How much should gasoline be taxed when electric vehicles conquer the market?

An experimental analysis of the relationship between gasoline taxes and electric vehicle market diffusion

Stefan Tscharaktschiew
Technische Universität Dresden
Institute of Transport & Economics

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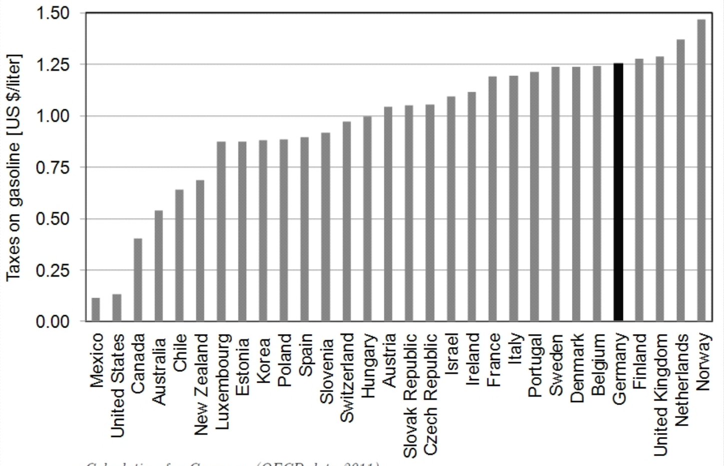

Calculation for Germany (OECD data 2011):

Average fuel price at the pump = 1.55 €/*liter* (incl. fuel tax and consumption tax)
Fuel tax = 0.65 €/*liter*; Consumption tax = 0.25 €/*liter* (1.30 €/*liter* × 0.19)
Tax on gasoline = (0.65 €/*liter* + 0.25 €/*liter*) × 1.40 $/€ = 1.26 $/*liter*

Question

What is the appropriate level of the gasoline tax in Germany from an economic efficiency point of view ?

- Main arguments for taxation:
  - different externalities associated with the combustion of motor fuel and vehicle kilometrage
  - generating tax revenue in a relatively efficient way due to the low price elasticity of gasoline demand ($\approx$ 35 billion € in 2012)

Question

What is the economically efficient level of the gasoline tax in Germany **in the time to come** ?

- the composition of the passenger car fleet will be subject to fundamental changes in the near future due to the emergence of electric mobility
  - the German federal government pursues the strategy of achieving one million EVs by 2020

$\Rightarrow$ EVs could influence the rationale of "traditional" fuel taxes

1. there are significant differences with respect to external costs caused by EVs compared with conventional fuel powered cars
2. differential tax treatment among car types (fuel vs. electric power)

1. We analytically derive the optimal gasoline tax and then calculate the optimal tax using data for Germany

2. We study the feedback effect of EVs on the optimal gasoline tax (depending on different assumptions concerning EV market share, EV diffusion, external costs, and EV purchase subsidies)

3. $\left.\begin{array}{c} Tax\ (opt\ with\ EV) \\ Tax\ (opt\ current) \end{array}\right\}$ vs. current gasoline tax 0.65€/l

Fuel Taxes

- Impact on vehicle ownership and usage [1]
- Fuel taxes and economic efficiency (optimal level of fuel tax) [2]
- Distributional impacts [3]
- Environmental impacts [4]

- [1]: Anas/Hiramatsu (2012); Berkovec/Rust (1985); Bhat/Guo (2007); Bhat/Sen (2006); Bhat et al. (2009); Dahl (1995); De Jong (1990, 1996); Feng et al. (2013); Fullerton/Gan (2005); Gillingham et al. (2013); Goodwin (1992); Goodwin et al. (2004); Golob/Van Wissen (1989); Graham/Glaister (2004); Graham/Glaister (2002); Linn (2013); Mannering/Winston (1985)
- [2]: De Borger (2001); De Borger/Mayeres (2007); Lin/Prince (2009); Mayeres/Proost (2001); Parry (2011); Parry/Small (2005), Parry/Timilsina (2009); West/Williams (2007)
- [3]: Bento et al. (2009); Metcalf (1999); Parry/Williams (2010); Poterba (1991); Sterner (2012); Walls/Hanson (1999); West/Williams (2004)
- [4]: Austin/Dinan (2005); Fullerton/Gan (2005); Proost/Van Dender (2012); Steiner/Cludius (2010); Sterner (2007)

Electric mobility/ Electric vehicles

- Market potential of EVs; Determinants of EV demand [1]
- Impact of EVs on energy demand and supply [2]
- (Life-cycle) cost analyses [3]
- EVs and economic efficiency (cost-benefit analyses etc.) [4]
- EV externalities; Environmental impacts [5]
- EV user behavior [6]

- [1]: Brown et al. (2010), Diamond (2009); Driscoll et al. (2013); Ewing/Sarigöllü (2000); Green et al. (2014); Hackbarth/Madlener (2013); Hidrue et al. (2011); Krause et al. (2013); Kurani et al. 1996; Lieven et al. (2011); Shafiei et al. (2012); Sierzchula et al. (2014)
- [2]: Davies/Kurani (2013); Huang et al. (2012); Jargstorf/Wickert (2013); Loisel et al. (2014); Wu/Aliprantis (2013)
- [3]: Delucchi/Lipman (2001); Karabasoglu/Michalek (2013); Tseng et al. (2014); Wu et al. (2014)
- [4]: Baum et al. (2010); Carlsson/Johansson-Stenman (2003); Funk/Rabl (1999); Hirte/Tscharaktschiew (2013)
- [5]: Cocron/Krems (2013); Garay-Vega et al. (2010); Hawkins et al. (2012); Karabasoglu/Michalek (2013); Morgan et al. (2010); Tseng et al. (2014); Verheijen/Jabben (2010); Wogalter et al. (2001); Wu/Aliprantis (2013);
- [6]: Franke/Krems (2013); Klöckner et al. (2013); Pearre et al. (2012)

- Representative agent framework à la (Parry/Small, 2005)
- Individual travelers maximize utility derived from travel activities and consumption subject to a monetary budget and time constraint
- Households, however, also suffer from travel related externalities stemming from energy use (local air pollution, CO_2) and from vehicle kilometrage (road congestion, accidents, noise)
- Externalities are caused, to varying degrees, by ICE vehicles (gasoline and diesel) and EVs
- The government aims at maximizing utility of households by setting the gasoline tax subject to a public budget constraint, where changes in governmental tax revenues due to a change in the level of the gasoline tax are balanced by labor taxes

Households

$$u\left(m_g, v_g, m_d, v_d, m_p, v_p, X, \ell, T, E\right)$$

m : Vehicle kilometrage

v : Number of vehicles

X : General consumption not related to private transport

ℓ : Leisure

T : Travel time

E : Index of non-congestion related externalities

$$\frac{\partial u}{\partial m} > 0 \quad \frac{\partial u}{\partial v} > 0 \quad \frac{\partial u}{\partial X} > 0 \quad \frac{\partial u}{\partial \ell} > 0$$

$$\frac{\partial u}{\partial T} < 0 \quad \frac{\partial u}{\partial E} < 0$$

Households – budget and time constraint

Budget Constraint:

- The monetary budget constraint equates expenditures for general consumption and expenditures for travel activities with disposable (after-tax) income

Time Constraint:

- $L + \ell + T = \bar{L}$
  - $\bar{L}$: fixed (annual) time endowment
  - L : Labor time
  - ℓ : Leisure time
  - T : Total travel time $\rightarrow T = t(M)\,M$, $(t' > 0)$
    - t : Average travel time per unit of distance
    - M : Annual aggregate kilometrage

Government

The government budget constraint equates fixed public spending GOV with tax revenues:

$$\tau_G G + \tau_D D + \tau_P P + \tau_z B + \tau_L wL - \Gamma v_p = GOV$$

where the gasoline (G), the diesel (D), the electric power (P) and the consumption tax (B) bases are

$$G = gM_G = gm_g v_g$$

$$D = \tilde{d} M_D = \tilde{d} m_d v_d$$

$$P = \tilde{p} M_P = \tilde{p} m_p v_p$$

$$B = (p_G + \tau_G)\, G + (p_D + \tau_D)\, D + (p_P + \tau_P)\, D + p_X X$$

$\Longrightarrow$ Budgetary effects are financed by labor tax adjustment $(\frac{d\tau_L}{d\tau_G})$!

The government's optimization program is to maximize the household's indirect utility function (expressed as a set of parameters $\Omega \equiv \{\tau_G, \tau_D, \tau_L, \tau_z, t, E\}$ that are exogenous to the household)

$$
\begin{aligned}
V(\Omega) = \max_{m_g, v_g, g, m_d, v_d, m_p, v_p X, \ell} & u\left(m_g, v_g, m_d, v_d, m_p, v_p, X, \ell, T, E\right) \\
& - \lambda \left\{ \left[P_G g m_g + c(g) \right] v_g \right\} \\
& - \lambda \left\{ \left[P_D \tilde{d} m_d + c(\tilde{d}) \right] v_d + \left[P_P \tilde{p} m_p + c(\tilde{p}) \right] v_p \right\} \\
& - \lambda \left\{ P_X X \right\} \\
& + \lambda \left\{ (1 - \tau_L) w \left(\bar{L} - \ell - tM \right) + \Gamma v_p \right\}
\end{aligned}
$$

$\Rightarrow$ From totally differentiating $V(\Omega)$ w.r.t. the gasoline tax τ_G ...

$$\frac{1}{\lambda}\frac{dV}{d\tau_G} = \underbrace{e_G\left\{-\frac{dG}{d\tau_G}\right\} + e_D\left\{-\frac{dD}{d\tau_G}\right\} + e_P\left\{-\frac{dP}{d\tau_G}\right\}}_{\text{Energy related externalities}}$$

$$+ \underbrace{e_M^c\left\{-\frac{dM}{d\tau_G}\right\}}_{\text{Distance related congestion externality}} + \underbrace{e_{M_F}^{nc}\left\{-\frac{dM_F}{d\tau_G}\right\} + e_{M_P}^{nc}\left\{-\frac{dM_P}{d\tau_G}\right\}}_{\text{Distance related non-congestion externalities}}$$

$$- \underbrace{\left[\tau_G\left\{-\frac{dG}{d\tau_G}\right\} + \tau_D\left\{-\frac{dD}{d\tau_G}\right\} + \tau_P\left\{-\frac{dP}{d\tau_G}\right\}\right]}_{\text{Energy tax revenue}} + \underbrace{\tau_L w \frac{dL}{d\tau_G}}_{\text{Labor tax revenue}}$$

$$\underbrace{-\tau_z\left((p_G+\tau_G)\left\{-\frac{dG}{d\tau_G}\right\} + (p_D+\tau_D)\left\{-\frac{dD}{d\tau_G}\right\} + (p_P+\tau_P)\left\{-\frac{dD}{d\tau_G}\right\}\right)}_{\text{Consumption tax revenue}}$$

$$- \underbrace{\tau_z p_X\left\{-\frac{dX}{d\tau_G}\right\}}_{\text{Consumption tax revenue}} + \underbrace{\Gamma\left\{-\frac{dv_p}{d\tau_G}\right\}}_{\text{EV purchase subsidy}}$$

$$\tau_G^* = \tau_G^C + \tau_G^I$$

Corrective (Pigouvian) tax component

$$\tau_G^C \equiv \underbrace{e_G + \alpha \left(e_{M_F}^{nc} + e_M^c \right) / g}_{\text{Gasoline cars}} + \underbrace{\beta \left(e_D + \left(e_{M_F}^{nc} + e_M^c \right) / \tilde{d} \right)}_{\text{Diesel cars}} + \underbrace{\gamma \left(e_P + \left(e_{M_P}^{nc} + e_M^c \right) / \tilde{p} \right)}_{\text{Electric Vehicles}}$$

→ τ_G^C accounts for the traffic related externalities

$$\alpha \equiv \frac{g \times dM_G / d\tau_G}{dG / d\tau_G} \qquad \beta \equiv \frac{dD / d\tau_G}{dG / d\tau_G} \qquad \gamma \equiv \frac{dP / d\tau_G}{dG / d\tau_G}$$

$$\tau_G^* = \tau_G^C + \tau_G^I$$

Fiscal tax component

$$\tau_G^I \equiv \Omega_{\tau_L} \frac{(1+\tau_z)\, G}{-dG/d\tau_G} - (1+\Omega_{\tau_L})\,[A - \psi\Gamma]$$

$$A \equiv [\beta\tau_D + \gamma\tau_P + \tau_z\left((p_G+\tau_G) + \beta\,(p_D+\tau_D) + \gamma\,(p_P+\tau_P) + \delta p_X\right) + \varphi\tau_L w]$$

$$\Omega_{\tau_L} \equiv \frac{-\tau_L w \frac{\partial L}{\partial \tau_L} - \tau_z p_X \frac{\partial X}{\partial \tau_L}}{W + \tau_L w \frac{\partial L}{\partial \tau_L} + \tau_z p_X \frac{\partial X}{\partial \tau_L}}$$

→ τ_G^I reflects the interaction of the gasoline tax with the other distortive taxes

→ Fuel tax revenue can be used to cut other distortionary taxes in the economy $(+)$

→ Fuel tax distorts labor/leisure choice and so may reduce labor tax revenue $(-)$

$$\beta \equiv \frac{dD/d\tau_G}{dG/d\tau_G} \qquad \gamma \equiv \frac{dP/d\tau_G}{dG/d\tau_G} \qquad \delta \equiv \frac{dX/d\tau_G}{dG/d\tau_G} \qquad \varphi \equiv \frac{dL/d\tau_G}{dG/d\tau_G} \qquad \psi \equiv \frac{dv_p/d\tau_G}{dG/d\tau_G}$$

To calculate the optimal gasoline tax, information are needed w.r.t.

- *general economic figures*
  - initial fuel/energy (pre-tax) prices
  - initial fuel/energy taxes, labor tax, consumption tax
  - wage (value of time)
- *transport related data (for all car types)*
  - initial vehicle kilometrage
  - initial fuel/energy intensity (fuel/energy economy)
- *behavioral responses*
  - own- and cross price elasticities of fuel and travel demand
  - income elasticities
  - labor supply elasticities
- *marginal external cost (for all car types)*
  - fuel/energy related (local and global air pollution)
  - distance related (congestion, accidents, noise)

- Our baseline case refers to 2012, where electric mobility is almost negligible $\left(12-31-2012: \approx 7000 EVs \rightarrow 0.017\%\right)$

Result

Description	Value	Dimension
Optimal gasoline tax τ_G^*	0.96	€/*liter*
Tax differential $(\tau_G^* - \tau_G^0)$	$+0.31$	€/*liter*
Tax ratio (τ_G^*/τ_G^0)	1.48	€/*liter*
	Welfare	
Welfare $(\tau_G^*$ vs. $\tau_G^0)$	$+450$	Mio €/*year*

Description	Value	Dimension
Optimal gasoline tax τ_G^*	0.96	€/*liter*
Tax differential $(\tau_G^* - \tau_G^0)$	+0.31	€/*liter*
Tax ratio (τ_G^* / τ_G^0)	1.48	€/*liter*
Optimal gasoline tax formula components		
[1] : Corrective tax τ_G^C	+0.64	€/*liter*
[1*a*] : $+e_G$	+0.19	€/*liter*
[1*b*] : $+\alpha\left(e_M^{nc} + e_M^c\right)/g$	+0.66	€/*liter*
[1*c*] : $+\beta\left(e_D + \left(e_M^{nc} + e_M^c\right)/\tilde{d}\right)$	−0.21	€/*liter*
[2] : Fiscal component τ_G^I	+0.32	€/*liter*
[2*a*] : Revenue Recycling Effect	+0.90	€/*liter*
[2*b*] : Tax Interaction Effect	−0.58	€/*liter*
$\tau_G^* = [1] + [2]$	0.96	€/*liter*
Externalities[1]		
Congestion	40.4 / −10.5	€-cents/*liter*
Accidents	19.8 / −5.1	€-cents/*liter*
Noise	5.5 / −1.4	€-cents/*liter*
Air pollution	8.9 / −2.5	€-cents/*liter*
Climate change (CO_2)	10.4 / −1.6	€-cents/*liter*
Transport characteristics[2]		
Fuel economy gasoline car	12.66 / 13.17	*km/liter*
Gasoline vehicle kilometrage	8582 / 8088	*km/year*
Diesel vehicle kilometrage	6172 / 6295	*km/year*
Gasoline demand	678 / 614	*liters/year*
Diesel demand	414 / 422	*liters/year*

[1] Gasoline car/Diesel car [2] Baseline/Policy

- Even though there is a vastly growing literature around different aspects of electric mobility, there is still considerable uncertainty in terms of EV market potential, external costs of EVs and future policies to foster EV demand etc.

- We consider different scenarios w.r.t.
  - initial market share of EVs
  - degree of EV diffusion
  - external costs of EVs
  - existence of EV purchase subsidy

- Initial market share of EVs
  - 0%, 2.5%, 10%, 25%
- Degree of EV diffusion (potential of τ^G to foster EV traveling)
  - 0.0 → no switch to EVs as a response to higher fuel prices (change in gasoline based car driving is captured by diesel cars only)
  - 0.5 → Diesel cars and EVs are equal substitutes (change in gasoline car driving is attracted by EVs and diesel cars in equal shares)
  - 1.0 → no switch to Diesel cars as a response to higher fuel prices (change in gasoline based car driving is captured by EVs only)
- External costs of driving EVs
  - [1] share of RE on total EG 22%; +50% AC; –0% NC ⇒ not EV friendly
  - [2] share of RE on total EG 35%; +25% AC; –25% NC
  - [3] share of RE on total EG 50%; + 0% AC; –50% NC
  - [4] share of RE on total EG 100%; + 0% AC; –100% NC ⇒ EV friendly
- Existence of EV purchase subsidy
  - 0 €, 2500€

External noise cost of EVs

Why to consider a scenario where external noise costs of EVs are equal/lower?

- Usually it is argued that noise costs of EVs are roughly zero due to the low noise level of battery engines
- Indeed, at low speeds (7-8 km/h or 4-5 mph) and in the initial phase of acceleration (≈0.5 m/s^2), noise levels tend to be, on average, lower for EVs compared to ICEs (Garay-Vega et al., 2010; Morgan et al., 2010)
- However, it is also argued that meanwhile modern ICE vehicles may also be as quiet as their electric equivalents
- At higher speeds (> 20 km/h), noise levels are comparable as road and tire noise become more dominant
- $\Longrightarrow$ noise (EVs) $\lesssim$ noise (ICEVs)

External accident cost of EVs

Why to consider a scenario where external accident costs of EVs are equal/higher?

- Usually it is argued that accident costs of EVs are higher since the low noise level of EVs raise additional safety issues
- Indeed, accident costs of EVs are suggested to be higher because EVs are more difficult for pedestrians to hear and, therefore, compromise traffic safety (Hanna, 2009; Morgan et al., 2010)
- However, some other studies found no statistical evidence for a higher incidence rate for accidents between EVs and pedestrians or bicyclists (e.g. because EV drivers adjust their perceived risk of harming other road users over time; Cocron/Krems, 2013; Verheijen and Jabben, 2010)
- $\Longrightarrow$ accident (EVs) $\gtrapprox$ accident (ICEVs)

Optimal Gasoline Tax [€-cents/liter]	**EV market share**				**EV market share**				**EV market share**				**EV market share**			
	0%				2.5%				10%				25%			
	EV mec scenario				**EV mec scenario**				**EV mec scenario**				**EV mec scenario**			
EV diffusion	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.0	96	96	96	96												
0.5																
1.0																

- With zero EV diffusion, zero market share and zero EV purchase subsidy, EVs (and so their external cost) do not play any role for optimal gasoline tax calculations (→baseline)

Optimal Gasoline Tax [€-cents/liter]	**EV market share**				**EV market share**				**EV market share**				**EV market share**			
	0%				2.5%				10%				25%			
	EV mec scenario				**EV mec scenario**				**EV mec scenario**				**EV mec scenario**			
EV diffusion	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.0	96	96	96	96												
0.5	89															
1.0	84															

- If drivers switch to EVs and not to diesel cars: $\tau_G^* \downarrow$ ($\tau_G^C \uparrow$ whereas $\tau_G^I \downarrow\downarrow$)
  - $\tau_G^C \uparrow$: externalities from EVs are lower i.r.t. diesel cars, $\rightarrow$ need to correct τ_G^C for diesel externalities becomes smaller $\rightarrow \tau_G^C \uparrow$
  - $\tau_G^I \downarrow\downarrow$: stronger EV diffusion erodes of the fuel tax bases and this softens the positive revenue recycling effect $\rightarrow \tau_G^I \downarrow\downarrow$

Optimal Gasoline Tax [€-cents/liter]	**EV market share**				**EV market share**				**EV market share**				**EV market share**			
	0%				2.5%				10%				25%			
	EV mec scenario				**EV mec scenario**				**EV mec scenario**				**EV mec scenario**			
EV diffusion	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.0	96	96	96	96												
0.5	89	90	90	91												
1.0	84	86	87	88												

- If assumptions on EV externalities favor EVs (more electricity from RE, noise cost lower,...) $\rightarrow$ need to correct τ_G^C for EV related externalities becomes smaller $\rightarrow$ $\tau_G^C \uparrow$
- Fiscal component τ_G^I is hardly affected

Optimal Gasoline Tax [€-cents/liter]	**EV market share** 0%				**EV market share** 2.5%				**EV market share** 10%				**EV market share** 25%			
	EV mec scenario				**EV mec scenario**				**EV mec scenario**				**EV mec scenario**			
EV diffusion	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.0	96	96	96	96					98	98	98	98				
0.5	89	90	90	91					91	92	92	93				
1.0	84	86	87	88					86	87	88	89				

- Higher EV market share slightly increases the fiscal tax component $\rightarrow \tau_G^I \uparrow$
  - MEB is larger with higher EV market share
  - This in turn rises the efficiency gain of using gasoline tax revenue to lower the labor tax

Optimal Gasoline Tax [€-cents/liter]	**EV market share** 0%				**EV market share** 2.5%				**EV market share** 10%				**EV market share** 25%			
	EV mec scenario				**EV mec scenario**				**EV mec scenario**				**EV mec scenario**			
EV diffusion	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.0	96	96	96	96	97	97	97	97	98	98	98	98	101	101	101	101
0.5	89	90	90	91	90	91	91	92	91	92	92	93	93	94	94	95
1.0	84	86	87	88	85	86	87	88	86	87	88	89	88	89	90	91

Main result:

1. If EVs are sufficiently competitive such that higher gasoline taxes force gasoline car users to drive EVs instead of diesel cars (EV diffusion>0), τ_G^* is likely to be slightly lower than the currently optimal tax
2. However, even in quite optimistic electric mobility scenarios, the optimal gasoline tax is still considerably higher than the current gasoline tax in Germany ($\tau_G^0 = 0.65$ €/km) !!!

Optimal Gasoline Tax [€-cents/liter]	EV market share 0%				EV market share 2.5%				EV market share 10%				EV market share 25%			
	EV mec scenario				EV mec scenario				EV mec scenario				EV mec scenario			
EV diffusion	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.0	96	96	96	96	86	86	86	86	57	57	57	57	34	34	34	34
0.5	89	90	90	91	81	82	82	83	57	57	58	58	36	36	36	36
1.0	84	86	87	88	78	79	80	81	57	58	58	59	37	37	37	37

Main result:

1. The optimal gasoline is closer to the current tax level $\tau_G^0 = 0.65$ €/km and could even fall below
2. Reason: EV purchase subsidy diminishes the positive fiscal net benefit of the gasoline tax ($\tau_G^I \downarrow$ and could even become negative)

- This paper has linked the literature on fuel taxes and EVs by analyzing how gasoline should be taxed efficiently under emerging electric mobility

Take home message:

- Current gasoline tax in Germany is not too high
- Without EV purchase subsidy:
    - Even with strong EV diffusion, the optimal gasoline tax is likely to be significantly higher than the current tax of 0.65 €/*km*
- With EV purchase subsidy:
    - Moderate EV market share: see above
    - High EV market share: the optimal gasoline tax could even fall below its current level of 0.65 €/*km*

Thanks for your attention!

Calibration - parameters

Description	Symbol	Value	Dimension
Transport and other data			
Initial gasoline intensity	g^0	0.079	*liters / vkm*
Diesel intensity	$\tilde{d}$	0.067	*liters / vkm*
Initial gasoline vehicle kilometrage	M_G^0	8582	*vkm*
Initial diesel vehicle kilometrage	M_D^0	6172	*vkm*
Initial level of general consumption	X^0	325	*units*
Free-flow travel time	ξ_1	0.012	*hours / vkm*
Parameter congestion function	ξ_2	0.124	–
Parameter congestion function	ξ_3	4	–
Value of travel time	θ	9.50	*€/ hour*
Prices and taxes			
Gasoline producer price	p_G	0.74	*€/ liter*
Diesel producer price	p_D	0.78	*€/ liter*
Price of the general consumption goods basket	p_X	60	*€/ unit*
Initial gasoline tax	τ_G^0	0.65	*€/ liter*
Diesel tax	τ_D	0.47	*€/ liter*
Consumption tax rate	τ_z	0.19	%
Labor tax rate (baseline)	τ_L	0.44	%

Calibration - parameters

Description	Symbol	Value	Dimension
Elasticities			
Own-price elasticity of gasoline intensity	ϵ_g	−0.20	%
Own-price elasticity of gasoline kilometrage	ϵ_{M_G}	−0.30	%
Gasoline cross-price elasticity of diesel kilometrage	$\epsilon_{M_D^G}$	+0.10	%
Gasoline cross-price elasticity of general consumption	ϵ^c_{XG}	+0.01	%
Income elasticity of general consumption	ϵ_{XI}	+0.60	%
Income elasticity of vehicle kilometrage	ϵ_{MI}	+0.71	%
Income elasticity (compensated) of gasoline demand	ϵ^c_{GI}	+0.25	%
Income elasticity of labor supply	ϵ_{LI}	−0.15	%
Labor supply elasticity (compensated)	ϵ^c_{LL}	+0.35	%
Labor supply elasticity (uncompensated)	ϵ_{LL}	+0.20	%
External Costs			
Kilometrage related external congestion costs	e^c_M	0.056	€/*vkm*
Kilometrage related external non-congestion costs	e^{nc}_M	0.027	€/*vkm*
Gasoline related external costs	e_G	0.193	€/*liter*
Diesel related external costs	e_D	0.299	€/*liter*

External cost

Table: Social climate cost of electric power (22% renewable energies on total electricity generation)

Energy	Share 2012 [%]	CO_2-eq [g/kwh][1]	Cost share [€-cents/kwh][2]
Natural Gas	11	439	0.22
Hard Coal	19	923	0.79
Lignite	26	1085	1.27
Nuclear energy	16	20	0.01
Others (fuel oil, pumped storage)	6	706	0.19
Wind	7	12	0.00
Solar	5	69	0.02
Hydro power	3	4	0.00
Biomass	7	100	0.03
Total	100	—	2.53

Renewable Energies 22%

[1] Environmental protection agency (Umweltbundesamt), 2012a)

[2] Assuming social cost of carbon of 45 €/tCO_2

External cost

Table: External air pollution cost of electric power (22% renewable energies on total electricity generation)

Energy	Share 2012 [%]	Cost rate [€-cents/kwh][1]	Cost share [€-cents/kwh]
Natural Gas	11	1.06	0.12
Hard Coal	19	1.61	0.31
Lignite	26	2.15	0.56
Nuclear energy	16	2.15	0.34
Others (fuel oil, pumped storage)	6	2.51	0.15
Wind	7	0.18	0.01
Solar	5	0.65	0.03
Hydro power	3	0.15	0.00
Biomass	7	2.89	0.20
Total	100	—	1.73

Renewable Energies 22%

[1] Environmental protection agency (Umweltbundesamt), 2012b)

External cost

Table: Social climate cost of electric power (100% renewable energies on total electricity generation)

Energy	Share [%]	CO_2-eq [g/kwh][1]	Cost share [€-cents/kwh][2]
Natural Gas	0	439	0.00
Hard Coal	0	923	0.00
Lignite	0	1085	0.00
Nuclear energy	0	20	0.00
Others (fuel oil, pumped storage)	0	706	0.00
Wind	25	12	0.01
Solar	25	69	0.08
Hydro power	25	4	0.01
Biomass	25	100	0.11
Total	100	—	0.21

Renewable Energies 100%

[1] Environmental protection agency (Umweltbundesamt), 2012a)

[2] Assuming social cost of carbon of 45 €/tCO_2

External cost

Table: External air pollution cost of electric power (100% renewable energies on total electricity generation)

Energy	Share [%]	Cost rate [€-cents/kwh][1]	Cost share [€-cents/kwh]
Natural Gas	0	1.06	0.00
Hard Coal	0	1.61	0.00
Lignite	0	2.15	0.00
Nuclear energy	0	2.15	0.00
Others (fuel oil, pumped storage)	0	2.51	0.00
Wind	25	0.18	0.04
Solar	25	0.65	0.16
Hydro power	25	0.15	0.04
Biomass	25	2.89	0.72
Total	100	—	0.96

Renewable Energies 100%

[1] Environmental protection agency (Umweltbundesamt), 2012b)

1. External cost – energy related

External costs	Component	Value	Dimension
Energy related externalities			
Air pollution gasoline	e_G	0.089 (0.007)	€/*liter* (€/*vkm*)[2]
Air pollution diesel	e_D	0.179 (0.012)	€/*liter* (€/*vkm*)[3]
Air pollution EV[1]	e_P	0.021 (0.003)	€/*kwh* (€/*vkm*)[4]
Climate change (CO_2) gasoline	e_G	0.104 (0.008)	€/*liter* (€/*vkm*)[2]
Climate change (CO_2) diesel	e_D	0.120 (0.008)	€/*liter* (€/*vkm*)[3]
Climate change (CO_2) EV[1]	e_P	0.025 (0.003)	€/*kwh* (€/*vkm*)[4]

[1] Based on the 2012 electricity generation mix in Germany

Energy intensity: [2] 7.9 *liters*/100*km* [3] 6.7 *liters*/100*km* [4] 14 *kwh*/100*km*

- Local + Global pollution
  - 0.015 €/*vkm* (Gasoline car)
  - 0.020 €/*vkm* (Diesel car) → 133%
  - 0.006 €/*vkm* (Electric vehicle) → 40%

1. External cost – distance related

External costs	Component	Value	Dimension
Kilometrage related externalities			
Accidents (fuel powered vehicles)	$e^{nc}_{M_F}$	0.025	€/vkm
Accidents (electric vehicles)	$e^{nc}_{M_P}$	???	€/vkm
Noise (fuel powered vehicles)	$e^{nc}_{M_F}$	0.007	€/vkm
Noise (electric vehicles)	$e^{nc}_{M_P}$	???	€/vkm

- By now the literature on external accident and noise cost of EVs is scarce and it is not clear at all whether external cost of EVs are higher or lower in comparison to ICE vehicles

1. External cost differences

- Evaluating the empirical external cost literature, using data for average energy intensity of car types and underlying the 2012 electricity generation mix in Germany for electr. power production, marginal external cost w.r.t.local + global pollution are estimated at
  - 0.015 €/ *vkm* (Gasoline car)
  - 0.020 €/ *vkm* (Diesel car) → 133%
  - 0.006 €/ *vkm* (Electric vehicle) → 40%
- Concerning distance related mec the empirical literature provides sufficient estimates of marginal external accident/noise costs for conventional ICE vehicles. However, by now the literature on external accident and noise cost of EVs is scarce. Mostly it is argued
  - *menc* (EVs) $<$ *menc* (ICEVs) → low noise level of battery engines
  - *meac* (EVs) $>$ *meac* (ICEVs) → low noise level of EVs raises additional safety issues

2. Differential tax treatment

Car Usage

- Based on 2012 data, the Consumer price per unit of energy:
  - $P_G = (1 + 0.19)(0.74 + 0.65) = 1.65$ €/liter $(0.77$ €/ *liter*$)$
  - $P_{EV} = (1 + 0.19)(0.18 + 0.04) = 0.26$ €/kwh $(0.05$ €/ *kwh*$)$
- Tax per km $= (1 + \tau_z)(\tau) \times$ *energy intensity*
  - $T_G = 0.77$ €/liter$\times 0.079$ *liter / km* $= 6$ €-cents/km
  - $T_{EV} = 0.05$ €/kwh$\times 0.14$ *kwh / km* $= 0.7$ €-cents/km

→ Assuming annual vehicle distance traveled 10000 km

→ Annual car usage tax differential of 530 €

Car Ownership

Annual tax differential ≈100 €, dep. on car type, registration date, ...