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Taxing Car-produced Carbon Dioxide Emissions: Matching the Cure to the Disease

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Abstract

The amount of carbon dioxide (CO_2) emissions produced by cars is a linear (albeit fuel specific) function of the amount of fuel consumed. Because CO_2 emissions generate social costs, through their effect on climate change, which escape the price mechanism, a tax on CO_2 is indicated. An ideal tax would alter the consumer prices so that they match the marginal social costs. This setting thus calls for a specific tax on fuel equal to the value of externality resulting from the combustion of a unit of fuel. Since such tax scheme is readily available, we study to what extent the existing CO_2 tax policies make use of it. We find that they do only to a limited extent. Thus our policy prescription is to drop existing CO_2 taxes and use the existing fuel taxes to adjust fuel prices so that they match the marginal social costs related to burning of fuel.

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1. Introduction

Motor vehicle movement is also associated with the emissions of carbon dioxide (CO_2) – a result of fuel combustion. Unlike toxic emissions from cars that have adverse effects on people living today (Chen, Ebenstein, Greenstone, and Li 2013; Hoek, Brunekreef, Goldbohm, Fischer, and van den Brandt 2002), particularly children (Arceo-Gomez, Hanna, and Oliva 2012; Brauer et al. 2002), the effects of increased amount of carbon dioxide work through

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the costs related to the climate change. They will be borne by future generations. Thus the impossibility of Coasian bargaining solution (Calabresi and Melamed 1971; Coase 1960) rests not so much on high transaction costs and information problems, rather the fundamental problem is that there is no-one to contract with in the first place—as those should ultimately bear the costs are not (yet) alive. As a result, the nature as well as the magnitude of these costs is more speculative.

More specifically, the uncertainty has three sources: (i) the uncertainty related to prediction of climate decades from now, as well as the size of the causal effect of human activity in that; (ii) the uncertainty in estimating the future costs as well as future resources, technology, and the ability of future societies to cope with those costs—as opposed of today's actions; and (iii) the discount rate that should be applied to those costs, which is necessary in order determine the appropriate amount of today's investments into the preventive measures—as opposed to compensating the future generations (Pearce 2003; Pindyck 2013a,b; Schelling 2007, 2009; see also Tol 2012). However, the uncertainty does not imply that there should be no policy response. In addition, even if mean predictions of future costs due to climate change were zero, there is a risk of a catastrophic outcome, which calls for a policy response (Pindyck 2013a,b; Pindyck and Wang 2013; Posner 2005; Weitzman 2007).[1] Thus, we do not discuss the explicit value of the carbon dioxide-related externalities generated by motor vehicles, rather we treat that externality as a cost and study policies that would lead consumers to choose the socially optimal amount of it.

2. Background

As can be seen in Figure 1, CO_2 coming from motor gasoline and diesel fuel combustion contribute between 25 and 30 percent to the total emissions. To the extend these costs do not enter into drivers' or passengers' cost functions, the chosen level of driving activity, as well as the amount of pollution produced per kilometer, may be above the optimum. This is because the equality between the marginal utility from a driving the next journey with its marginal costs obtains at a higher level of driving activity than would be justified by the marginal costs of that journey born by the society as whole (assuming diminishing marginal utility from travel). This is a blueprint example of an externality situation where an appropriate tax may correct the incentives. In a textbook notation we have inequality between the private marginal costs MC and the social marginal costs SMC and we are looking for a tax, which would equate the two, that is $T = SMC - MC$.

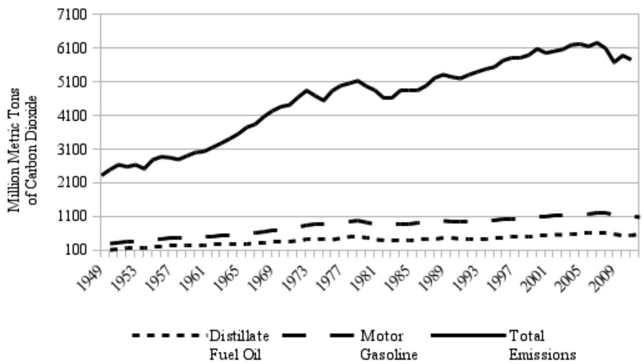

Fig. 1. Carbon Dioxide Emissions From Energy Consumption, United States 1949–2011. Data source: U.S. Department of Energy 2012, Table 11.1.

As long as a car stays in the garage, it produces zero CO_2 emissions (assuming the engine is off). Once it begins moving, the marginal externalities are determined by the laws of nature. Specifically, when hydrocarbon burns in

[1] See, however, Schelling (2007, 4) who recommends us not to "be obsessed with either extreme tail of the distribution".

oxygen the result is mainly water and carbon dioxide. Thus, the amount of CO_2 increases linearly in the amount of fuel combusted by a car (National Research Council, 2002; U.S. Environmental Protection Agency 2009) and no mitigating technologies are available (Parry, Walls, and Harrington 2007). To check this empirically we have estimated a set of OLS models using data on fuel economy and CO_2 emissions at a model-engine-year level collected by the Vehicle Certification Agency of the United Kingdom Department for Transport. Specifically, denote $y_{p,m,g,t}$ the amount of CO_2 per kilometre produced by a car, where *p* identifies the producer, *m* the model, *g* the engine type, and *t* the year of production, we estimate

$$\log y_{p,m,g,t} = \beta_0 + \beta_1 \log c_{p,m,g,t} + \beta_2 d_g + \beta_3 \log c_{p,m,g,t}\, d_g + \boldsymbol{\beta}_4' \boldsymbol{x}_{p,m,g,t} + \epsilon_{p,m,g,t}, \tag{1}$$

where $c_{p,m,g,t}$ is the fuel consumption per 100 kilometres, d_g is a dummy set to 1 if an engine g is a diesel and 0 for petrol engines and $\boldsymbol{x}_{p,m,g,t}$ is a vector of additional controls. We estimate four alternative specifications of regression (1): the first specification is estimated without any $\boldsymbol{x}$s; in the second specification we add the year of production and its square; in the third specification we add the full set of interactions between the fuel type and year of production dummies; and in fourth specification we a add full set of dummies for car producer. Because fuel consumption as well as CO_2 emissions per kilometer are in logs, β_1 and β_3 are elasticities while β_2 picks up the (approximate) percentage difference between the average CO_2 per kilometer for cars with petrol engine and cars with diesel engine.[2] Looking at regression (1), one may worry that the residuals are not independent because fuel consumption as well as CO_2 emissions are measured by car producers; we therefore report standard errors clustered at the producer level, allowing for an arbitrary correlation among residuals within individual car producers.

If the description in previous paragraph is correct, then β_1 and β_3 should be equal to 1 and 0, respectively, however this expectation would only be correct if fuel was burned perfectly. In reality, burning is imperfect and therefore small portion of carbon is un-oxidized; the Intergovernmental Panel on Climate Change (IPCC) guidelines state the oxidization factor for oil products to be 0.99, that is 99 percent of carbon in the fuel is oxidized (U.S. Environmental Protection Agency 2009). However, that value is likely conservative as modern efficient engines and cleaner fuels result in more complete combustion (providing better fuel economy and fewer toxic emissions, which consist of the un-oxidized fuel). Thus we expect the true value of β_1 to be between 0.99 and 1 and β_3 to be between -0.01 and zero because diesel engines burn fuel slightly less perfectly than petrol engines.

First four columns of Table 1 report the results. Focusing on the coefficients in the first row which contains our four alternative OLS estimates of β_1. All are between 0.98 and 0.99, suggesting that increasing the fuel consumption per kilometer by 1 percent results in an increase of CO^2 emissions by almost 0.99 percent; very close to the expected range of values. As reported at the bottom of Table 1, the hypothesis that $\beta_1 = 0.99$ is rejected in specifications (1) and (2) but not in specifications (3) and (4). Note that the coefficient on the interaction term for diesel cars is systematically larger than the expected range of values and it is highly statistically significant; suggesting that for the subset of diesel cars the elasticity of CO_2 emissions with respect to fuel consumption is between 0.94 and 0.97.

There are reasons, however, to be worried that the OLS estimates suffer from the attenuation bias, i.e. are biased towards zero. This is because the fuel consumption is measured with an error and, more importantly, the data on consumption are rounded at one decimal point introducing additional measurement error. Note also that the measurement error may be relatively more influential in the case of diesel engine cars; this is because the former have substantially lower consumption on average (6.24 versus 8.61 liters per 100 km) resulting in smaller variance

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[2] That is taking derivatives of both sides of regression (1) with respect to c we obtain $\frac{1}{Y}\frac{\delta Y}{\delta C}_{\mid D=0} = \beta_1 \frac{1}{C}$. Solving for β_1 yields $\beta_1 = \frac{\delta Y}{\delta C}_{\mid D=0}\frac{C}{Y}$, which is the elasticity of *Y* with respect to *C* (for the subset of cars with petrol engine). F$\beta_1$or, because d_g is a discrete variable, fix $\varsigma, \boldsymbol{\kappa} \in \mathbf{R}$, then we can write $\beta_2 = \log \mathrm{E}(Y \mid c = \varsigma,\ \boldsymbol{x} = \boldsymbol{\kappa},\ d = 1) - \log \mathrm{E}(Y \mid c = \varsigma,\ \boldsymbol{x} = \boldsymbol{\kappa},\ d = 0)$, which is approximately the proportional difference between $\mathrm{E}(Y \mid \dots d = 1)$ and $\mathrm{E}(Y \mid \dots d = 0)$; the exact proportional difference being $\frac{\mathrm{E}(Y \mid \dots d=1) - \mathrm{E}(Y \mid \dots d=0)}{\mathrm{E}(Y \mid \dots d=0)} = e^{\beta_2} - 1$, but the two quantities are similar for small βs as $\lim_{\beta \to 0} \beta = e^{\beta_2} - 1$.

(standard deviations are 1.57 and 2.46, for diesel and petrol cars, respectively). Therefore the (same) measurement error would take up a larger share on variance of fuel consumption in the case of diesel cars.

Table 1. Carbon dioxide emissions and fuel economy

	OLS				IV			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log fuel economy	0.982	0.985	0.989	0.987	0.993	0.994	0.995	0.998
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Year		−0.004				−0.004		
		(0.001)				(0.001)		
Year^2		0.0004				0.0004		
		(0.0001)				(0.0001)		
Diesel ×								
Log fuel economy	−0.043	−0.029	−0.022	−0.023	−0.015	−0.010	−0.010	−0.011
	(0.008)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.004)
Year		−0.009				−0.01		
		(0.001)				(0.001)		
Year^2		0.001				0.001		
		(0.0001)				(0.0001)		
Diesel (= 1)	0.187	0.179	0.156	0.156	0.140	0.146	0.135	0.138
	(0.015)	(0.014)	(0.012)	(0.012)	(0.011)	(0.012)	(0.009)	(0.008)
Constant	3.213	3.214	3.200	3.200	3.189	3.193	3.186	3.174
	(0.006)	(0.006)	(0.005)	(0.006)	(0.005)	(0.005)	(0.004)	(0.006)
Years × Fuel	–	–	Yes	Yes	–	–	Yes	Yes
Make	–	–	–	Yes	–	–	–	Yes
Observations	26 450	26 450	26 450	26 450	26 450	26 450	26 450	26 450
Adjusted R^2	0.986	0.987	0.991	0.991	0.985	0.986	0.99	0.991
Test: Log economy = 0.99								
t-statistic	−3.043	−2.159	−0.703	−1.328	1.418	2.037	2.690	3.435

Note: Huber-White standard errors clustered on car producers are in parentheses; clustered standard errs for IV estimates were estimated using formulas in Shore-Sheppard (1996). Unit of observation Shore-Sheppard (1996). Unit of observation is at the car type-year level. Fuel economy in IV models is instrumented by engine displacement, its interaction with dummy for diesel engines, and the rest of explanatory variables in each specification. Engine displacement and the interaction are the instruments excluded in the second stage. First stage estimates are reported in Table A1 in the appendix. Data source: the Vehicle Certification Agency, the United Kingdom Department for Transport.

In order to address the issue of measurement error we estimated a 2SLS model, instrumenting the fuel consumption with engine displacement, denoted e.[3] Specifically, we have estimated a system of two regressions: In the first stage we regress fuel consumption on engine displacement, the dummy for diesel, and its interaction with engine displacement, plus the rest of $\boldsymbol{x}$s

$$\log c_{p,m,g,t} = \alpha_0 + \alpha_1 \log e_{p,m,g,t} + \alpha_2 d_g + \alpha_3 \log e_{p,m,g,t} d_g + \boldsymbol{\alpha}'_4 \boldsymbol{x}_{p,m,g,t} + \varepsilon_{p,m,g,t}. \quad (2)$$

First stage estimates are reported in Table A1 in the appendix. Using the data and the estimated parameters from regression (2) we get the predicted values of c, denoted $\hat{c}$, that is

[3] See Ashenfelter and Krueger (1994) for a classic application of IV strategy to deal with attenuation bias.

$$\log \hat{c}_{p,m,g,t} = \hat{\alpha}_0 + \hat{\alpha}_1 \log e_{p,m,g,t} + \hat{\alpha}_2 d_g + \hat{\alpha}_3 \log e_{p,m,g,t} d_g + \hat{\boldsymbol{\alpha}}'_4 \boldsymbol{x}_{\boldsymbol{p,m,g,t}}. \tag{3}$$

Finally we replace c by $\hat{c}$ in regression (1) and estimate

$$\log y_{p,m,g,t} = \beta_0 + \beta_1 \log \hat{c}_{p,m,g,t} + \beta_2 d_g + \beta_3 \log \hat{c}_{p,m,g,t} d_g + \boldsymbol{\beta}'_4 \boldsymbol{x}_{\boldsymbol{p,m,g,t}} + \epsilon_{p,m,g,t}. \tag{4}$$

The exclusion restriction for this IV model requires that engine displacement does not affect CO_2 except through engine displacement. This appears to be satisfied as long as CO_2 emissions depend only on fuel consumption. We estimated the IV model for our four specifications. Reported standard errors are again clustered at the car producer level and were computed according to the results in Shore-Sheppard (1996).[4]

The results are reported in columns (5) through (8) of Table 1. Compared with the OLS estimates, the IV coefficients on fuel consumption are about one log point higher and never below 0.99. This is the expected result; the difference between IV and OLS estimates is consistent with attenuation bias in OLS due to measurement error. Tests whether $\beta_1 = 0.99$ do not reject in specifications (5) and (6) but do in (7) and (8).

A more dramatic change occurs in the case of the coefficients on the interaction between fuel consumption and the dummy for diesel engines. The estimates of β_3 fall by approximately two log points and only in two case are statistically significant at the 5 percent level (although they are all significant at the 10 percent level), which is a substantial change in comparison with the OLS estimates. This, again, is an expected result if the attenuation bias was more severe in the case of diesel engine cars. Note also that the coefficient on the dummy for diesel engine suggests that diesel engines produce between 13.5 to 14.6 log points more CO_2 per unit of fuel compared to fuel engines, the proportional difference in CO_2 emissions per unit off between diesel and petrol is 0.144 (in logs we have $\log[0.144 + 1] \times 100 = 13.5$).

To summarize, it is reasonable to believe the elasticity of CO_2 emissions with respect to fuel consumption is between 0.99 and 1, and this holds for petrol as well as, although less precisely, for diesel engines. This implies that increasing fuel consumption by 1 percent result in close to one 1 increase of CO_2 emissions.

3. The Model

3.1. The setup

Automobile-related CO_2 pollution, at the individual car level, can be described as a function of three variables: activity, that is kilometers driven, denoted a; fuel consumption per kilometer, denoted c; and the amount of emissions per combusted unit of fuel, denoted e. Let i be a car identifier, the discussion above implies that e_i varies only with the fuel type, thus it can be denoted e_f, where f is a fuel identifier. Let the units of e_f be normalized so that their monetary value is equal to one Euro. Then the value of the externality, denoted v, produced by car i is simply

$$v_i = a_i c_i e_f \tag{5}$$

[4] Specifically, let $\boldsymbol{X}$ be the matrix of explanatory variables (including the intercept) from regression (1) and $\boldsymbol{Z}$ be the matrix of instruments (including the non-excluded $\boldsymbol{x}$s from the second stage) from regression (2), then the estimate of the variance-covariance matrix of $\boldsymbol{\beta}$ can be obtained from the sandwich estimator $\text{var}(\hat{\boldsymbol{\beta}}) = [\boldsymbol{X'Z}(\boldsymbol{Z'Z})^{-1}\boldsymbol{Z'X}]^{-1}\boldsymbol{X'Z}(\boldsymbol{Z'Z})^{-1}\boldsymbol{Z'\Omega Z}(\boldsymbol{Z'Z})^{-1}\boldsymbol{Z'X}[\boldsymbol{X'Z}(\boldsymbol{Z'Z})^{-1}\boldsymbol{Z'X}]^{-1} \left(\xrightarrow{p} \text{var}(\boldsymbol{\beta})\right)$. The meat matrix can be estimated using $\boldsymbol{Z'}\hat{\boldsymbol{\Omega}}\boldsymbol{Z} = a\sum_p \boldsymbol{Z}'_{\boldsymbol{p}}\boldsymbol{\epsilon_p}\boldsymbol{\epsilon}'_{\boldsymbol{p}}\boldsymbol{Z_p} \left(\xrightarrow{p} \boldsymbol{Z'\Omega Z}\right)$ (Shore-Sheppard 1996; Söderbom 2011; White 1980; see also Davidson and MacKinnon 2003, chap. 5.5 and 8.5), that is for each producer the transformed subset of p's $\boldsymbol{Z}$, a $k \times n_p$ matrix $\boldsymbol{Z}'_{\boldsymbol{p}}$, is multiplied with p's $n_p \times n_p$ covariance matrix of residuals and a $n_p \times k$ matrix $\boldsymbol{X_p}$, where k is the number of explanatory variables, n_p denotes the number of cars from producer p in the data, and a is a degrees of freedom correction factor obtained as $a = \frac{m}{m-1}\frac{n-1}{n-k}$, where m is the number of car producers in the data and n is the number of observations. The result is m of $k \times k$ matrices, one matrix for each producer, sum of which is the estimate of $\boldsymbol{Z'\Omega Z}$. Taking the square root of the vector of diagonal elements of $\text{var}(\hat{\boldsymbol{\beta}})$ yields the estimate of clustered standard errors for coefficients from regression (4).

Euro, where $a_i c_i$ is the total fuel consumption by car i. Note that fuel consumption is allowed to vary within cars as individual-level factors, such as driving style, load, cold start, or urban and extra-urban driving, do affect it (see Stock 2004). As a result, two identical cars will have different fuel consumption, unless they are driven under same conditions. Allowing fuel consumption to be a choice variable is a conceptual difference from the existing literature, which treats fuel consumption as fixed by car design (Fischer, Harrington, and Parry 2007; Fullerton and West 2002; Innes 1996; Parry and Small 2005). Driver's behavior thus affects the total externality through three channels,

$$dv_i = da_i c_i e_f + dc_i a_i e_f + de_f a_i c_i. \tag{6}$$

However, de_f is different from zero only when the driver is choosing her car, once she has one in possession, equation (6) simplifies to

$$dv_i = (da_i c_i + dc_i a_i) e_f, \tag{7}$$

stating that the marginal externality depends on the change in total fuel consumption, which can come from two sources, the change in kilometers driven and the change in fuel consumption.

3.2. The policy response

Let p_f be the price of fuel f, then the marginal social costs from increasing the total fuel consumption by car i by an additional liter are $p_f + e_f$, however the private marginal costs are p_f so we are looking for a tax, denoted t, which satisfies

$$p_f + t = p_f + e_f, \tag{8}$$

and so it is

$$t = e_f. \tag{9}$$

This tax would thus price the marginal externalities from driving along two important margins, the distance travelled and the fuel consumption giving people appropriate incentives for optimizing the two quantities.

3.3. Why is fuel tax so good?

If the tax is set at the optimum level, that is $t = e_f$, it sets the right incentives to choose the socially optimal distance travelled as well as fuel consumption. However, does the tax give the people incentives to choose vehicles that are optimal from the social point of view? Two margins are relevant with respect to CO_2 emissions: (i) car size and engine efficiency to the extent they affect fuel consumption and (ii) fuel type, as fuel efficiency as well as CO_2 emissions per litre of fuel differ across fuel types. The effect of vehicle choice on fuel efficiency is already taken care of by our fuel tax—but is the same true with respect to the choice of the fuel type?

Since fuel type is a discrete variable, we can rewrite equation (6) as

$$\Delta v_i = d(a_i c_i) e_f + \Delta e_f a_i c_i. \tag{10}$$

The social marginal costs are now $d(a_i c_i)(p_f + e_f) + a_i c_i(\Delta p_f + \Delta e_f)$, while private marginal costs are ly $d(a_i c_i) p_f + a_i c_i \Delta p_f$, that is a sum of the effect of total fuel consumption and the effect of changing fuel type on private and social costs of driving. Thus we need a tax, denote it t_f, which would satisfy

$$d(a_i c_i)(p_f + e_f) + a_i c_i(\Delta p_f + \Delta e_f) = d(a_i c_i)(p_f + t_f) + a_i c_i(\Delta p_f + \Delta t_f). \tag{11}$$

Let $t_f = t$, then $t = e_f \implies \Delta t = \Delta e_f \implies \Delta t_f = \Delta e_f$, which is what we need.

Thus a fuel tax gives people also correct incentives to choose the fuel type, on top of incentives to select a car with optimum fuel economy, drive optimum number of kilometers, and choose the optimum fuel consumption. In addition, because the valuation of driving, fuel type, and car amenities vary across individuals, while the marginal externality is the same for all, fuel tax gives each person incentives to behave optimally from the social point of view, yet fully in accordance with their individual preferences and means.

4. The policies in place

Most common policies that bear CO_2-emissions in name are registration and annual car taxes (or bonuses). Table A2 in the Appendix summarizes the prevalence of these schemes in the EU countries. Out of 27 EU countries, 13 have a one-time car registration tax and 15 have an annual car tax (nine countries have both). While the specific tax designs differ, the size of all these taxes are (co-)determined by CO_2 emissions. Such taxes, however, affect the marginal costs of car ownership (per year), rather than the marginal costs of emitting CO_2—once paid they become a sunk cost and thus are irrelevant with respect to decisions whether to drive an additional journey, or whether to save on fuel consumption or not. In addition, while these taxes give people incentives to buy fuel efficient cars, the related savings on fuel as well as savings on the car tax itself after a car is bought represent a positive income shock. This may increase the number of kilometers driven and weaken incentives to save on fuel consumption. As a result, at least part of the positive effects of these taxes on CO_2 emissions gets crowded out. These taxes are thus hardly optimal with respect giving correct incentives to curb CO_2 emissions.[5]

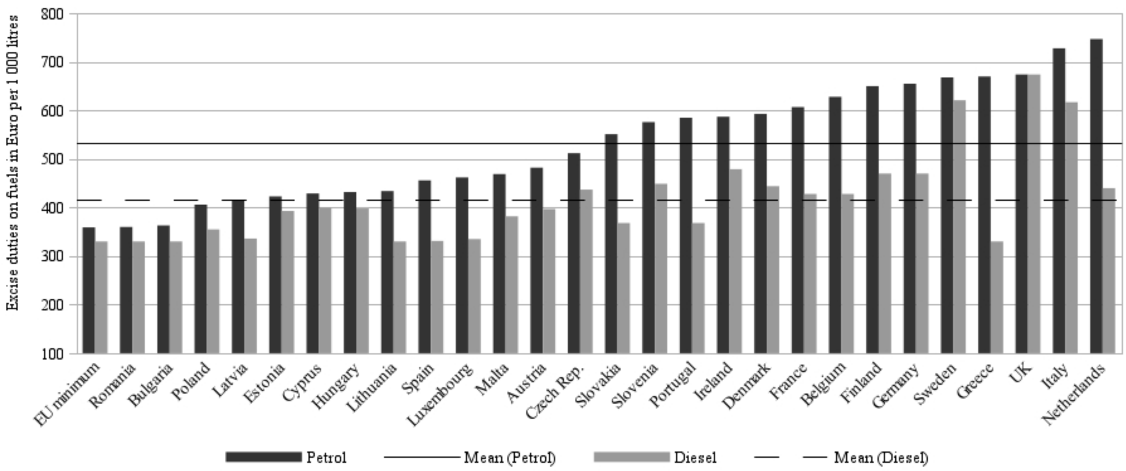

Fig. 2. Excise duties of fuels in the EU as of 1 January 2013 (calculations are based on exchange rates from 18 March 2013). Data source: European Commission 2013.

Shifting attention to our policy of choice, Figure 2 plots the specific taxes on fuel across the EU countries. Excise duties on alcohol, tobacco, and energy products are harmonized in the EU so that there are EU-wide minimum rates (European Commission 2003). Although this tax is an ideal one for taxing the CO_2-related externalities, the

[5] One may be tempted to argue, that these taxes are not true CO_2 taxes, rather they put price on different externalities that depend on car size or fuel consumption per kilometer (toxic emissions, congestion, accidents, and fuel dependence). For this argument to be correct, such externalities would need to depend on car ownership, its size, or fuel economy, but not on the number of kilometers driven or total fuel consumption. We suggest that this is hardly the case, for as long as the car is in the garage the related externalities are close to, if not exactly, zero.

directive only mentions that taxation of energy products is one of the instruments for achieving the Kyoto Protocol objectives (European Comission 2003, par. 7).

Can the fuel tax be realistically the primary policy addressing the costs related to CO_2 emissions from driving? One may worry that imposing additional fuel taxes would damage EU economies. This is a problematic argument for three reasons: (i) should the same goals be achieved by different means, the effects on the economy would be probably worse, since fuel tax is very close to first best policy (of taxing emissions directly); (ii) the policy we propose would indeed require an international coordination (i.e. we do not want tax competition for CO_2-related fuel taxes), but so would alternatives—and we believe that, in the case of fuel tax, it is a comparatively less ambitious requirement; (iii) it is not implied that a new tax should be imposed on top of the existing ones, since the existing fuel taxes already *are* taxing CO_2 emissions as well as other externalities; thus the implied fuel taxes may be higher or lower than the existing ones.

What would the CO2-related fuel tax rates be? Table 3 summarizes the most often cited estimates of social costs per ton of CO2, and translates them into today's prices. The range of estimates is rather wide, starting at \$20 per ton (Nordhaus 2007), through \$50, which is an upper bound in Tol's (2005) meta-analysis of 103 estimates from 28 studies, up to \$311 in Stern's (2007) influential book (all estimates in 2005 USD). However, the main source of variation in these estimates does not come from differences in methodologies; rather studies differ in their assumptions (Pindyck 2013a; Stern 2013). Notably the choice of the discount rate on future consumption has (an exponential) impact on the estimates (Nordhaus 2007; Pindyck 2013a; Stern 2008; Tol 2005). A more recent estimate in a general equilibrium framework by Nordhaus (2011) puts the social costs of ton of CO_2 at \$12 (in 2005 USD).

Table 2. Estimates of CO_2-related social costs per litre of fuel

	Estimates of social cost per ton[a] of CO_2			CO_2 grams per liter[b]	
USD 2005	20[c]	50[d]	311[e]	Gasoline	2322
Euro 2005[f]	16.13	40.32	250.81	Diesel	2664
Euro 2013[g]	18.91	47.28	294.06		
	Social cost per liter in 2013 Euro				
Petrol	0.05	0.12	0.75		
Diesel	0.06	0.14	0.86		

Notes: [a]One ton equals 907.185 Kg. [b]Data source: U.S. Environmental Protection Agency 2009. [c]Nordhaus (2007). [d]Upper bound, Tol (2005). [e]Stern (2007), assuming 1 percent discount rate. [f]Average exchange rate in 2005 was 0.804 Euro per one USD (ECB). [g]The 2013/2005 inflation rate in the Eurozone was 17.25 percent (Eurostat).

Taking Tol's (2005, 2073) upper bound estimate of \$50 as the marginal social costs of emissions of one ton of CO_2, the implied carbon tax is 12 Euro cents per liter of petrol and 14 per liter of diesel. Since the EU minimum harmonized rates are 36 and 33 cents for petrol and diesel, respectively, it is fully feasible that fuel tax be used to fully internalize CO_2-related externalities. Taking into account other externalities (oil dependence, local pollution, congestion, and accidents), sum of which Parry, Walls, and Harrington (2007, 384) estimated at \$2.22 per gallon (in 2005 USD), which gives 55.3 Euro cents per liter of fuel in 2013 prices, the implied fuel tax is approximately 60 Euro cents per liter. This estimate must be taken with a grain of salt. Taken at face value it suggests that the EU minimum rates should rise by 2/3 for petrol and by about 90 percent for diesel. This would however allow removal of the registration and annual car taxes.

5. Conclusion

We have developed and shown a strong case for fuel tax as the ideal policy for correcting relative prices in order to internalize the social costs related to CO_2 emissions. This is because (i) the amount of CO_2 emissions depends linearly, and solely, on the amount of fuel burned, thus fuel tax prices all relevant decision margins and gives individuals and other entities, such as car producers, incentives for socially optimal decisions; (ii) fuel tax is simple and easy to administer, making it a good candidate for a policy on which countries may coordinate. While we are not the first to point this out (see Nordhaus 2007), the apparent mismatch between the existing policies and this prescription suggests that public authorities have not been very attentive. We would begin by changing the labels of specific taxes so that they match the externalities they put price on. Specifically, we suggest that fuel consumption taxes be called “carbon and pollution” taxes.

Appendix A.

Table A1. First stage estimates of IV models in Table (1)

	(1)	(2)	(3)	(4)
Log engine displacement	0.572	0.569	0.568	0.575
	(0.029)	(0.028)	(0.028)	(0.037)
Year		−0.001		
		(0.003)		
$Year^2$		−0.002		
		(0.0003)		
Diesel ×				
Log engine displacement	0.252	0.224	0.216	0.217
	(0.052)	(0.049)	(0.048)	(0.045)
Year		0.032		
		(0.006)		
$Year^2$		-0.002		
		(0.0005)		
Diesel (= 1)	−2.235	−2.089	−1.977	−1.992
	(0.388)	(0.375)	(0.370)	(0.348)
Constant	−2.241	−2.136	−2.111	−2.132
	(0.218)	(0.207)	(0.207)	(0.283)
Years × Fuel	–	–	Yes	Yes
Make	–	–	–	Yes
Observations	□6 450	26 450	26 450	26 450
Adjusted R^2	0.765	0.826	0.835	0.868

Note: Huber-White standard errors clustered on car producers are in parentheses. Unit of observation is at the car type-year level. Models report first stage regressions for IV specifications (5) through (8) in Table 1; fuel economy is instrumented by engine displacement, its interaction with dummy for diesel engines, and the rest of explanatory variables in each specification. Data source: the Vehicle Certification Agency, the United Kingdom Department for Transport.

Table A2. CO_2-related vehicle taxes in the EU

	Registration tax or bonus	Annual tax or bonus
Austria		Yes
Belgium	Yes	Yes[a]
Bulgaria		
Cyprus	Yes	Yes
Czech Republic		
Denmark	Yes	Yes
Estonia		
Finland	Yes	Yes
France	Yes	Yes[a]
Germany		Yes
Greece		Yes
Hungary		
Ireland	Yes	Yes
Italy		
Latvia	Yes	
Lithuania		
Luxembourg		Yes
Malta	Yes	Yes
Netherlands	Yes	Yes
Poland		
Portugal	Yes	Yes
Romania	Yes	
Slovakia		
Slovenia	Yes	
Spain	Yes	
Sweden		Yes
United Kingdom		Yes

Note: [a]Company car tax. Data source: European Automobile Manufacturers Association 2013.

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