An Empirical Assessment of the Effectiveness of Oil Taxes

February 6, 2010

Christian Beermann[1] Darko Jus[2] Markus Zimmer[3]

Abstract

Our empirical analysis for ten countries for the years 1965-2007 makes three important contributions to the existing literature on estimation of oil demand functions: By for the first time including data on direct taxes on oil refinery products and on taxes on their complementary goods and services, we find that the argument of a pigouvian tax can generally be supported over our sample of ten countries. Second, the influence, however, of direct taxes on oil refinery products differs substantially between countries: While in Portugal, Poland, Greece and Japan the effectiveness of the policy measures cannot be unambiguously shown, we find them to be highly significant and effective in central and northern European countries, like Germany, Austria, United Kingdom and Ireland and Finland. Third, we observe - as could be expected - that the taxes on complements of oil refinery products are less effective in reducing the oil demand and even contradict the desired effect in one case. Beyond a qualitative evaluation of the policy measures we are able to quantify the short-run and the long-run effects. Moreover we are able to show that the effectiveness of this type of eco-taxation has generally improved recently.

Keywords: oil demand, environmental taxes, short-run tax elasticity, long-run tax elasticity

JEL Classification: H23, Q31, Q54

[1]Center for Economic Studies, University of Munich
Address: Schackstr. 4, 80539 Munich, Fon: +49 (0) 89 21 80 30 15, E-Mail: beermann@ces.vwl.uni-muenchen.de
[2]Center for Economic Studies, University of Munich
Address: Schackstr. 4, 80539 Munich, Fon: +49 (0) 89 21 80 31 04, E-Mail: darko.jus@lrz.uni-muenchen.de
[3]Ifo Institute for Economic Research at University of Munich
Address: Poschingerstr. 5, 81679 Munich, Fon: +49 (0) 89 92 24 12 60, zimmer@ifo.de

1 Introduction

The ongoing public debate about the most efficient and applicable policy interventions to reduce the speed of global warming deserves empirical examination in order to evaluate the effectiveness of the discussed policy instruments. From a practical point of view many scientists will argue that all polluting nations have to reduce their demand for oil and other carbon resources in order to emit less of the climate-damaging carbon dioxide gas. This seems to be reasonable as in fact only few countries in the world are suppliers of carbon resources, so that the set of policy options for most countries is limited to demand side interventions. The internationally most popular and perhaps politically most feasible policy instruments can be summarised under the idea of pigouvian taxation, i.e. the taxation of the consumption of fossil fuels and their complements. Following the pigouvian argument environmental taxes do not have a fiscal motivation but are primarily used to correct for market failures, e.g. negative externalities. These may arise from individual overconsumption of carbon resources as the climate can be regarded as a global public good with initially a price of zero. Therefore, most countries in the world impose a price by setting taxes. This paper explicitly aims at examining the effects of taxes which are aiming at a reduction of the consumption of oil.

In addition to the intention of reducing the traded quantity of oil, there are, however, also reasons why taxation of oil demand (and a shift in the demand curve) might be welfare enhancing from the perspective of oil consuming countries. Bergstrom (1982) has argued that a sales tax on oil would shift rents from producers to consumers if the supply of oil was too a large degree inelastic. Then the incidence of such a tax would fall entirely on the suppliers while tax revenues would be generated in the consumer countries. As we do not consider the supply side in this paper, this conclusion remains perfectly valid if we assume the oil supply to be inelastic. In contrast if it was elastic and the demand would react to a tax on oil, then the traded quantity of oil would certainly change as well while the net price would not fall for the full amount of the tax. In any case, the effect and the interpretation of a tax on the demand remains the same. Another argument that is to test is that oil is taxed highly because of its demand being inelastic. In this case optimal taxation theory would suggest to tax inelastic goods higher than elastic ones in order to the welfare losses. Thus if revenue generation is the main effect of oil-taxation we should not observe significant negative effects on the demand.

Our data set on taxes related to oil consumption includes direct measures such as taxes on gasoline but also indirect measures such as car insurance. By estimating oil demand functions for a set of ten countries for a data set spanning the years 1965-2007, we not only identify the effect of environmental taxes on oil demand but also correct for weaknesses in previously assumed models: A typical drawback of former investigations regarding the relationship between oil prices and demand is the usage of pre-tax prices, i.e. crude oil prices, when estimating the price elasticity of oil demand. Ignoring the influence of taxes on the end-price previous work on this topic might have obtained biased estimates for the price elasticities. Cooper (2003) estimates, using data on crude oil prices, short-run and long-run price elasticities of demand for 23 countries and concludes that demand for oil is highly insensitive to changes in the oil price.

A similar result was also obtained by Ibrahim and Hurst (1990).

In addition to confirming the results by Cooper (2003) and Ibrahim and Hurst (1990) that price elasticities of oil demand are low, we provide empirical evidence that presumably environmental taxes ceteris paribus actually reduce the demand for oil. In Section 2 we explain our data set and further plans of extending it. Afterwards we derive from a simple model the demand function we estimate. In Section 4 we present our results. We find that a pigouvian tax actually reduces demand for refinery products within our sample of ten countries wile, as would be expected, taxes on complements of oil refinery products are less effective in attenuating the oil demands. We conclude in Section 5.

2 Data

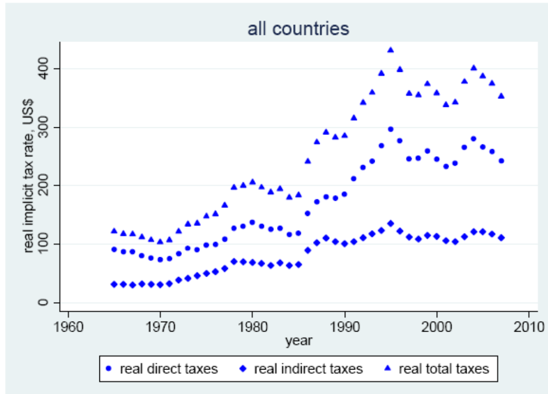
In our empirical analysis of the demand for oil, we use data for the time period 1965-2007. All our variables are yearly observations. In addition to the usually taken variables, real GDP per capita and real oil price, we employ data on environmental taxes in order to show their effect on oil demand. This data is the result of a large-scale project, in which we firstly have combined two data sets of the OECD on tax revenues of major OECD countries. After having filtered out those taxes that are explicitly taxing the goods which have crude oil as a primary production factor, we began to verify this data and to develop our database further by asking national tax authorities. Some of them have provided us with additional data for their country. Moreover, since for oil consumption not only the direct taxes on oil goods matter, but also taxes on complementary goods and services, we have extended our data set to cover these tax revenues as well.So far, we have obtained data on the tax revenues from oil-related taxes for a set of ten countries. [4]We employ this data to calculate implicit tax rates for the consumption of oil. An implicit tax rate is computed by dividing the total tax revenue by the tax base, here the amount of consumed oil. Since we have two sources of tax revenue, from taxes on oil refinery products and from taxes on goods and services which are complementary to these products, we derive the implicit tax rates for both (first called "real direct taxes", latter called "real indirect taxes"). In the following we briefly explain the implicit tax rate paths and the tax revenue drivers in the countries in our sample. The implicit tax rates are presented in national currency (in order to provide a picture free of exchange rate volatility) and per ton of oil consumed.

In Figure 1 we plot the calculated average implicit tax rate of our sample against time and thus show the overall tax rate development within our data set of ten countries. On average the tax revenues per ton of consumed oil are on a rising scale. Thus, although proposals to implement carbon / energy taxes on EU level during the 1990's have been avoided by industrial lobbying, national governments independently decided to impose them.

Moreover, a closer look at the data on country level reveals that the majority of the considered countries in fact constantly increase the implicit taxation of oil. To motivate the observed

[4]We are working on obtaining data for further countries in order to extend our sample. In the final state the data on the carbon related taxes are supposed to cover all OECD countries and those emerging countries that have a significant influence on climate change.

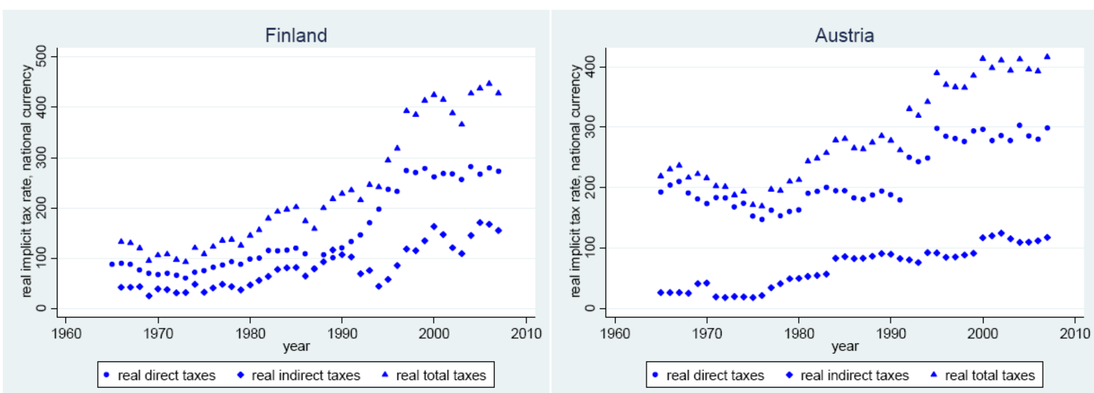
Figure 1: Tax rate development: all countries in the sample



tax patterns across countries, some recent national tax policy changes directly and indirectly affecting the consumption of oil are worth mentioning.

A precursor regarding the introduction of carbon taxes is Finland. Already in 1990 they implemented a tax of 90 US-Dollar per ton of emitted carbon. Shortly after Austria set up a Strategic Plan to Reduce Transport's CO2 Emissions in 1991. Targeting a decrease in emissions of 20 percent until 2005 compared to 1988 levels the plan intended to shift traffic to more energy efficient and environmentally friendly transportation thus likely reducing oil demand. Previously Austria introduced a road charge for highways in 1985 thereby indirectly lessening demand.

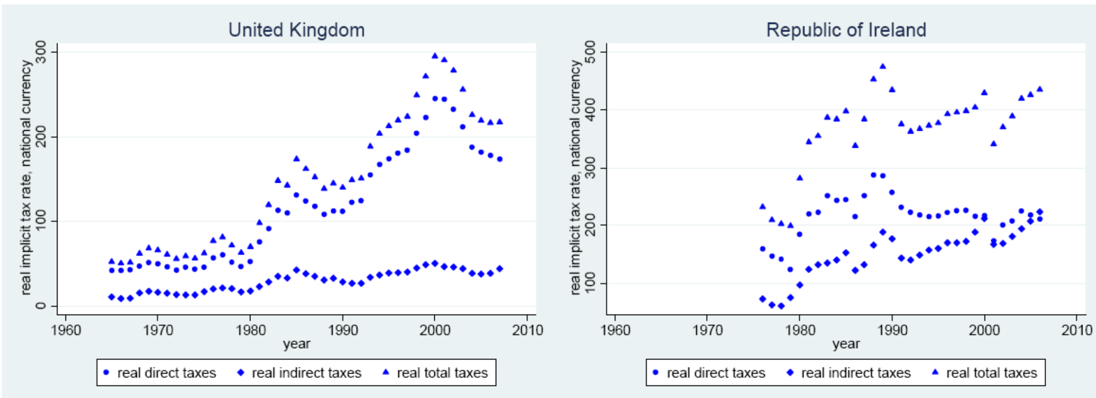
Figure 2: Tax rate development: Finland and Austria



The British government imposed a fuel duty escalator in 1993 which basically introduced a fuel tax. Several tax increases between 1993 and 1999 thereby rose British fuel prices from one of the lowest to one of the highest levels within the EU with taxes representing more than 75 percent of the actual fuel price. However, due to emerging protests the government abandoned the fuel escalator in 2000 as can be seen in the graph. Since 2007 the government again commenced to gradually increase fuel taxes. The neighbouring Irish government presented its Green Paper on

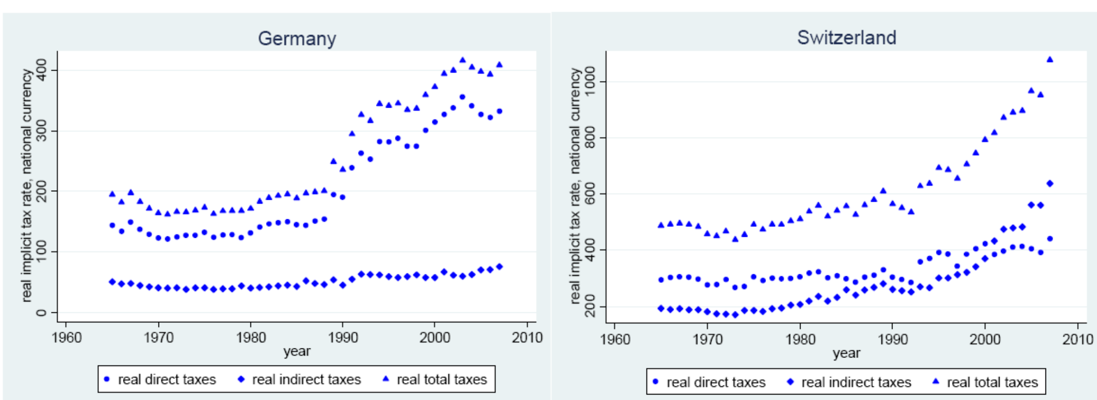
Sustainable Energy suggesting a carbon tax in line with an emission trading system in 1999. Currently a carbon tax of 15 Euro is charged per ton carbon emission.

Figure 3: Tax rate development: United Kingdom and Republic of Ireland



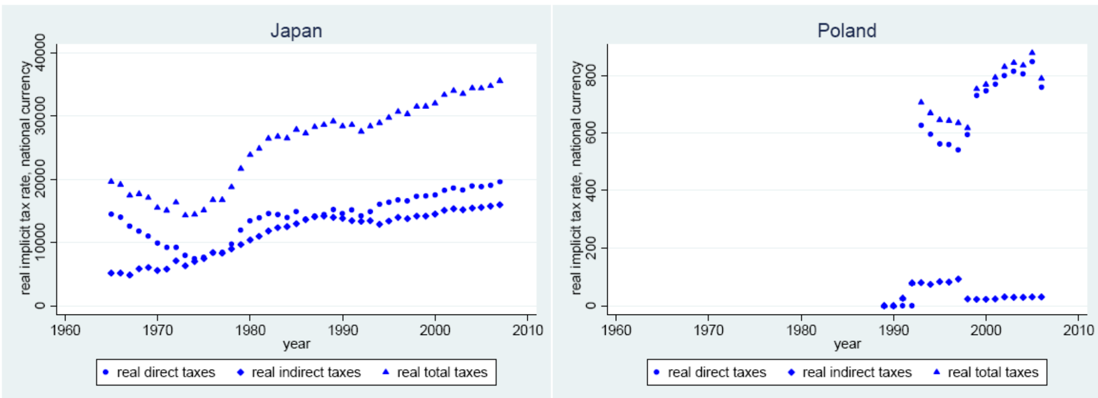
The German government contemporaneously presented its Eco-Tax Reform in 2003 essentially attempting to reduce fossil fuel consumption. The reform had a three-stage design with further tax increases scheduled for 2000 and 2004 and a constant tax level thereafter. In addition, a National Climate Change Protection Program had been enforced in 2000 which among other measures included an additional levy on air traffic. These objectives are currently further pursued via the Integrated Climate Change and Energy Program 2007 which aims to reduce greenhouse emissions by 40 percent until 2020 compared to the 1990 level. In order to fulfill its Kyoto targets Switzerland implemented a carbon tax per ton in 2008 and the government agreed to gradually increase carbon taxes according to a three-step plan when it becomes foreseeable that emission reductions are not sufficient to reach the emission targets.

Figure 4: Tax rate development: Germany and Switzerland



Japan realised an Energy Tax Reform on Fossil Fuels in 2003 including a revision of the tax on fossil which, however, remained unchanged. Moreover, the government induced a preferential taxation for fuel-efficient cars in order to encourage the development of hybrid and electric cars. Similarly Poland recently set up a Long-term Program for Promotion of Biofuels or Other Renewable Fuels in 2008. The primary reason for promoting biofuels is to become more independent from oil imports which indirectly attenuates oil demand. According to the above measures to lower carbon emissions, the arising question is whether these interventions have been successful in directly and indirectly reducing oil demand.

Figure 5: Tax rate development: Japan and Poland



3 Empirical Strategy

Oil is used as production factor within an economy. The typical assumptions about the production technology being Cobb-Douglas or CES will result in isoelastic demand curves. Log-linearisation of this demand curve allows the coefficients to be directly interpreted as elasticities. The estimated tax elasticities quantify the percentage change of oil demand for a given one percent increase in the implicit tax rate.[5] We assume small economies that do not influence the oil price with their oil demand. Following Cooper's (2003) estimation of price elasticities of oil demand we employ an adaption of Nerlove's (1958) partial adjustment model. Contrary to Cooper we use growth rates for the estimation. Further discussion of the approach can be e.g. found in Kennan (1979), Shapiro (1986) or in Blundell's (1988) survey paper. Following the theoretical considerations we define the demand function to be:

$$q_t = \mathrm{e}^{\beta} \cdot y_t^{\gamma} \cdot p_t^{\pi} \cdot \theta_{D,t}^{\tau_D} \cdot \theta_{I,t}^{\tau_I} \cdot q_{t-1}^{\delta}$$

With e^{β_0} being a constant, q the per capita oil demand, y the real GDP per capita in national currency, p the real crude oil price in national currency and θ is one plus the implicit value added tax rate. θ can be split up in θ_D, the direct implicit tax rate on oil refinery products, and

[5]For small tax rates a one percent tax rate increase can approximately be interpreted as an increase by one percent.

in θ_I, the implicit tax rate on oil complements, e.g. an engine displacement based vehicle tax. The estimation equation is specified as first differences of the log-linearized demand functions

$$\ln\left(\frac{q_t}{q_{t-1}}\right) = \beta - \beta + \gamma \cdot \ln\left(\frac{y_t}{y_{t-1}}\right) + \pi \cdot \ln\left(\frac{p_t}{p_{t-1}}\right)$$

$$+\tau_D \cdot \ln\left(\frac{\theta_{D,t}}{\theta_{D,t-1}}\right) + \tau_I \cdot \ln\left(\frac{\theta_{I,t}}{\theta_{I,t-1}}\right) + \delta \cdot \ln\left(\frac{q_{t-1}}{q_{t-2}}\right) + \epsilon_t$$

which is more intuitive to read if you assume that the logs are an approximation of the growth rates $\hat{x}_t \approx \ln(x_t/x_{t-1})$

$$\widehat{q_t} = \gamma \cdot \widehat{y_t} + \pi \cdot \widehat{p_t} + \tau_D \cdot \widehat{\theta}_{D,t} + \tau_I \cdot \widehat{\theta}_{I,t} + \delta \cdot \widehat{q_t} + \epsilon_t$$

The main focus of this analysis will be the effect of the tax rate on the oil demand. Explicitly, as we can observe above, τ_D and τ_I can still be directly interpreted as the tax-rate elasticity of oil demand. This follows directly from the elasticities for the assumed demand function:

$$\varepsilon^S_{q,\theta_D} = \frac{\partial q_t}{\partial \theta_{D,t}} \cdot \frac{\theta_{D,t}}{q_t} = \tau_D \qquad \text{and} \qquad \varepsilon^s_{q,\theta_I} = \frac{\partial q_t}{\partial \theta_{I,t}} \cdot \frac{\theta_{I,t}}{q_t} = \tau_I$$

Given the partial adjustment structure of the demand the long-run elasticities can be calculated by using the estimates for the short-run elasticities:

$$\varepsilon^L_{q,\theta_D} = \frac{\varepsilon^S_{q,\theta_D}}{1-\delta} = \frac{\tau_D}{1-\delta} \qquad \text{and} \qquad \varepsilon^L_{q,\theta_I} = \frac{\varepsilon^S_{q,\theta_I}}{1-\delta} = \frac{\tau_I}{1-\delta}$$

A simple proof for that useful relation can be found in the appendix of Cooper (2003).

4 Results

In a first step we have divided the time horizon into four sub-units, 1965-1974, 1975-1986, 1987-1998 and 1999-2007, and pool the independent cross sections across time. The underlying idea of having four time periods is to see how the effectiveness of the environmental policy measures evolves over time. In Table 2 (Appendix) we present our estimation results. The left specifications gives the results for a scenario in which we do not distinguish between direct taxes on oil refinery products and taxes on goods and services which are complementary to these goods. However, to control for differences of direct taxes and taxes on complements we estimate a second specification shown in the middle of Table 2. The coefficient giving us the elasticity of the direct-tax elasticity of demand becomes significant after 1987 and increases in size after 1999. In the right specification in Table 2 we additionally include country and year fixed effects. By using country fixed effects we capture all the unobserved heterogeneity between the countries in our cross sections so that we can correctly identify the effects of direct taxes on oil goods and of taxing their complements. Furthermore we employ year fixed effects since we want exclude the possible influence of occurrences such as the oil crises on oil demand patterns.

In our preferred specification (Table 2, right) we find for the direct-tax elasticity of demand significantly negative coefficients for all four time periods which is line with the theory of pigouvian taxation: A tax increase on oil goods reduces the demand for oil. The elasticity is quite small from 1975-1986 which is not very surprising as after the first oil crisis (1973-74) and during the second oil crisis (1981-82) - and clearly also in the years before and after - other factors may played a larger role than taxes. However, since 1987 the elasticity becomes stronger, i.e. a change in direct taxes on oil goods affects oil demand to a large degree. We obtain similar results for the taxes on complements of oil goods. After having no influence during the turbulent years from 1975-1986, now higher taxes on complements significantly reduce the demand for oil. Thus we conclude that over the whole sample oil-taxes do not only generate fiscal revenues but also do have a beneficial environmental effect and that second environmental taxes have become more effective over time.

In step two we want to focus on differences regarding the impact of tax policies between the countries in our sample. Consequently we estimate tax elasticities for each country and present the results in the Tables 3 and 4 (Appendix). In Table 3 we observe that generally the direct-tax elasticities of demand are as expected, typically negative, but differ in size quite substantially between the countries. In Portugal, Poland, Greece and Japan the effect of higher direct taxes has the desired direction but is not significant. In contrast, we find very strong effects in Germany, Austria, United Kingdom and Ireland. Still significantly negative but slightly smaller effects we detect in Switzerland and Finland. Hence, for six countries in our sample we can show that pigouvian taxation works. We will be able to provide more evidence on this issue after having included data for additional countries into our sample. In a further specification (Table 4) we control explicitly for the oil crises, the first Iraq War and other major events in recent history. Our findings remain the same.

Taking a brief look at the tax-elasticities of demand for complements of oil goods we see that they generally have a smaller influence and are less significant some countries. Austria is an exception as in both specifications higher taxes on the complements of refinery products reduce the demand for oil. For example this could mean that the introduction of the toll for using Austrian highways could have significantly influenced Austria's demand for oil. Further country-specific analyses could give more insights in the success or failures of policy measures aiming at a reduction of the demand for oil.

Using the above specification of the long-run elasticities, we can exemplary derive the long-run elasticities from the results presented in Table 3. These are shown in Table 1.

Table 1: Short-run and long-run elasticities

country	oil tax elasticity		oil-complements tax elasticity	
	short-run	long-run	short-run	long-run
UK	-0.528	-0.439	0.019	0.016
Switzerland	-0.480	-0.487	-0.382	-0.387
Ireland	-0.565	-0.671	-0.108	-0.128
Portugal	-0.110	-0.113	-0.301	-0.309
Poland	-0.120	-0.104	-0.136	-0.118
Japan	-0.193	-0.290	-0.200	-0.300
Greece	-0.030	-0.033	-0.050	-0.055
Germany	-0.636	-0.676	0.151	0.160
Finland	-0.340	-0.402	-0.200	-0.237
Austria	-0.631	-0.946	-0.120	-0.181

5 Conclusion

Our empirical analysis for ten countries for the years 1965-2007 makes three important contributions to the existing literature on estimation of oil demand functions: By for the first time including data on direct taxes on oil refinery products and on taxes on their complementary goods and services, we find that the argument of a pigouvian tax can generally be supported over our sample of ten countries. Second, the influence, however, of direct taxes on oil refinery products differs substantially between countries: While in Portugal, Poland, Greece and Japan the effectiveness of the policy measures cannot be unambiguously shown, we find them to be highly significant and effective in central and northern European countries, like Germany, Austria, United Kingdom and Ireland and Finland. Third, we observe - as could be expected - that the taxes on complements of oil refinery products are less effective in reducing the oil demand and even contradict the desired effect in one case. Beyond a qualitative evaluation of the policy measures we are able to quantify the short-run and the long-run effects. Moreover we are able to show that the effectiveness of this type of eco-taxation has generally improved recently.

Further work will have to focus on extending the sample by including tax data for additional countries. Also policy comparisons within single countries could be provided in order to ex-post evaluate the effectiveness of measures and ex-ante derive policy recommendation. The latter would particularly be important as almost all countries need to reduce their demand for oil in order to meet carbon dioxide emission targets specified by the Kyoto protocol.

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Appendix

Table 2: Tax elasticities of oil demand over time

period	1965-1974	1975-1986	1987-1998	1999-2007	1965-1974	1975-1986	1987-1998	1999-2007	1965-1974	1975-1986	1987-1998	1999-2007
Number of obs	64	106	115	86	64	106	113	86	64	106	113	86
Prob > F	0	0	0.0206	0	0	0.0001	0.0005	0	0	0	0	0
R-squared	0.727	0.1856	0.1572	0.3114	0.6989	0.1991	0.3087	0.3209	0.8167	0.5357	0.5651	0.625
Root MSE	0.03892	0.06024	0.05317	0.03521	0.04122	0.06003	0.04804	0.03519	0.03692	0.05079	0.04225	0.02947
dependend							ln oil demand					
ln GPD per capita	0.297 **	0.645 ***	0.535 ***	0.458	0.239	0.571 ***	0.539 ***	0.492 *	0.108	0.335 *	0.599 ***	0.722 **
ln oil demand t-1	0.167	0.134	-0.098	-0.076	0.187	0.155	-0.062	-0.071	-0.086	-0.002	-0.128	-0.223 **
ln price	-0.310 ***	-0.121 ***	-0.027	-0.293 ***	-0.269 ***	-0.120 **	-0.201 ***	-0.300 ***	-0.008	-0.139 *	-0.359 ***	-0.331 ***
ln total tax	-0.510 ***	-0.169 **	-0.054	-0.645 ***	-	-	-	-	-	-	-	-
ln direct tax	-	-	-	-	-0.280	-0.064	-0.224 ***	-0.482 ***	-0.278 *	-0.166 ***	-0.320 ***	-0.492 ***
ln indirect tax	-	-	-	-	-0.117 **	-0.111 *	-0.163 ***	-0.153 *	-0.122 **	-0.060	-0.138 ***	-0.169 **
year dummy	no	no	no	no	no	no	no	no	yes	yes	yes	yes
country dummy	no	no	no	no	no	no	no	no	yes	yes	yes	yes
_cons	0.403 ***	0.108 **	0.039	0.439 ***	0.335 **	0.117 *	0.279 ***	0.437 ***	0.440 ***	0.197 ***	0.413 ***	0.472 ***

Notes: * indicates significance at the 10% level, ** indicates significance at the 5% level, *** indicates significance at the 1% level

Table 3: Tax elasticities of oil demand by country

	UK	Switzerland	Ireland	Portugal	Poland	Japan	Greece	Germany	Finland	Austria
Number of obs	41	41	30	40	13	41	40	41	41	41
Prob > F	0.0073	0	0.005	0.0055	0.0029	0	0	0	0	0
R-squared	0.5419	0.7416	0.6174	0.4435	0.8476	0.8505	0.7026	0.845	0.7073	0.7797
Root MSE	0.04929	0.03479	0.06578	0.06769	0.02712	0.03047	0.0321	0.02756	0.03774	0.03132
dependend	ln oil demand									
ln GPD per capita	-0.056	0.477 *	0.532	0.530 **	1.070 **	0.968 ***	0.594 ***	0.929 ***	0.459 ***	0.559 *
ln oil demand t-1	-0.203	0.014	0.158	0.026	-0.148	0.334 ***	0.090	0.059	0.155	0.333 ***
ln price	-0.239 ***	-0.474 ***	-0.415 ***	-0.194 *	-0.098	-0.200 **	-0.035	-0.264 ***	-0.287 ***	-0.420 ***
ln direct tax	-0.528 **	-0.480 ***	-0.565 **	-0.110	-0.120	-0.193	-0.030	-0.636 ***	-0.340 **	-0.631 ***
ln indirect tax	0.019	-0.382	-0.108	-0.301 *	-0.136 **	-0.200	-0.050 ***	0.151	-0.200 ***	-0.120 **
_cons	0.382 ***	0.618 ***	0.479 ***	0.318 **	0.179	0.269 **	0.069	0.337 ***	0.388 ***	0.544 ***

Notes: * indicates significance at the 10% level, ** indicates significance at the 5% level, *** indicates significance at the 1% level

Table 4: Tax elasticities of oil demand by country including dummies

	UK	Switzerland	Ireland	Portugal	Poland	Japan	Greece	Germany	Finland	Austria
Number of obs	41	41	30	40	13	41	40	41	41	41
Prob > F	0.0073	0	0.005	0.0055	0.0029	0	0	0	0	0
R-squared	0.5419	0.7416	0.6174	0.4435	0.8476	0.8505	0.7026	0.845	0.7073	0.7797
Root MSE	0.04929	0.03479	0.06578	0.06769	0.02712	0.03047	0.0321	0.02756	0.03774	0.03132
dependend	ln oil demand									
ln GPD per capita	-0.226	0.315	0.245	0.252	-0.769	0.798 ***	0.423 **	0.607 **	0.317 **	0.236
ln oil demand t-1	-0.480 ***	-0.184 *	0.067	-0.213	-0.061	0.008	-0.334 *	-0.164 **	-0.180	0.187
ln price	-0.331 **	-0.423 ***	-0.362 **	-0.173	-0.232	-0.263 **	0.008	-0.310 ***	-0.247 ***	-0.400 ***
ln direct tax	-0.856 **	-0.618 ***	-0.471 *	-0.098	-0.336	-0.369	-0.032	-0.846 ***	-0.343 **	-0.564 ***
ln indirect tax	0.101	-0.125	-0.089	-0.275 *	-0.368 **	-0.180	-0.037 ***	0.252 **	-0.074	-0.136 ***
Jom Kipur War	-0.070 **	-0.033 *	-	-0.063	-	-0.028	-0.065 ***	-0.039 **	-0.042	-0.005
Iranian Revolution	0.043	-0.048 **	-0.076	-0.023	-	-0.080 ***	-0.028	-0.051 ***	-0.070 **	-0.067 ***
Netback Pricing	-0.037	0.022	0.043	0.017	-	0.060 **	0.080 ***	0.033 *	0.030	0.026 *
First Iraq War	0.007	0.000	0.006	-0.011	-	-0.002	-0.045 ***	0.002	0.004	0.011
Asian Crisis	-0.019	0.017	0.018	0.002	-0.143 **	-0.014	-0.025 *	0.000	0.002	0.009
9/11	-0.042	-0.044 *	-0.038	-0.066	0.056	-0.016	-0.005	-0.033 *	-0.013	-0.030
_cons	0.629 **	0.588 ***	0.446 **	0.378 **	0.648 *	0.443 ***	0.134 ***	0.477 ***	0.377 ***	0.551 ***

Notes: * indicates significance at the 10% level, ** indicates significance at the 5% level, *** indicates significance at the 1% level