\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}$ gives

$$\frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}u'_{km}(km_{high}) = \frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}p_l f_{high} + \frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}t_l f_{high}$$

Multiplying equation (3) with $\frac{\overline{N}-N}{\overline{N}}$ gives

$$\frac{\overline{N}-N}{\overline{N}}u'_{km}(km_{low}) = \frac{\overline{N}-N}{\overline{N}}p_l f_{low} + \frac{\overline{N}-N}{\overline{N}}t_l f_{low}.$$

Summing these equations imply that

$$\frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}u'_{km}(km_{high}) + \frac{\overline{N}-N}{\overline{N}}u'_{km}(km_{low})$$

$$= \frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}p_l f_{high} + \frac{\overline{N}-N}{\overline{N}}p_l f_{low} +$$

$$\frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}t_l f_{high} + \frac{\overline{N}-N}{\overline{N}}t_l f_{low}.$$

The first order conditions w.r.t. t_l and t_{car}, and this equation imply that

$$\frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}t_l f_{high} + \frac{\overline{N}-N}{\overline{N}}t_l f_{low}$$

$$= \frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}p_{CO2} f_{high} + \frac{\overline{N}-N}{\overline{N}}p_{CO2} f_{low}$$

$$+ \frac{N}{\overline{N}}\frac{d_{high}'{}_{t_l}}{d_{low}'{}_{t_l}}p_d + \frac{\overline{N}-N}{\overline{N}}p_d\,.$$

Hence,

$$t_l^* = p_{CO2} + \frac{\left(\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} + \frac{\overline{N}-N}{\overline{N}} \right) p_d}{\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} f_{high} + \frac{\overline{N}-N}{\overline{N}} f_{low}},$$

or

$$t_l^* = p_{CO2} + \frac{\left(N{d_{high}}'_{t_l} + (\overline{N}-N){d_{low}}'_{t_l} \right) p_d}{N{d_{high}}'_{t_l} f_{high} + (\overline{N}-N){d_{low}}'_{t_l} f_{low}}.$$

Implementing $t_l *$ into equation (7) gives

$$u(d_{high}(t_l *)) + b_{\max} - aN(t_l^*, t_{car}) - p_{car,high} - t_{car} - p_l f_{high} d_{high}(t_l *)$$

$$- p_{CO2} f_{high} d_{high}(t_l *) - \frac{\left(\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} + \frac{\overline{N}-N}{\overline{N}} \right) p_d f_{high}}{\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} f_{high} + \frac{\overline{N}-N}{\overline{N}} f_{low}} d_{high}(t_l *)$$

$$= u(d_{low}(t_l *)) - p_{car,low} - p_l f_{low} d_{low}(t_l *)$$

$$- p_{CO2} f_{low} d_{low}(t_l *) - \frac{\left(\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} + \frac{\overline{N}-N}{N} \right) p_d f_{low}}{\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} f_{high} + \frac{\overline{N}-N}{\overline{N}} f_{low}} d_{low}(t_l *)$$

Hence,

$$u(d_{high}(t_l *)) + b_{\max} - aN(t_l^*, t_{car}) - p_{car,high} - t_{car} - p_l f_{high} d_{high}(t_l *)$$

$$- p_{CO2} f_{high} d_{high}(t_l *) - p_d d_{high}(t_l *)$$

$$- \frac{\frac{\overline{N}-N}{\overline{N}} \left[f_{high} - f_{low} \right]}{\frac{N}{\overline{N}} \frac{{d_{high}}'_{t_l}}{{d_{low}}'_{t_l}} f_{high} + \frac{\overline{N}-N}{\overline{N}} f_{low}} p_d d_{high}(t_l *)$$

$$= u(d_{low}(t_l *)) - p_{car,low} - p_l f_{low} d_{low}(t_l *)$$

$$- p_{CO2} f_{low} d_{low}(t_l *) - p_d d_{low}(t_l *) - \frac{\frac{N}{\overline{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} \left[f_{low} - f_{high} \right]}{\frac{N}{\overline{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{low}(t_l *)$$

Implementing first order conditions v.r.t. t_{car} gives

$$t_{car}^{*} = \frac{\frac{\overline{N} - N}{\overline{N}} \left[f_{low} - f_{high} \right]}{\frac{N}{\overline{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{high}(t_l *) \quad + \frac{\frac{N}{\overline{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} \left[f_{low} - f_{high} \right]}{\frac{N}{\overline{N}} \frac{d_{high}{'}_{t_l}}{d_{low}{'}_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{low}(t_l *)$$

Both expressions on the right hand side are negative. This proves that t_{car}^{*} is negative.

Appendix B

Second order conditions for the government maximization problem, equations (13). The welfare function is labeled W.

$$\frac{\partial^2 W}{\partial t_l \partial t_l} = \frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a} \text{x} \left[-a \left[\frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a} \right] \right.$$

$$+ u'_{km} d_{high}{'}_{t_l} - p_l f_{high} d_{high}{'}_{t_l} - p_{CO2} f_{high} d_{high}{'}_{t_l} - p_d d_{high}{'}_{t_l} - u'_{km} d_{low}{'}_{t_l} + p_l f_{low} d_{low}{'}_{t_l}$$
$$+ p_{CO2} f_{low} d_{low}{'}_{t_l} + p_d d_{low}{'}_{t_l}]$$

$$+ \frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a} \text{x}$$

$$[u'_{km} d_{high}{'}_{t_l} - p_l f_{high} d_{high}{'}_{t_l} - p_{CO2} f_{high} d_{high}{'}_{t_l} - p_d d_{high}{'}_{t_l} - u'_{km} d_{low}{'}_{t_l} + p_l f_{low} d_{low}{'}_{t_l}$$
$$+ p_{CO2} f_{low} d_{low}{'}_{t_l} + p_d d_{low}{'}_{t_l}]$$

$$+ N(t_l, t_{CO2})[u'_{km}{'}_{km} d_{high}{'}_{t_l} d_{high}{'}_{t_l} + u'_{km} d_{high}{'}_{t_l}{'}_{t_l} - p_l f_{high} d_{high}{'}_{t_l}{'}_{t_l} - p_{CO2} f_{high} d_{high}{'}_{t_l}{'}_{t_l}$$
$$- p_d d_{high}{'}_{t_l}{'}_{t_l} - u'_{km}{'}_{km} d_{low}{'}_{t_l} d_{low}{'}_{t_l}$$

$$- u'_{km} d_{low}{'}_{t_l}{'}_{t_l} + p_l f_{low} d_{low}{'}_{t_l}{'}_{t_l} + p_{CO2} f_{low} d_{low}{'}_{t_l}{'}_{t_l} + p_d d_{low}{'}_{t_l}{'}_{t_l}]$$

$$+ \overline{N}[u'_{km}{'}_{km} d_{low}{'}_{t_l} d_{low}{'}_{t_l} + u'_{km} d_{low}{'}_{t_l}{'}_{t_l} - p_l f_{low} d_{low}{'}_{t_l}{'}_{t_l} - p_{CO2} f_{low} d_{low}{'}_{t_l}{'}_{t_l} - p_d d_{low}{'}_{t_l}{'}_{t_l}] < 0$$

$$\frac{\partial^2 W}{\partial t_{car} \partial t_{car}} = \frac{1}{-a} < 0 .$$

$$\frac{\partial^2 W}{\partial t_l \partial t_{car}} = \frac{f_{low} d_{low}(t_l) - f_{high} d_{high}(t_l)}{a} - \frac{1}{a}[u'_{km}\, d_{high}{}'_{t_l} - p_l\, f_{high} d_{high}{}'_{t_l} - p_{CO2}\, f_{high} d_{high}{}'_{t_l}$$
$$- p_d d_{high}{}'_{t_l} - u'_{km}\, d_{low}{}'_{t_l} + p_l\, f_{low} d_{low}{}'_{t_l} + p_{CO2}\, f_{low} d_{low}{}'_{t_l} + p_d d_{low}{}'_{t_l}\,]$$

The second order condition is satisfied if

$$\frac{\partial^2 W}{\partial t_{car} \partial t_{car}} < 0 \text{ and}$$

$$\frac{\partial^2 W}{\partial t_{car} \partial t_{car}} \frac{\partial^2 W}{\partial t_l \partial t_l} - \left(\frac{\partial^2 W}{\partial t_l \partial t_{car}} \right)^2 > 0 .$$

The first inequality condition is satisfied if $a > 0$.

The second inequality condition is satisfied when

$$-\frac{1}{a} N(t_l, t_{car})[u'_{km}{}'_{km}\, d_{high}{}'_{t_l}\, d_{high}{}'_{t_l} + u'_{km}\, d_{high}{}'_{t_l}{}'_{t_l} - p_l\, f_{high} d_{high}{}'_{t_l}{}'_{t_l} - p_{CO2}\, f_{high} d_{high}{}'_{t_l}{}'_{t_l}$$
$$- p_d d_{high}{}'_{t_l}{}'_{t_l} - u'_{km}{}'_{km}\, d_{low}{}'_{t_l}\, d_{low}{}'_{t_l}$$

$$- u'_{km}\, d_{low}{}'_{t_l}{}'_{t_l} + p_l\, f_{low} d_{low}{}'_{t_l}{}'_{t_l} + p_{CO2}\, f_{low} d_{low}{}'_{t_l}{}'_{t_l} + p_d d_{low}{}'_{t_l}{}'_{t_l}\,]$$

$$-\frac{1}{a} \overline{N}[\, u'_{km}{}'_{km}\, d_{low}{}'_{t_l}\, d_{low}{}'_{t_l} + u'_{km}\, d_{low}{}'_{t_l}{}'_{t_l} - p_l\, f_{low} d_{low}{}'_{t_l}{}'_{t_l} - p_{CO2}\, f_{low} d_{low}{}'_{t_l}{}'_{t_l}$$

$$- p_d d_{low}{}'_{t_l}{}'_{t_l}\,] - \frac{1}{a^2}[u'_{km}\, d_{high}{}'_{t_l} - p_l\, f_{high} d_{high}{}'_{t_l} - p_{CO2}\, f_{high} d_{high}{}'_{t_l} - p_d d_{high}{}'_{t_l}$$
$$- u'_{km}\, d_{low}{}'_{t_l} + p_l\, f_{low} d_{low}{}'_{t_l} + p_{CO2}\, f_{low} d_{low}{}'_{t_l} + p_d d_{low}{}'_{t_l}\,]^2 > 0$$

Parameter values and functional forms are restricted to those that satisfy this condition. These restrictions are also sufficient to satisfy the second order conditions in the case with myopic behavior.

Appendix C

Second order conditions for the government maximization problem, equations (19).

$$
\begin{aligned}
& N[u'_{km}{}'_{km}\, d_{high}{}'_{t_l}\, d_{high}{}'_{t_l} + u'_{km}\, d_{high}{}'_{t_l}{}'_{t_l} - p_l f_{high} d_{high}{}'_{t_l}{}'_{t_l} - p_{CO2} f_{high} d_{high}{}'_{t_l}{}'_{t_l} - p_d d_{high}{}'_{t_l}{}'_{t_l}\,] \\
& + (\overline{N} - N)[\, u'_{km}{}'_{km}\, d_{low}{}'_{t_l}\, d_{low}{}'_{t_l} + u'_{km}\, d_{low}{}'_{t_l}{}'_{t_l} - p_l f_{low} d_{low}{}'_{t_l}{}'_{t_l} - p_{CO2} f_{low} d_{low}{}'_{t_l}{}'_{t_l} \\
& - p_d d_{low}{}'_{t_l}{}'_{t_l}\,] < 0
\end{aligned}
$$

Parameter values and functional forms are restricted to those that satisfy this condition.

Appendix E

Equation (20) is modified so that

$$
\begin{aligned}
& \frac{0{,}3}{0{,}7}(b_{\max} - aN(t_l^{***}, t_{car}) - p_{car,high} - t_{car} + p_{car,low}) \\
& + u(d_{high}(t_l^{***})) + b_{\max} - aN(t_l^{***}, t_{car}) - p_{car,high} - t_{car} - (p_l + t_l) f_{high} d_{high}(t_l^{***}) \\
& = u(d_{low}(t_l^{***})) - p_{car,low} - (p_l + t_l) f_{low} d_{low}(t_l^{***})
\end{aligned}
$$

The only difference between this condition and equation (7) is the first term on the left hand side. Hence, implementing equation (21) and (14) imply that

$$
\begin{aligned}
t_{car}^{***} = {} & \frac{\frac{\overline{N} - N}{\overline{N}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{high}(t_l *) + \frac{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{low}(t_l *) \\
& + \frac{0{,}3}{0{,}7}(b_{\max} - aN(t_l^{***}, t_{car}) - p_{car,high} - t_{car} + p_{car,low})
\end{aligned}
$$

Implementing equation (21) imply that

$$
\begin{aligned}
t_{car}^{***} = {} & \frac{\frac{\overline{N} - N}{\overline{N}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{high}(t_l *) + \frac{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}}\left[f_{low} - f_{high}\right]}{\frac{N}{\overline{N}} \frac{d_{high}{}'_{t_l}}{d_{low}{}'_{t_l}} f_{high} + \frac{\overline{N} - N}{\overline{N}} f_{low}} p_d d_{low}(t_l *) \\
& + 0{,}3[u(d_{low}(t_l^{***})) - (p_l + t_l^{***}) f_{low} d_{low}(t_l^{***}) - (u(d_{high}(t_l^{***})) - (p_l + t_l^{***}) f_{high} d_{high}(t_l^{***}))].
\end{aligned}
$$

Appendix F

Table 1F, Technical data, Volkswagen Passat.

Model	Passat 2,0 TDI DSG 4MOTION	Passat 1,6 TDI Businessline	Passat GTE Plug-in hybrid
Weight, kg	1599*	1410*	1647*
Power, hp	190*	120*	218*
Fuel cons. l/km	0,051*	0,041*	0,041
CO2 g/km	134*	105*	105
Driving distance, km	240.000	250.000	250.000

*Source: Volkswagen.no,

A linear approximation of the accumulated demand for driving distance minus total private fuel costs for low-emission vehicles equals the area abc in Figure 1F. Accumulated demand for driving distance minus total private fuel costs for vehicles with high fuel consumption equals the area cde. Hence, the difference between the accumulated demand for driving distance minus total private fuel costs for high- and low-emission vehicles equals the area abde. Implementing estimates of current prices, taxes, driving and fuel consumption, $p_l = 0{,}4924$ dollars, $t_l = 0{,}6234$ dollars, $\left(\frac{l}{km}\right)_{high} = 0{,}051$, $\left(\frac{l}{km}\right)_{low} = 0{,}041$, $km_{high} = 240.000$, $km_{low} = 250.000$, imply that the area abde equals 2.733,71 dollars. Thirty percent of 2.733,71 amount to approximately 820 dollars. The case with electric vehicles is implemented by assuming that $\left(\frac{l}{km}\right)_{low} = 0$ and $km_{low} = 280.000$. The area abde becomes 14.796 dollars in this case. Thirty percent of 14.796 approximately equals 4.439 dollars.

Figure 1F.