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RESEARCH ARTICLE

The German Environmental Tax Reform: a difference-in-differences analysis of its impacts in European comparison

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Abstract

In 1998, the red-green Schröder government implemented the Environmental Tax Reform (ETR), raising taxes on petrol, diesel, natural gas and heating oil and introducing a new duty on electricity in Germany. At the same time, it cut non-wage labour costs by reducing public pension contributions. The goal was to achieve Germany's Kyoto Protocol emissions targets and to reduce a level of unemployment unprecedented since World War II while avoiding the burden on the public budget through revenue recycling. Employing microdata from household budget surveys of 1998 and 2003, this article analyses whether increased duties on motor fuels and electricity lead to a substantial reduction in households' consumption of these goods. Considering the ETR as a natural experiment, it uses the difference-in-differences approach in a European context with Germany as the treatment group and Italy, Spain and the UK as the control group. Ordinary least square regressions reveal that motor fuel demand is price inelastic, while electricity consumption increased despite the substantial rise in prices. Quartile regressions show that the effect of the motor fuel tax is slightly higher at the bottom than at the upper tail of the distribution supporting the notion that low-level consumers are more likely to find alternative substitutes.

Keywords Energy taxes · Environmental tax reform · Microdata · Household budget surveys · Difference-in-differences · Regression analysis

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1 Introduction[1]

While Germany's overall greenhouse gas (GHG) emissions came down by more than a third between 1990 and 2019, emissions caused by traffic remained almost the same (German Environment Agency 2021a). The main reason for this development lies in a higher demand for SUVs and other vehicles with high fuel consumption. CO_2 emissions from motor vehicles could have been reduced by 15% between 2010 and 2017 if the engine performances of the fleet had remained constant (Statistisches Bundesamt 2018). As almost a fifth of all GHG emissions in Germany stems from traffic, reductions in this sector are vital to achieve the ambitious targets outlined in the Paris Agreement. Besides climate change, air pollution leads to more than 73,900 premature deaths in Germany (European Environmental Agency 2019). In June 2021, the Court of Justice of the EU (2021) ruled that Germany has continually violated the regulatory limits on nitrogen dioxide in 26 air quality zones. The cities of Berlin, Darmstadt, Hamburg and Stuttgart have implemented driving restrictions in strongly affected streets and districts to reduce pollution (Töller 2021).

To deal with negative externalities, economists often prefer market-based instruments such as fees or permits. They argue that these approaches result in the same reductions as command-and-control measures and will achieve the desired level more efficiently (German Council of Economic Experts 2019; Kolstadt 2011). Having been a fringe issue during most of the 2010s and only supported by individual politicians (Bewarder and Gaugele 2015; Kellner and Baerbock 2015), CO_2 taxation has risen to prominence since the beginning of the Fridays for Future protests in Germany in 2018. The demonstrations and heavy losses in state and European elections led the parties of Merkel's grand coalition to the adoption of a climate protection programme in 2019, which among others introduced CO_2 certificates in the transportation sector in 2021 (Eddy 2019; Federal Government 2020).

When designing environmental policies, policymakers face limited knowledge and uncertainties of environmental, economic and technological processes, making it difficult to forecast whether the design will be effective and efficient (Pindyck 2007). Furthermore, surveys and experiments show that the acceptability of environmental taxes is low (Cherry et al. 2012; Kallbekken and Sælen 2011). Therefore, a strong empirical argument is vital. Hence, it becomes appealing to look back to the 1990s and 2000s, when several European countries including Germany introduced so-called environmental tax reforms (ETR) increasing the taxes on and thus the price of fossil fuels and electricity, while reducing public pension contributions (PPC) at the same time.

In this article, I analyse whether the German ETR was an environmental success. While other studies focused on individual countries, this article compares the changes of motor fuel and electricity consumption in Germany with those in three

[1] ATE: Average treatment effect; DID: difference-in-differences approach; EEA: European Economic Area; ETR: environmental tax reform; GHG: greenhouse gas; HBS: household budget survey; HICP: harmonised index of consumer prices; NSI: national statistical institute; OLS: ordinary least square; PPC: public pension contribution; PPP: purchasing power parity.

other EU countries – Italy, Spain and the UK –, which experienced no or only slight changes in fuel and electricity duties. To this end, microdata of 171,779 households from household budget surveys (HBS) of 1998 and 2003 are employed in a difference-in-differences approach (DID) with ordinary least square (OLS) and quartile regressions. This comparative, microeconometric approach reveals whether the changes in German household consumption are systematically different from the developments in the three other countries. Thus, the article and its innovative methodological design contribute to the literature on the internalisation of externalities through incentives in the form of environmental taxation.

2 The German ETR: legal and financial development

After winning the federal election of 1998, the new German government of Schröder's Social Democratic Party (SPD) and Alliance 90/The Greens implemented the first stage of the ETR within three months after the election, when the red-green coalition introduced the bill for the *Act on the Introduction of the ETR*[2] to parliament. The law increased duties on petrol, diesel, natural gas and heating oil, and introduced a new tax on electricity. In 1999, the Schröder government passed the *Act on the Continuation of the ETR*,[3] prescribing further annual tax increases until 2003. The last law in this series[4] modified certain tax rates and exemptions.[5] Table 1 shows the changes in taxation due to these three laws.

This tax reform had two objectives: increasing energy taxes and recycling the revenue to reduce social security contributions. Thus, the policy combines a Pigovian tax aimed at decreasing the externalities of energy consumption, while reducing the cost of labour to promote job creation. Binswanger et al. (1988) first proposed this concept. If successful, it achieves two goals at the same time and realises a so-called double dividend. The red-green government viewed the policy as a way to reduce an unemployment rate of 12.7%, which had been unprecedented since World War II. The high amount of non-wage labour costs was considered one cause of this crisis (Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung 1997). Additionally, the binding Kyoto Protocol emission targets of 1997, made cutting GHG emissions an urgent political objective.

The ecotax generated additional revenue of up to 18.7 billion euros p.a. and was primarily used to decrease PPC from 20.3 to 18.6% of gross income, reducing non-wage labour costs by 1.7 percent points. The remainder was used to promote private retirement provision and renewable energies and to reduce the public budget deficit (Bundesministerium der Finanzen 2004, 2006). Table 2 shows the exact distribution.

[2] Gesetz zum Einstieg in die ökologische Steuerreform, 1999.

[3] Gesetz zur Fortführung der ökologischen Steuerreform, 1999.

[4] *Act on the Further Development of the ETR* (Gesetz zur Fortentwicklung der ökologischen Steuerreform, 2002).

[5] Agricultural and forestry businesses, energy-intensive industries, public transport and more environmentally-friendly technologies such as renewable energies, biofuels, power-heat cogeneration and gas-powered vehicles were largely exempted from the ETR.

Table 1 Development of the tax rates on fossil fuels and electricity from 1999 to 2003

Tax item	Additional tax per act in cents			
	Act on the Introduction of the ETR (1999)	Act on the Continuation of the ETR (1999)	Act on the Further Development of the ETR (2002)	Tax rate in 2003 in cents
Petrol (per litre)	3.07	12.28	0.00	65.45
Diesel (per litre)	3.07	12.28	0.00	47.04
Heating oil (per litre)	2.05	0.00	0.00	6.14
Natural gas (per kilowatt-hour)	0.16	0.00	0.20	0.55
Electricity (per kilowatt-hour)	1.02	1.03	0.00	2.05

Source: Bundesministerium der Finanzen (2004, p. 37)

Table 2 Application of the tax revenue from the ETR

	In billion euros						
	1999	2000	2001	2002	2003	2004	2005
Reduction of public pension contributions	4.5	8.4	11.2	13.7	16.1	16.0	15.9
Subsidies for private retirement provisions	0.0	0.0	0.0	0.0	0.4	0.4	0.4
Market incentive programme for renewable energies	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Reduction of public budget deficit	–0.3	0.3	0.4	0.4	0.8	0.5	0.3
Total (revenue = expenditure)	4.3	8.8	11.8	14.3	18.7	18.1	17.8

Source: Bundesministerium der Finanzen (2006, p. 6)

The policy proved controversial. Opposition parties considered the environmental steering effect negligible and accused the government of misusing tax money, as the revenue was not used for ecological projects (Beutler et al. 2000). They coined the term "speeding for the pension"[6] to discredit the policy. Germany's biggest newspaper *Bild* actively campaigned against it. This negative perception of the ecotax also prevailed among the general public, as less than a third of the population supported it (Kuckartz and Grunenberg 2002). Qualitative interviews showed that revenue recycling is largely "not understood and not welcomed" (Beuermann and Santarius 2006, p. 917). Nevertheless, the four successive governments led by Merkel's Christian Democrats and the current SPD-led Scholz government have not repealed the provisions. According to the most current analysis the policy has created about 114,000 jobs and increased GDP by 0.4% between 1999 and 2010 (Lehr et al. 2012).

3 Literature review: externalities and environmental taxes

The main derivative of fossil fuel combustion is CO_2, which is the most prevalent GHG and mainly responsible for anthropogenic climate change. In Germany, stationary and mobile energy production caused 83.7% of all GHG emissions in 2019 (German Environment Agency 2021b). Additionally, internal combustion engines lead to local air pollution responsible for pulmonary diseases, and noise pollution. (Parry et al. 2007). From an economic perspective, the environmental impacts of fossil fuel combustion represent negative externalities, since "the consumption or production choices of one person or firm enters the utility or production function of another entity without that entity's permission or compensation" (Kolstad 2011, p. 87). The prices of fossil fuels and electricity do not reflect their respective environmental impacts. Gössling et al. (2019) estimate that driving by car results in external costs of 0.11 euros per kilometre in the EU. Thus, social marginal costs exceed private marginal costs leading to a higher equilibrium output than socially optimal. The imposition of a Pigovian tax equal to the difference between private

[6] *"Rasen für die Rente"* (Westerwelle 2001, p. 18375B) in German.

and social marginal costs – the marginal damage – increases the private marginal cost to the level of the social marginal cost and internalises the externality, resulting in the optimal output. The success of this market-based approach depends on the consumers' demand elasticities. Viable alternatives providing similar utility such as public transportation in the case of motor fuels increase the substitution effect and hence elasticity. Therefore, it tends to rise over time, as consumers can change their behaviour or new products emerge as substitutes (Baumol and Oates 1988; Frank 2010; Snyder and Nicholson 2008).

Many empirical studies have tested these theoretical analyses employing a multitude of methods. For Germany, Bach et al. (2001), Kohlhass (2005) and Lehr et al. (2012) conducted a macroeconometric simulation of the effects of an ecotax on GHG emission. They find that energy consumption and emissions have decreased. In a microeconomic analysis using panel data, Steiner and Cludius (2010) confirm the environmental effects. They calculated that an increase in the price of motor fuel by 10% leads to a reduction in the annual distance driven by 1.8%. Frondel and Vance (2017) examine microeconomic data with an instrumental variable approach and conclude that higher fuel efficiency standards led to a rebound effect which increased driving and hence completely offset the impacts of fuel taxation.

For other EU member states with comparable policies, Speck et al. (2011) arrive at similar conclusions. Patuelli et al. (2005) examine 186 simulations in 61 studies on ecotaxes and their effects in a quantitative meta-analysis. In general, they found green taxes to have a strong environmental effect, reducing CO_2 emission by 9.7% compared to the baseline scenarios. The meta-analysis of more than 170 individual studies by Dahl (2012) models elasticities for petrol and diesel for 124 countries. It places the long-term elasticities in the EU-15 member states between –0.54 and –0.24 for petrol and between –0.44 and –0.01 for diesel. Comparing the elasticities of petrol, diesel and electricity in a global meta-analysis, Labandeira et al. (2017) find that electricity is rather inelastic with –0.13 in the short term and –0.37 in the long run. Their results for diesel are similar with values of –0.15 and –0.44, respectively, while demand for petrol is relatively more elastic with –0.29 and –0.77. For Europe, Cialani and Mortazavi (2018) and globally, Zhu et al. (2018) also conclude that electricity demand is inelastic in the short term but increases in the long term. In summary, the body of literature regards the demand for petrol, diesel and electricity as price inelastic at least in the short term.

4 Methodology and data collection

The analysis of environmental effects focuses on the specific markets for the goods affected by increasing taxation. This section is solely interested in the markets for motor fuels and electricity. A microeconomic model fits this purpose since it examines the individual situations of households and their reactions to the ETR.

Implementing the ecotax is considered a natural experiment, in which treatment is applied in non-controlled circumstances. All German households had to pay additional taxes and hence form the treatment group. The control group consists of households from Italy, Spain and the UK, which have been subject to no or clearly lower tax increases. Analyses without a control group for comparison lack internal validity, since it remains unclear whether the policy caused behavioural change among German households, indeed, or whether other factors were responsible. If changes occurred due to the ecotax, the change in consumption should be systematically different from the developments in the control group (Bryman 2012).

The research design described before compares treatment and control groups at two different points in time – before and after the ETR was implemented in Germany. Hence, the examination consists of pooled cross-sections of the four countries in 1998 and 2003 representing an intermediate-run perspective.[7] For these designs, the regression model-based DID is a suitable instrument and regularly employed in policy analyses. It computes an average treatment effect (ATE) *(δ_1)* indicating the difference in energy consumption *(y)* between the treatment *(T)* and control group *(C)* and the temporal difference before and after the treatment—1998 and 2003, respectively—as shown in Eq. 1.

$$\hat{\delta}_1 = \left(\bar{y}_{T,2003} - \bar{y}_{T,1998}\right) - \left(\bar{y}_{C,2003} - \bar{y}_{C,1998}\right) \quad (1)$$

In the regression setting illustrated in Eq. 2, energy consumption *(y)* is the dependent variable. Dummy variables for the two periods *(d2003)* and the two groups *(dT)* are employed to estimate the ATE *(δ_1)* – the coefficient of the interaction term *($d2003 \times dT$)*. The remaining variables are: intercept *(β_0)*, coefficient for *d2003 (δ_0),* coefficient for *dT (β_1),* other explained *(u)*[8] and unexplained factors *(ε)*. Instead of the dummy variable *dT*, the continuous tax rates are used (Angrist and Pischke 2009; Wooldridge 2016).

$$y = \beta_0 + \delta_0 d2003 + \beta_1 dT + \delta_1 d2003 \times dT + u + \varepsilon \quad (2)$$

Employing the DID requires microdata on fossil fuel and electricity consumption of German and non-German households. Since EU member states share the *acquis communautaire* – the body of EU law –, form a single market and belong to a group of high-income economies, they share a certain level of similarity, which makes them suitable for the described research design. This also applies, albeit to a limited extent, to the non-EU member states of the European Economic Area (EEA) at that time. The 1970 EU directive 70/220/EEC defined emission standards for motor vehicles in the member states. Starting in the early 1990s, the so-called Euro standards were introduced by amending the mentioned directive which was replaced in 2013 (Franckx 2015). These regulations were applied in all EU and EEA member states strengthening the argument to define the control group based on EU and EEA membership.

[7] Basso and Oum (2007) summarize that “in aggregate data studies, short-run and long-run notions are basically related to time windows (one and many years) while in disaggregate data studies, they are related to the authors [sic] judgement, which is in turn mostly based on what is fixed and what is not.” (p. 470). Since household characteristics in the population are neither completely fixed nor variable, the classification as intermediate-run seems appropriate.

[8] These explained factors include the country fixed effects.

Table 3 HBS analysed and their numbers of participants and weights

Country	Name of HBS	Year	Number of respondents	Average weight	Source
Germany	*Einkommens- und Verbrauchsstichprobe* (Sample Survey of Income and Expenditure)	1998	49,720	0.62	Forschungsdatenzentren der statistischen Ämter des Bundes und der Länder (1998, 2003)
		2003	42,744	0.73	
Italy	*Indagine sui Consumi delle Famiglie* (Survey of Household Consumption)	1998	19,623	1.01	Istituto nazionale di statistica (1998, 2003)
		2003	27,155	0.73	
Spain	*Encuesta Continua de Presupuestos Familiares* (Household Budget Continuous Survey)	1998	9871	1.19	Instituto Nacional de Estadística (1998; 2003)
		2003	9138	1.41	
UK	Family Expenditure Survey	1998	6480	3.59	Office for National Statistics (1998, 2003)
	Expenditure and Food Survey	2003	7048	3.19	
Total	–	1998	85,694	1.00	–
		2003	86,085	1.00	

Accordingly, the 18 national statistical institutes (NSI) of Germany and the other EU-15 countries plus Iceland, Liechtenstein and Norway were contacted and asked for microdata from HBS. Only those of Germany, Italy, Spain and the UK, as shown in Table 3, were included, as the other NSIs prohibited access or their HBS did not take place in 1998 and 2003. In total, the cross-sectional data analysed contains 171,779 observations.

The NSIs conduct HBS mainly to update the weights of the basket of goods and services for the calculation of the consumer price index. Since no EU regulation exists to harmonise the various surveys, sampling, definitions and classifications differ between the member states (Eurostat 2003, 2008). A major challenge was generating standardised variables out of the original data sets. Additionally, regional data on the temperature and density of the motorway system was included. Since the four countries use the Classification of Individual Consumption According to Purpose (COICOP), a differentiation between expenditure on petrol and diesel is not possible as code 07.2.2 includes all "[f]uels and lubricants for personal transport equipment" (United Nations Statistics Division 2000).

Monetary data were provided in the respective national currency. First, they were converted into euros using annual, nominal exchange rates, which compared to monthly or daily rates minimise distortions due to currency fluctuations. Then, employing national inflation rates of the EU harmonised index of consumer prices (HICP), the data was adjusted for inflation and converted into 1999 euros (Eurostat 2022a). Since the HICP is an annually chain-linked index (Eurostat 2021c), the increased share of diesel vehicles in the fleets of the four countries is incorporated into the model on an aggregated level. For 1999, Eurostat (2022b) also harmonised the aggregated results of the various HBS with purchasing power parity (PPP). To remove differences in the price levels between countries, a correction factor for each country was calculated. The aggregated expenditure of the original data was brought in line with the harmonised values of official statistics, resulting in expenditures in 1999 euros under PPP. Thus, the monetary data became comparable across time and space, which renders the variables on expenditure in euros a suitable proxy for the underlying, but unobservable consumption in e.g. litres or kilowatt-hours. Therefore, the terms "expenditure" and "consumption" are used interchangeably henceforth.

Furthermore, a regional weighting coefficient was applied to correct differences in representation e.g. due to oversampling. Additionally, the household members were weighted using the modified OECD equivalence scale converting individuals into equivalised adults[9] (Eurostat 2021b).

5 Results

5.1 Household characteristics

Similarities between the treatment and control group constitute an important requirement for a natural experiment. Table 4 provides an overview of the

[9] All per-capita values use the equivalence scale, unless otherwise indicated.

Table 4 Socio-demographic characteristics and equipment of households

Year	Country	Arithmetic mean (standard deviation)					In % of all households			
		nind	nchild	nwork	agerp	ncar	femalerp	retired	wash	fridge
1998	Germany	2.6 (1.0)	0.7 (0.7)	1.1 (0.7)	48.7 (11.6)	1.1 (0.5)	29.4	24.1	99.6	94.8
	Italy	2.8 (1.2)	0.5 (0.8)	1.0 (0.9)	54.1 (15.4)	1.1 (0.8)	21.0	35.4	99.1	96.3
	Spain	3.3 (1.5)	0.7 (1.0)	1.1 (1.0)	53.4 (16.3)	0.9 (0.7)	18.1	28.7	99.6	97.5
	UK	2.4 (2.5)	0.6 (2.0)	1.1 (1.9)	50.3 (33.1)	1.0 (1.6)	25.6	25.0	99.4	92.4
	Overall	2.7 (1.3)	0.6 (0.9)	1.1 (0.9)	51.1 (15.8)	1.1 (0.8)	24.9	27.6	99.4	94.9
2003	Germany	2.4 (1.0)	0.5 (0.8)	1.0 (0.7)	50.7 (12.5)	1.2 (0.6)	31.9	27.9	99.6	95.7
	Italy	2.6 (1.1)	0.4 (0.7)	1.0 (0.8)	55.3 (12.4)	1.2 (0.7)	26.1	38.4	99.4	97.2
	Spain	2.9 (1.6)	0.5 (1.0)	1.1 (1.2)	55.9 (18.3)	1.0 (0.9)	22.9	32.2	99.8	98.4
	UK	2.4 (2.3)	0.6 (1.8)	1.1 (1.8)	51.1 (29.8)	1.1 (1.5)	37.4	24.8	95.8	94.3
	Overall	2.5 (1.3)	0.5 (0.9)	1.1 (0.9)	52.7 (15.5)	1.1 (0.8)	30.7	30.1	98.6	96.1

nind number of individuals in the household; *nchild* number of children in the household; *nwork* number of working people in the household, *agerp* age of the household's reference person (years); *female* female reference person; *retired* retired reference person; *ncar* number of cars in the household; *fridge* household owns a refrigerator, freezer or combination; *wash* household owns a washing machine

Table 5 Excise duties on motor fuels

	Petrol (cents/litre)			Diesel (cents/litre)		
	1998	2003	Change (%)	1998	2003	Change (%)
Germany	49.77	65.45	31.5	31.49	47.04	49.4
Italy[1]	52.60	54.18	3.0	38.46	40.32	4.8
Spain[1]	36.34	39.57	8.9	26.38	29.39	11.4
UK[2]	63.80	66.64	4.4	64.95	66.64	2.6

Based on: European Commission (2022)

[1]The Italian Region of Piedmont and the Spanish Community of Madrid imposed regional taxes on motor fuels in 1998 and 2003. The table shows only the national duties, while the subsequent analyses include the regional taxes as well

[2]The UK increased its excise duties in March 1998 and October 2003. The table indicates the annual average duty

socio-demographic characteristics of the sampled households. It also includes information on car ownership and household appliances relevant to electricity consumption.

The general household composition differed only slightly between the four countries. Typical households consisted of two to three people with one or no child and one economically active person. Spanish households tended to be larger, whereas British and German families were smaller. Generally, household size was declining between 1998 and 2003. Females headed only a fifth to a quarter of households in 1998. This proportion increased to approximately a quarter with British and German households in the lead. The typical reference person[10] was – with the exemption of Germany in 1998 – in his/her early to mid-fifties. A pensioner headed a quarter to a third of households. Furthermore, the typical household owned one car with only minor variations between the countries. The same applies to ownership of fridges or freezers and washing machines. These appliances were an almost universal household standard across the four countries. In conclusion, these statistics do not show pronounced differences between the countries.

5.2 Motor fuels

Motor fuel includes petrol and diesel. In their respective tax codes,[11] Germany, Italy and Spain disfavoured petrol and privileged diesel, while the UK abolished this differentiation in 1999. Germany saw the greatest difference in 1998 when it taxed petrol almost 60% higher than diesel. This difference came down to slightly under

[10] The definition of the reference person varies between the four countries. It can refer to the highest income earner, the owner of the dwelling or is defined by the household at its own discretion.

[11] Besides duties on motor fuels, all four countries employed registration taxes or fees and circulation taxes to charge purchases and ownership of motor vehicles (European Commission's Directorate-General for Environment 2002). However, the effect of these type on taxes on GHG emissions (Gerlagh et al. 2018) and fuel consumption (Grigolon et al. 2018) is rather limited.

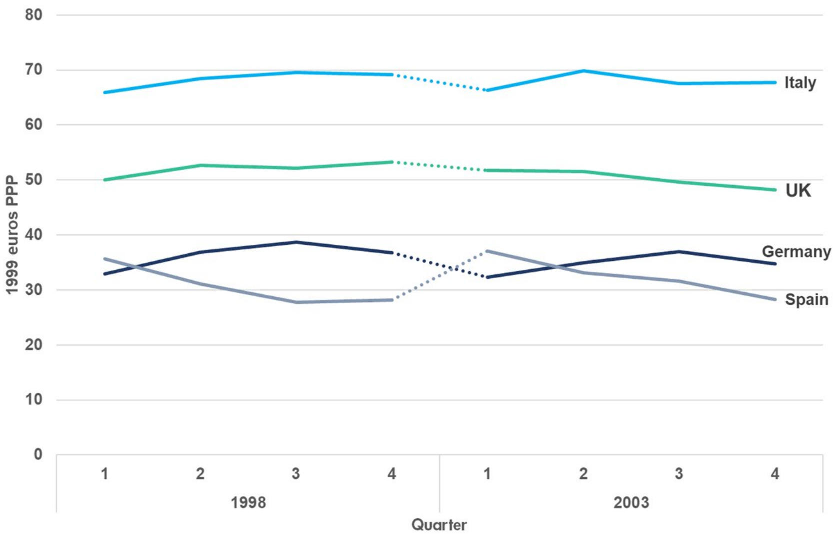


Fig. 1 Average expenditure on motor fuels p.p. between 1998 and 2003

40% in 2003. Between 1998 and 2003, these fuels saw an average tax increase in all four countries. The highest rise occurred in Germany, where existing excise duties increased by more than 31.5% and 49.4%, respectively. Italian taxes increased only slightly by 3.0% and 4.8%. The UK experienced a similar increase, while Spain's excise duties rose by 8.9% and 11.4%, see Table 5. The strong increase in Germany compared to the countries of the control group is an essential prerequisite for the design of the natural experiment.

The four countries experienced only small variations in their average expenditure p.p. on motor fuels. Only the UK saw a decrease, while the values remained largely unchanged for the other countries. Beside these temporal changes, the level of expenditure differed strongly between the four countries. Italian expenditure is roughly twice as high as that of Germany and Spain with the UK located in between, see Fig. 1.

However, these variations were not uniform. To a certain extent, the countries exhibited large regional differences. Figure 2 shows the changes in expenditure p.p. on motor fuels in the various regions of the four countries between 1998 and 2003. In Germany, an East–West divide was still visible. East German regions, except Berlin, increased their consumption, while in West German states, except Hesse, expenditure decreased. Italy experienced a North–South divide with decreasing consumption in the North and rises in the South. However, Umbria, Basilicata and Calabria defied this categorisation. Still, this could hint at a catch-up effect in less affluent regions. In Spain, all Southern, Eastern and North-Western regions on the mainland saw increasing motor fuel expenditure, while the capital region of Madrid, Castile and León, Navarre, the Basque Country and the Balearic Islands experienced a slope in consumption. In the UK, Greater London saw the largest increase. Wales, Northern Ireland, the West Midlands, and Yorkshire and the Humber exhibit only

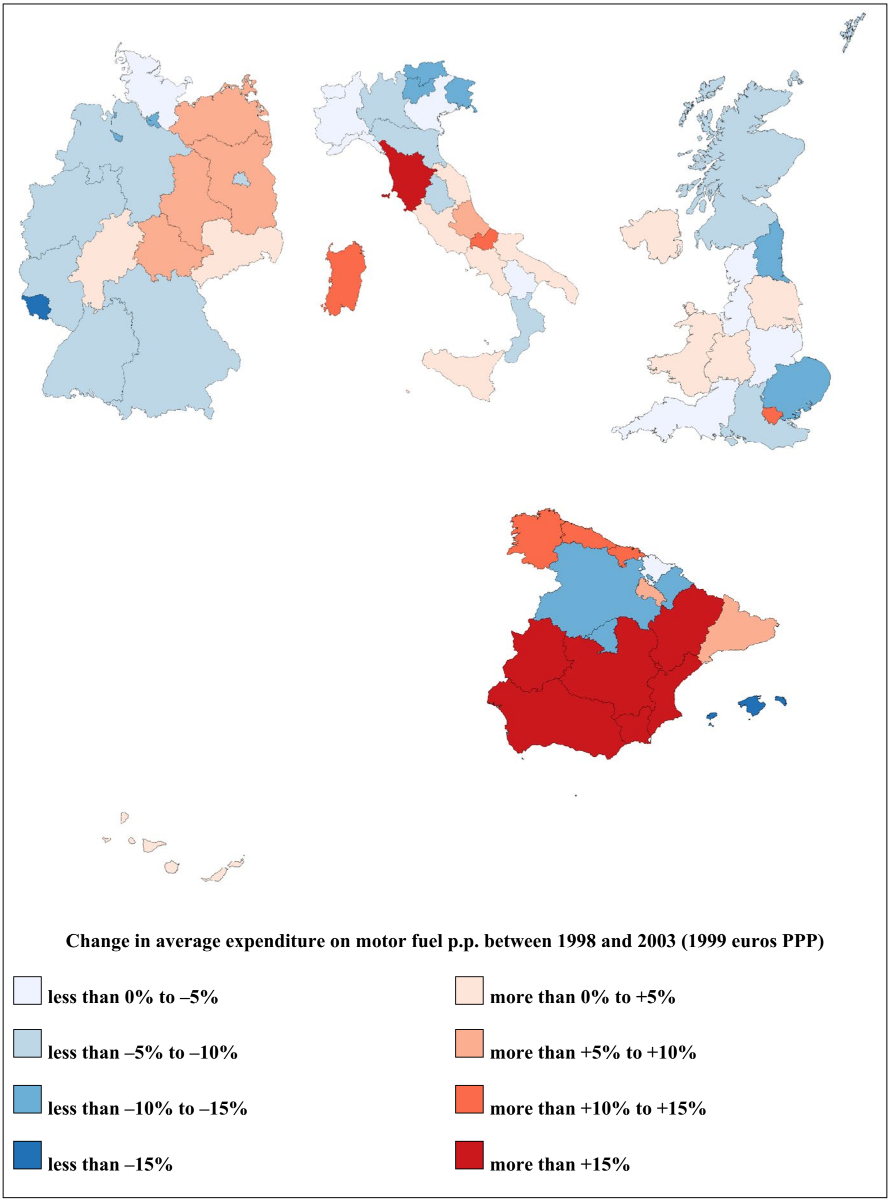


Fig. 2 Choropleth maps of regional changes in motor fuels consumption between 1998 and 2003

a slight rise, while Scotland's and the rest of England's expenditure on motor fuels decreased. No clear pattern emerges from the regional results for Spain and the UK.

These descriptive analyses focus on national and regional developments, while a regression analysis using the DID emphasises the individual level. Thus, it can identify the most important factors driving consumption and whether the German

Table 6 Regression analysis of motor fuel expenditure

Dependent variable: log(fuel)

Coefficient (standard error)

Independent variables	Model 1: OLS	Model 2: Quantile regression				
		0.1	0.25	0.5	0.75	0.9
Constant	1.88* (0.51)	0.31 (0.93)	0.73 (0.59)	1.93* (0.43)	3.24* (0.40)	3.12* (0.56)
y2003	1.24* (0.19)	1.44* (0.33)	1.32* (0.21)	1.37* (0.16)	1.32* (0.17)	1.18* (0.19)
log(tax)	–0.20* (0.04)	–0.15 (0.08)	–0.07 (0.05)	–0.17* (0.04)	–0.26* (0.04)	–0.24* (0.05)
y2003 × log(tax)	–0.18* (0.03)	–0.22* (0.05)	–0.20* (0.03)	–0.20* (0.02)	–0.18* (0.03)	–0.16* (0.03)
it	0.72* (0.01)	0.72* (0.02)	0.71* (0.01)	0.71* (0.01)	0.72* (0.01)	0.72* (0.01)
es	0.13* (0.01)	–0.05 (0.03)	0.08* (0.02)	0.17* (0.02)	0.22* (0.02)	0.25* (0.02)
uk	0.56* (0.01)	0.51* (0.03)	0.45* (0.02)	0.52* (0.02)	0.62* (0.02)	0.64* (0.02)
femalerp	–0.05* (0.01)	–0.05* (0.01)	–0.05* (0.01)	–0.06* (0.01)	–0.05* (0.01)	–0.05* (0.01)
agerp	0.01 (0.01)	0.06* (0.03)	0.04* (0.01)	0.02 (0.01)	–0.02 (0.01)	–0.04* (0.01)
$agerp^2$	–0.01* (0.00)	–0.01* (0.00)	–0.01* (0.00)	–0.01* (0.00)	–0.01* (0.00)	–0.00 (0.00)
nchild	–0.23* (0.01)	–0.21* (0.03)	–0.18* (0.02)	–0.21* (0.02)	–0.26* (0.01)	–0.31* (0.02)
nwork	0.17* (0.01)	0.16* (0.02)	0.17* (0.01)	0.17*(0.01)	0.16* (0.01)	0.14* (0.01)
log(expenditure)	0.41* (0.01)	0.37* (0.01)	0.37* (0.01)	0.40* (0.01)	0.43* (0.01)	0.44* (0.01)
nocar	–0.33* (0.02)	–0.78* (0.03)	–0.52* (0.03)	–0.26* (0.02)	–0.09* (0.02)	0.05* (0.02)
ncar	0.34* (0.01)	0.32* (0.02)	0.37* (0.01)	0.38* (0.01)	0.35* (0.01)	0.34* (0.01)
log(pubtrans)	–0.03* (0.00)	–0.04* (0.00)	–0.03* (0.00)	–0.03* (0.00)	–0.03* (0.00)	–0.03* (0.00)
log(netpfuel)	0.04 (0.07)	0.10 (0.10)	–0.00 (0.07)	0.00 (0.06)	–0.02 (0.05)	0.00 (0.07)
infpubtrans	–0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	–0.00 (0.00)	–0.01* (0.00)	0.00* (0.00)
log(mways)	–0.02* (0.00)	–0.03* (0.01)	–0.03* (0.01)	–0.02* (0.00)	–0.02* (0.00)	–0.02* (0.00)
q1	–0.03* (0.01)	–0.06* (0.02)	–0.03* (0.01)	–0.03* (0.01)	–0.02* (0.01)	–0.01 (0.01)

Table 6 (continued)

Dependent variable: log(fuel)

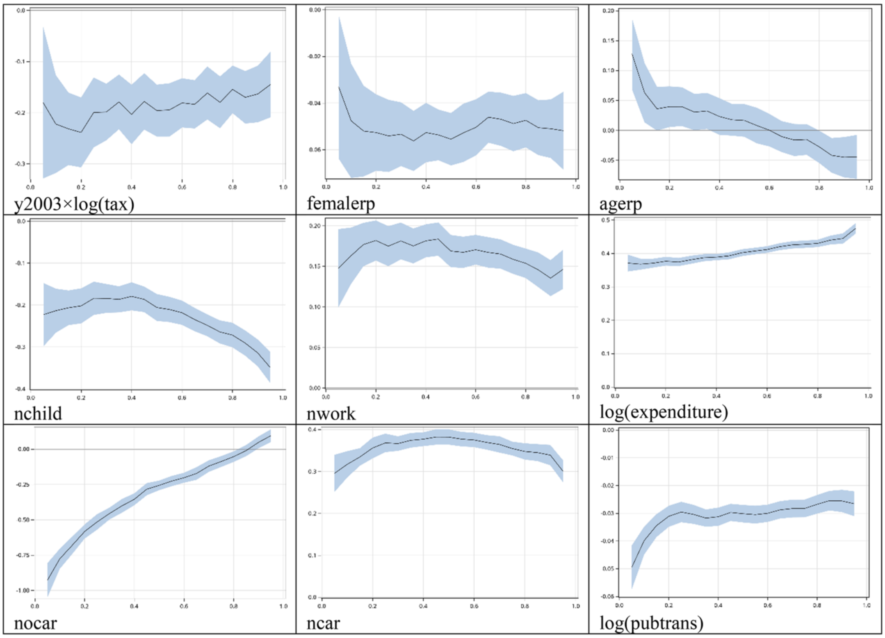
Coefficient (standard error)

Independent variables	Model 1: OLS	Model 2: Quantile regression				
		0.1	0.25	0.5	0.75	0.9
q2	0.02* (0.01)	0.01 (0.01)	0.02* (0.01)	0.02* (0.01)	0.01 (0.01)	0.02* (0.01)
q3	0.02* (0.01)	0.01 (0.01)	0.02* (0.01)	0.03* (0.01)	0.03* (0.01)	0.02* (0.01)
Observations	136,079	136,079				
Adjusted R^2/R^1	0.373	0.184	0.200	0.225	0.252	0.267

Instead of the logarithmic transformation, the inverse hyperbolic sine transformation is employed, when a variable takes the value of zero (Burbidge et al. 1988)

log logarithm of variable; *fuel* expenditure on motor fuels p.p. (1999 euros PPP); *y2003* year 2003 (dummy); *tax* tax on motor fuels (cents/litre); *it* Italy (dummy); *es* Spain (dummy); *femalerp* female reference person (dummy); *agerp* age of reference person (decades); *nchild* no. of children per household member; *nwork* no. of working people per household member; *expenditure* total household expenditure (1999 euros PPP); *nocar* household without car (dummy); *ncar* no. of cars p.p.; *pubtrans* expenditure for public transportation (1999 euros PPP); *netpfuel*: net price of motor fuels (cents/litre); *infpubtrans* inflation rate of public transportation (%); *mways* regional density of motorways (kilometres per 1000 square kilometres); *q1* first quarter of the year (dummy)

*$p < 0.05$



x: quantile levels; y: regression coefficient of respective variable.

Fig. 3 Estimated quantile regression effect on motor fuel consumption p.p. with 95% confidence limits. *x* quantile levels; *y* regression coefficient of the respective variable

tax increase led to a significant reduction in consumption. Only households with a positive fuel consumption have been included, which represent three-quarters of the total sample. An OLS regression (model 1) and a quantile regression (model 2) are employed to analyse the tax effect on different parts of the distribution especially at the lower and upper tail. Table 6 presents the results of the different models.

The adjusted R^2 implies a moderate fit for the OLS model 1 explaining more than a third of the variance of the dependent variable. While model 1 describes the effects of the independent variables on the average fuel consumption p.p., the quantile regression of model 2 explains the impact on the different parts of the distribution, as illustrated for selected regressors in Fig. 3. R^1, proposed by Koenker and Machado (1999) as the goodness of fit measure, increases from the bottom to the upper tail implying that the explanatory power of the independent variables rises alongside the quantiles. The following analysis focuses on model 1 with additional input from model 2.

The variable *y2003×log(tax)* describes the ATE and the value of –0.18 shows that the increase of excise duties by 10% leads to a statistically significant[12] reduction of 1.8% in motor fuel consumption corresponding to an elasticity of –0.18.

[12] Besides $p<0.05$, no differences p-values are reported to focus on the actual effect of the independent variables (Nuzzo 2014; Wasserstein and Lazar 2016).

Hence, an ecotax reduces consumption, even though the relatively low absolute value implies a price-inelastic demand. Furthermore, the effect of the tax is higher at the bottom than at the upper tail of the distribution. It is fair to assume that households with a low level of consumption are more likely to find alternative substitutes such as public transportation, cycling or walking, while high-level consumers face greater difficulties to adapt. This favours a stronger substitution effect at the lower end of the distribution. Unsurprisingly, the models show that Italian and British households consume more motor fuels on average, while the consumption of Spanish households is close to that of their German counterparts, a result which was already depicted in Fig. 1.

Regarding household composition, the number of working household members and children under the age of 18 per total number of members have opposing effects on motor fuel consumption. Increasing the proportion of working household members by one percentage point raises motor fuel consumption by 0.17% on average, while expenditure on fuels diminishes by 0.23% regarding additional children. Gender and age have only a small or statistically insignificant effect.

Total expenditure has a strong effect on motor fuel consumption increasing it by 4.1%, when expenditure raises by 10%. An important influence on consumption behaviour stems from the decision to own a car. Car owners spend 33% more on motor fuels. Predictably, the effect declines sharply with increasing consumption as car owners are less likely to be found in the lower than in the upper tail of the distribution. Furthermore, an additional car p.p. raises consumption by 34% with a relatively stable effect over the distribution.

The remaining variables have only negligible and in some cases statistically insignificant effects on motor fuel consumption. The low effect of expenditure on public transportation shows that in many cases public transportation is no viable substitute for motor vehicle usage which explains the inelastic demand for fuels. Furthermore, the tiny and statistically insignificant effect of the net prices probably stems from their dependence on global oil prices. Even though world market prices and national net prices fluctuated strongly, this did not lead to tangible relative price differences between the four countries and subsequently to the described negligible effect on relative consumption.

5.3 Electricity

In 1998, the German government introduced a new tax on electricity, while comparable duties in Italy and Spain decreased between 1998 and 2003. In the UK, no

Table 7 Excise duties and levies on electricity (annual average)

	1998	2003	Change
	Cents/kilowatt-hour		%
Germany	0.09	2.05	2172.2
Italy	4.02	3.41	– 15.1
Spain	0.48	0.44	– 8.3
UK	0.00	0.00	–

Based on: Eurostat (2021a)

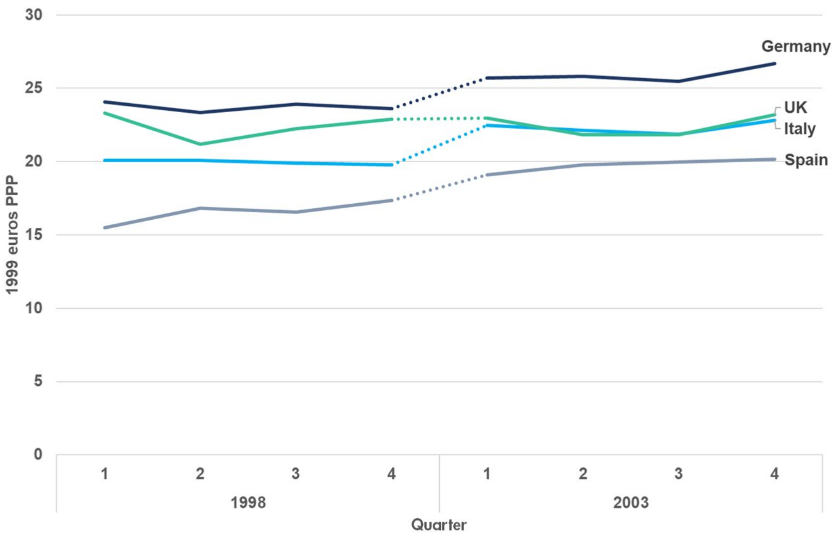


Fig. 4 Average expenditure on electricity p.p. between 1998 and 2003

excise duty on electricity existed as shown in Table 7. Again, there are strong differences between Germany and the countries of the control group.

Meanwhile, households in all countries except the UK increased spending on electricity, while British expenditure remained constant. The differences between the countries are less pronounced compared to expenditure on motor fuels. German households had the highest amount of expenditure, Spain the lowest with Italy and the UK in between, see Fig. 4.

On the regional level, Germany, Italy and Spain experienced spending increases in all or almost all regions, as illustrated in Fig. 5. Only Hamburg saw a decrease in electricity consumption, while the strongest increases occurred in Brandenburg and Rhineland-Palatinate. In Italy, Campania and Sardinia were the only regions with a fall in expenditure on electricity. In contrast to motor fuels, an East–West or North–South divide was not visible in Germany and Italy, respectively. No clear trend emerged in the UK. While Greater London, the West Midlands, North East England, Wales and Scotland reduced average consumptions levels, expenditure rose in Northern Ireland and the other English regions. Spain saw a sharp rise in all of its regions, even though the increases were relatively smaller in the Community of Madrid and Catalonia.

The regression analyses of household expenditure on electricity examine and identify the main factors influencing household behaviour, see Table 8. Only 2.2% of all households in the sample had no electricity expenditure and are excluded. Again, OLS (model 1) and quantile regressions (model 2) are employed. A heat wave struck Western Europe in 2003 causing more than 70,000 deaths with France, Italy, Luxembourg, Portugal and Spain affected most severely (Robine et al. 2008). Since Spain, Italy and France had by far the largest markets for home air conditioning in the EU-15 during the 1990s and 2000s, this extraordinary weather event is likely

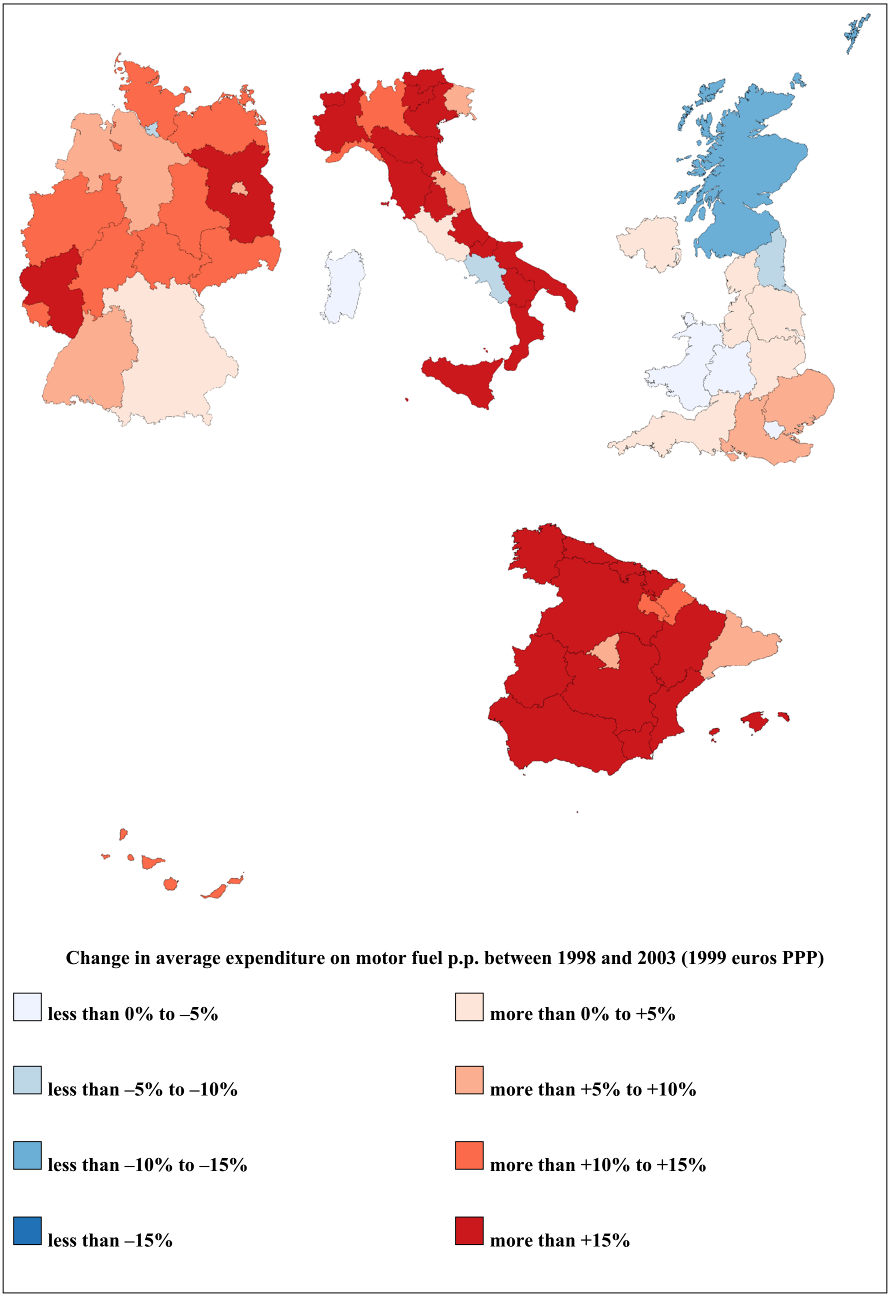


Fig. 5 Choropleth maps of regional changes in electricity consumption between 1998 and 2003

Table 8 Regression analysis of electricity expenditure

Dependent variable: log(elec)

Coefficient (standard error)

Independent variables	Model 1: OLS	Model 2: Quantile regression					Model 3: OLS (DE + UK)
		0.1	0.25	0.5	0.75	0.9	
Constant	1.48* (0.17)	0.19 (0.24)	0.05* (0.20)	0.98* (0.20)	2.22* (0.23)	3.28* (0.28)	9.35 (6.79)
y2003	–0.02 (0.01)	–0.04* (0.01)	–0.07* (0.01)	–0.05* (0.01)	0.01 (0.01)	0.04* (0.02)	0.01 (0.03)
log(tax)	–0.02* (0.00)	–0.01* (0.00)	–0.01* (0.00)	–0.02* (0.00)	–0.03* (0.00)	–0.03* (0.00)	–8.84 (8.22)
y2003 × log(tax)	0.04* (0.00)	0.07* (0.00)	0.06* (0.00)	0.04* (0.00)	0.02* (0.00)	0.02* (0.00)	6.93 (6.42)
it	–0.23* (0.01)	–0.40* (0.02)	–0.29* (0.02)	–0.18* (0.02)	–0.12* (0.02)	–0.15* (0.02)	–
es	–0.11* (0.03)	–0.08 (0.04)	–0.25* (0.03)	–0.19* (0.03)	–0.09* (0.04)	–0.06 (0.05)	–
uk	0.02 (0.02)	0.10* (0.03)	–0.08* (0.02)	–0.08* (0.02)	0.00 (0.02)	0.08* (0.03)	–7.07 (6.63)
femalerp	0.06* (0.00)	0.05* (0.01)	0.05* (0.00)	0.06* (0.00)	0.08* (0.01)	0.09* (0.01)	0.07* (0.01)
agerp	0.09* (0.01)	0.14* (0.01)	0.10* (0.01)	0.09* (0.01)	0.06* (0.01)	0.00 (0.01)	0.10* (0.01)
$agerp^2$	–0.01* (0.00)	–0.01* (0.00)	–0.01* (0.00)	–0.01* (0.00)	0.00* (0.00)	0.00 (0.00)	–0.01* (0.00)
nchild	–0.15* (0.01)	–0.07* (0.02)	–0.11* (0.01)	–0.16* (0.01)	–0.19* (0.01)	–0.27* (0.02)	–0.19* (0.01)
nwork	–0.06* (0.01)	–0.04* (0.01)	–0.04* (0.01)	–0.06* (0.01)	–0.07* (0.01)	–0.10* (0.01)	–0.06* (0.01)
log(expenditure)	0.20* (0.00)	0.18* (0.01)	0.19* (0.00)	0.19* (0.00)	0.22* (0.01)	0.25* (0.01)	0.15* (0.01)
size	0.09* (0.00)	0.09* (0.01)	0.09* (0.00)	0.08* (0.00)	0.08* (0.01)	0.08* (0.01)	0.07* (0.01)
own	0.03* (0.00)	0.07* (0.01)	0.06* (0.00)	0.03* (0.00)	0.01 (0.01)	–0.02* (0.01)	0.07* (0.01)
wash	0.06* (0.01)	0.16* (0.02)	0.09* (0.01)	0.05* (0.01)	0.02 (0.01)	–0.02 (0.02)	0.05* (0.01)
fridge	0.07* (0.03)	0.26* (0.04)	0.16* (0.03)	0.03 (0.03)	–0.05 (0.03)	–0.04 (0.04)	0.09* (0.04)
log(netpelec)	0.09 (0.08)	–0.06 (0.11)	–0.40* (0.10)	–0.18 (0.10)	0.24* (0.11)	0.55* (0.13)	0.36 (0.28)
log(heat)	–0.01* (0.00)	0.00* (0.00)	–0.01* (0.00)	0.00 (0.00)	0.00* (0.00)	–0.01* (0.00)	0.01 (0.01)
q1	0.00 (0.01)	–0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	–0.01 (0.01)	–0.01 (0.01)	0.00 (0.01)

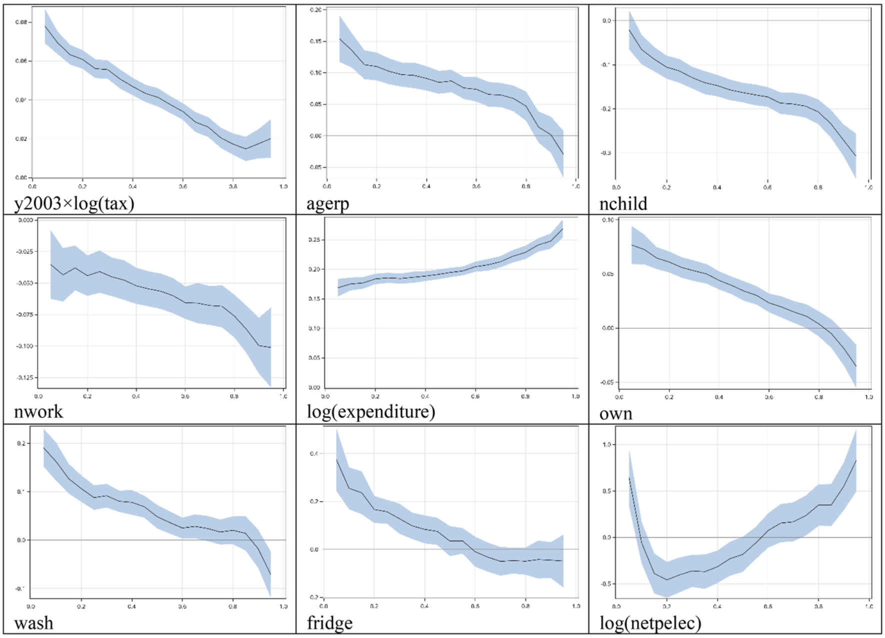
Table 8 (continued)

Dependent variable: log(elec)							
Coefficient (standard error)							
Independent variables	Model 1: OLS	Model 2: Quantile regression					Model 3: OLS (DE + UK)
		0.1	0.25	0.5	0.75	0.9	
q2	–0.03* (0.01)	–0.04* (0.01)	–0.03* (0.01)	–0.02* (0.01)	–0.03* (0.01)	–0.06* (0.01)	–0.03* (0.01)
q3	–0.03* (0.01)	–0.04* (0.01)	–0.04* (0.01)	–0.02* (0.01)	–0.03* (0.01)	–0.06* (0.01)	–0.01 (0.01)
Observations	170,095			170,095			104,517
Adjusted R^2/R^1	0.104	0.088	0.078	0.060	0.051	0.054	0.065

Instead of the logarithmic transformation, the inverse hyperbolic sine transformation is employed, when a variable takes the value of zero (Burbidge et al. 1988)

log logarithm of variable; *elec* expenditure on electricity p.p. (1999 euros PPP); *size* dwellings larger than the national median dwelling (dummy); *own* household owns dwelling (dummy); *wash* household owns a washing machine (dummy); *fridge* household owns refrigerator, freezer or combination (dummy); *netpelec* net price of electricity (cents/kilowatt-hour); *heat* actual heating degree-days expressing the severity of cold weather (°C)

*$p < 0.05$



x: quantile levels; y: regression coefficient of respective variable.

Fig. 6 Estimated quantile regression effect on electricity consumption p.p. with 95% confidence limits. *x* quantile levels; *y* regression coefficient of the respective variable

to have disrupted regular patterns of electricity consumption (Adnot 1999; Bertoldi and Atanasiu 2009). Therefore, model 3 drops Italian and Spanish households and includes only the German and British samples to test for consistency and robustness.

The models employ similar explanatory variables as those for motor fuels. Furthermore, variables that are theoretically related to electricity consumption such as the size of a dwelling and the regional temperature replace equivalent variables for motor fuel consumption such as the number of cars. The adjusted R^2 of the OLS regression in models 1 and 3 indicates that the independent variables explain only about 10.4% and 6.5% of the total variance of electricity consumption, respectively. This is clearly below the OLS regression for motor fuels. The goodness of fit measure R^1 for the quantile regression is also smaller than that of motor fuels. The following analysis focuses on model 1 with additional input from models 2 and 3.

The variable *y2003×log(tax)*, which indicates the ATE, has a statistically significant but small, positive effect. That means that despite raising taxes electricity consumption increased. When only German and British households are considered, the impact becomes statistically insignificant.[13] Hence, the increase in taxes did not achieve the intended objective – a reduction in electricity consumption. This assessment is not surprising considering that the duties increased almost 22 times in Germany between 1998 and 2003, but average electricity consumption went up by 9.3% at the same time.

The country dummies show that consumption was higher in Germany compared to Italy and Spain, while the UK had a similar level. The sociodemographic variables gender and age result in a relatively weak impact. However, at the lower tails of the distribution households headed by older people tend to consume more, see Fig. 6.

Household composition plays an important role in electricity consumption. Households with a larger share of children or working people consume less electricity. The effect of additional children amplifies at the upper percentiles. For motor fuels, more working people lead to higher consumption. Thus, working increases fuel consumption for commuting, while it diminishes time spent at home combined with electricity consumption. Total household expenditure p.p. shows a medium-sized impact which is lower than that on fuel consumption.

The size of the dwelling and whether the household owns it have a statistically significant, small positive impact on electricity consumption. The effect of home-ownership is stronger at the lower end of the distribution and becomes negative at the upper end. Owning a washing machine or fridge or freezer also increases electricity consumption. Their impacts are especially strong at the first decile of the distribution. However, 95% of the households in the sample own a washing machine and 99% a fridge or freezer. Furthermore, the effect of electricity net prices is statistically insignificant in model 1 and 3 and very unstable across the distribution casting doubt on its strength and direction. The other variables only show negligible or statistically insignificant effects.

6 Conclusion and policy implications

The main objective of the German ETR was to substantially reduce energy consumption by raising its price while creating jobs by recycling the revenue for reductions of PPC. With real expenditure under PPP serving as a close and suitable proxy for consumption, it was demonstrated that this market-based approach of increasing excise duties on motor fuels and electricity alone did not achieve the intended goal. Employing the DID with Germany as the treatment group and Italy, Spain and the UK as the control group, the OLS and quartile regressions show that the demand for motor fuels is clearly price inelastic with a reduction of only 1.8% for a tax increase of 10%. This finding is in line with the assessment of Steiner and Cludius (2010), who also estimated a drop of 1.8% for Germany. Compared to the results of the meta-analyses of Dahl (2012) and Labandeira et al.

[13] The UK did not charge an electricity tax resulting in larger but statistically insignificant effects in model 3 with regard the variables concerning tax rates: *log(tax)* and $y2003 \times log(tax)$.

(2017), the elasticity of –0.18 ranks at the lower end of the spectrum. Hence, the incentive-based policy had only a small impact. Apparently, alternative modes of transportation such as public transport, cycling or walking are not attractive or suitable to provide an appropriate substitute producing a more elastic reaction. The impact is slightly higher for households at the lower tail of the distribution indicating that marginal households are less dependent on private car traffic. Thus, a pricing scheme alone does not lead to a substantial reduction in fuel consumption and needs to be accompanied by other policy measures. Vehicle emission standards show potential for emission reductions. EU regulations decreased CO_2 emissions for new passenger cars by more than a quarter between 2000 and 2013 (International Council on Clean Transportation 2014). However, under real-world conditions these standards are regularly violated leading to about 11,500 premature deaths due to excess NO_x emission from diesel vehicles in the EU-28 (Anenberg et al. 2017). Additionally, the rebound effect often offsets large parts of the efficiency gains as drivers tend to travel more or longer distances (Fronder and Vance, 2017). Furthermore, infrastructure policies are essential to provide people with alternative modes of transportation. Intelligent solutions for public transport (Newman and Kenworthy 2011), land use promoting walking and cycling (Buehler and Pucher 2017; Gössling et al. 2019), and bike-sharing facilities (DeMaio 2009) can lead to a reduction in car usage. The IPCC (2022) offers a thorough review of the various policies and on-going technological developments in transport mitigation strategies. In Germany's federal system, an effective policy mix would require coordinated efforts and political will on the European, national, state and municipal levels. However, during the COVID-19 pandemic, several European cities including Berlin and Cologne have introduced provisional bike lanes, that led to a large rise in cycling (Kraus and Koch 2021) demonstrating that there are still low-hanging fruits to pick in this policy field. Further studies could identify political, social, cultural and technological barriers to behavioural change and reveal the best way to combine different environmental policy instruments.

For electricity consumption, the regression analyses demonstrated that despite the introduction of a new electricity tax and the resulting, strong increase in electricity prices, electricity consumption continued to rise. Even though saving electricity is an important policy goal, it becomes clear that the reduction in GHG emissions from energy production needs to be tackled primarily from the producer's side. That is the aim of the German energy transition *(Energiewende).* Guaranteed feed-in tariffs for renewable energies subsidise these green technologies and their producers receive the necessary planning reliability for investments over two decades (Pegels and Lütkenhorst, 2014). This policy is internationally considered as a success story as "well-adapted feed-in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity" (European Commission 2008). Compared to energy taxation, the creation of a solid, long-term investment climate is clearly the more effective solution to achieve lasting reductions in GHG emissions.

This article supports Bach's (2009) finding, which considers the ETR as half-hearted in terms of climate change policy, but fiscally successful. The policy stopped the further increase of PPC and paved the way to creating 114,000 jobs without an additional burden on the already strained public budget. Thus, the German ETR was an appropriate first step in implementing a more environmentally sustainable system of taxation, which actively promotes lower fossil fuel consumption. Despite the meagre environmental effects, this type of incentive-based policies could be an important component of a comprehensive agenda to reduce GHG emissions in light of Germany's international responsibilities for climate change mitigation.

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Data availability This study is based on HBS datasets which in the cases of Germany, Italy and the UK are not publicly available to preserve individuals' privacy under the respective EU and UK data protection regulations. However, Spanish HBS datasets are publicly available at the website of the National Statistics Institute (INE) as indicated in the list of references.

Declarations

Conflict of interest The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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