Transportation Research Part D 136 (2024) 104391

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Decarbonising transport: Can we rely on fuel taxes?

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ARTICLE INFO

Keywords:
Energy demand elasticity
Environmental taxation
Cohort effects
Dynamic model
Pseudo panel

ABSTRACT

Although not without criticism, carbon pricing has been identified as a key instrument to support the energy transition process, as it can convey the signal of the actual cost of carbon in relative prices. However, when price and tax elasticities are considered separately, the international literature has shown that energy demand may be more sensitive to changes in tax rates. We estimate gasoline and diesel demand elasticities for Italian households using a dynamic model on a custom-built pseudo-panel. Our results confirm that household demand for transport fuels is more sensitive to the tax component than to the oil price, controlling for income level, age and cohort effects. These results have important implications for the potential effectiveness of transport fuel taxation in setting the decarbonisation pathway: a lower tax rate is required to achieve the target than that assumed on the basis of gross price elasticities.

1. Introduction

Fuel taxes are signals designed to alter transport consumer behaviour and help countries meet climate change and energy security objectives by increasing the market price. In the EU tax rates applied to gasoline and diesel differ across member states and are frequently changed by national governments (Ptak et al., 2024). On average, the total burden of taxes (excises and VAT) on fuels in EU is noteworthy: the average tax rate on gasoline is 50 % of the final price and 46 % for gasoil.[1]

In the majority of cases, the existing academic literature refers to the effect of the final price on consumer choice, without considering the role of the net price and the tax rates as separate components. However, a number of empirical studies (Rivers and Schaufele, 2015; Davis and Kilian, 2011; Li et al., 2014; Douenne and Fabre, 2022; Andreassen et al., 2024), employing both primary (experimental or survey) and secondary data (econometric) approaches, have identified a distinct tax aversion attitude among consumers and firms. This attitude has been shown to explain specific behavioural reactions, both in the context of tax evasion and in ordinary behavioural choices. While tax aversion may impede the efficacy of certain policy initiatives, in the context of environmental or energy transition policies, a degree of overreaction may prove advantageous to limit the adverse distributional consequences of fuel taxes. In other words, a tax rate below the optimal level (the marginal cost of energy use externality) can be employed. However, the distributive implications of using taxes to limit negative externalities cannot be overlooked. The increased burden of energy expenditure on household budget has uneven effects across the population: low-income households have relatively higher expenditure shares in energy and food, have a lower saving rate and thus fewer options to modify choices in the short run (Bardazzi et al., 2021).[2]

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[1] Data refer to the first half of 2024. See https://www.unem.it.

[2] These vulnerable households may find it difficult to invest in more efficient vehicles, raising concerns about the affordability of the carbon strategy, which therefore requires a comprehensive approach with multiple instruments to offset negative distributional impacts.

https://doi.org/10.1016/j.trd.2024.104391
Received 27 March 2024; Received in revised form 14 August 2024; Accepted 26 August 2024
Available online 8 September 2024

This study contributes to the existing literature on consumer fuel expenditure choices. Our main research question is whether the response to tax changes can be considered separately from an equivalent change in gross fuel prices. This issue is of great importance for the proper design of fiscal policies within the context of the EU's green transition and the relevance assigned to market-based instruments in the European strategy. Furthermore, it is beneficial to gain a comprehensive understanding of the implications of recent policy interventions related to inflation, particularly in light of the widespread reduction in fuel tax rates (Bardazzi et al., 2024; Colabella et al., 2024).

This work focuses on Italy, a very interesting case study because of the country's two distinctive features: motorisation rate and fuel prices – including taxes – are among the highest in the world. In particular, Italy has the highest motorisation rate in the EU (682 vehicles per thousand inhabitants in 2022) and one of the highest in the world. At the same time, pump fuel prices are among the highest in EU: Italy ranks third for the gross price of gasoline and second for diesel. As we will discuss later, Italian consumers, even at very high fuel prices, are not prepared to give up their cars, but they rather prefer to reduce the intensity of their use.

To address this research question, we use a microsimulation model based on Italian microdata collected with Household Budget Surveys from 1997 to 2019, complemented with data on energy prices, tax rates, and emissions. We use this information to build a pseudo panel dataset to take full advantage of the longitudinal component and estimate price and tax elasticities of fuel consumption. We estimate a dynamic model to identify short run and long run elasticities after individuals have fully adjusted their behaviour as a result of system and policy variations and changes in travel habits. The results show that Italian consumers react more to fuel tax changes than to before-tax price equivalent variations, confirming what other scholars have found for different countries. We find that fuel consumption is responsive to the net price (with an elasticity that ranges from − 0.07 for gasoline to − 0.14 for diesel) and is more sensitive to the change of the excise component particularly in the case of gasoline with a tax elasticity of −0.82 compared to diesel (−0.6). As expected, the long-run elasticities exceed the short-run estimated parameters, notably in the case of gasoline, where the net price elasticity is −0.124 and the tax elasticity is −1.399. To test the robustness of our findings, we employ a static double hurdle model and pool the microdata from all surveys. This analysis aims to ascertain whether the results are influenced by the significant presence of zero observations and by the heterogeneity of households. Indeed, these characteristics may be somewhat weakened in the construction of the average observations in the pseudopanel. The results of the double hurdle model corroborate our previous findings, controlling for a comprehensive set of demographic and socio-economic characteristics, including age and cohort effects. The tax marginal effect (−0.52 for gasoline and −0.07 for diesel) is higher than that of the net price (respectively −0.01 and −0.04).

The remainder of the paper is organized as follows. The next section analyses the economic literature on transport fuel demand elasticities with a particular focus on the tax component. We discuss the general empirical strategy and the data in section 3, while section 4 presents the modelling approach and the estimation results. A robustness check based on pooled cross-sections is presented in Section 5, while the final section discusses the implications of our findings and concludes.

2. Price and tax Elasticities: Does it pay to distinguish?

Economic theory suggests that when the total cost of fuel increases, whether due to higher taxes or price changes, households will drive less and invest in more fuel-efficient car models, regardless of the source of the cost increase. However, several empirical studies (Rivers and Schaufele, 2015; Davis and Kilian, 2011; Li et al., 2014; Andersson, 2019; Tiezzi and Verde, 2019) highlight that consumers respond more strongly to changes in the tax rate than to equivalent price changes. This apparently non-rational attitude has important implications for energy and climate policies: to obtain a certain target decrease in energy use or in fossil fuel sources we can use an energy/carbon tax rate lower than expected.[3] In fact, estimates of fuel price elasticity tend to be low, suggesting that a large increase in the gas tax would be required to significantly reduce fuel consumption.

The difference in consumer responses can be rationalized in several ways, which we broadly classify as behavioural and informational explanations. Regarding the behavioural literature, Chetty et al. (2009), in a well-known field experiment, emphasize the importance of the salience of the tax rate level and highlight the role of inattention and cognitive framing as the causes of different responses to price and taxes. According to Tang and Sjoquist (2019), a tax aversion bias – meaning that tax payments may cause a greater loss of utility than equivalent market payments – can explain the higher elasticity to tax changes. In the same behavioural framework, Rivers and Schaufele (2015) consider the role of others regarding preference: some agents may reinforce their motivation to contribute to the common goal (energy-saving behaviour for climate preservation as an example) when a carbon tax is introduced, because it implies the polluter pays principle and all other citizens are obliged to pay for energy use.

On the information side, Davis and Kilian (2011) emphasize that the price changes caused by tax changes are rightly perceived as more persistent than net-of-tax price fluctuations, a factor magnified by the extensive media coverage of this type of policy intervention. Scott (2012) links the idea of the perceived persistent role of energy taxes to the formation of transport habits: energy taxes are more powerful than before-tax prices in influencing consumers' expectations of future market conditions, and are therefore able to change the habit attitudes.

Li et al. (2014) find robust evidence that excise tax changes are associated with larger changes in fuel consumption and vehicle choice than are corresponding changes in the tax-exclusive price of gasoline and potentially link this result to a different discount rate when considering intertemporal fuel costs.[4]

[3] To internalize the externality, the optimal tax rate should be equated to the marginal external cost of fossil fuel use in the social optimal point.

[4] Interestingly, Muhelagger (2008) interprets the difference between price elasticity and tax elasticity – confirming a higher tax elasticity – as an indication of tax evasion behaviour.

A recent review of the theoretical and empirical literature on vehicle and fuel taxation in developed countries is presented by He and Kim (2024).

3. Empirical strategy and data

Before discussing the empirical strategy for analysing price and tax elasticities, it should be noted that in Italy, which is almost entirely dependent on foreign supplies of fossil fuels, the pump price of fuels is particularly high compared with other European countries. This is due not only to the transport margins on imported quantities, but also to a particularly high level of taxation,[5] with the general aim of encouraging energy saving, but with tax rates set more in line with budgetary needs[6] than with marginal external costs. Italian excise taxes are therefore energy taxes and cannot be considered neither Pigouvian nor a part of a national carbon strategy.

The empirical literature on fuel consumption emphasizes that when estimating price elasticities the results may be biased due to the endogeneity of fuel prices, as the level of fuel consumption may affect the price of fuel. This endogeneity risk seems to be less important in Italy, a relatively small and oil-dependent country, where market fuel prices depend closely on international oil prices and cannot be influenced by changes in Italian household demand. Indeed, fuel prices exhibit a limited variability in the country. In theory, the same endogeneity risk can be discussed for tax rates which, according to some scholars, can in principle be fixed to compensate for price oscillations. Fig. 1 shows that there is no influence of the (pre-tax) international price on excise tax rates on gasoline and diesel, as they have been increased several times, even when pre-tax prices were rising. Therefore, an argument for endogeneity between pre-tax prices and tax rates does not seem to be relevant for the Italian case during the observation period, since the changes in tax rates have been determined more by public budget needs than by environmental or distributional concerns. It is worth noting, however, that during the recent oil price spike due to the geopolitical tensions (after the end of our observation period), fuel tax rates were reduced to mitigate the impact of the energy price increases on households and firms for about one year (Bardazzi et al. 2024).

In order to estimate price and tax elasticities of consumption demand, it is also necessary, as a preliminary step, to assess the degree of tax shifting in the fuel market, that is the pass-through of excise tax changes to consumer price changes. In the empirical literature, there is a general consensus on the idea of a full tax shifting: some studies consider both sides of the market and, in particular, the role of supply and market power to assess the degree of tax shifting (Jametti et al. 2013, Di Giacomo et al., 2015). Following the literature focussing only on the demand side of the market (Alm et al. 2009, Andersson 2019, Li et al. 2014) to evaluate tax shifting, we have conducted a preliminary assessment of tax shifting in Italy. Our findings indicate that, on average, fuel taxes are fully shifted to consumers. This was achieved by estimating an aggregate regression of the gasoline price on international oil prices and excise taxes.[7]This result confirms those of several papers, including Andersson (2019) and Marion and Muehlegger (2011), which find that for the US state and federal gasoline taxes are fully incorporated into the tax-inclusive price in a very short time.

Assuming a full tax shifting on consumers, price and tax elasticities can be estimated with a demand system (as in Tiezzi and Verde, 2019) or with a single equation model. Moreover, in the empirical literature we find different ways of disentangling tax and price effects. Indeed, in most countries the fuel market price has a before-tax component (also known as the industrial price, *p*), a tax component (a unit tax designed as an energy tax or a specific carbon price, *t*) and an ad valorem component (VAT in the EU or a sales tax in other countries). Therefore, the after tax or market price is $P_m = [p + t](1 + vat)$. Since the ad valorem tax affects homogeneously the two components, it is usually overlooked in empirical analysis, but it would nevertheless be possible to treat both price and tax rate gross of the ad valorem tax. To consider the effect of price and excise tax on consumption, scholars have generally chosen a linear model (linear, log–log or semi-log) either with the two components in the additive form (Tang and Sjoquist, 2019; Lawley and Thivierge, 2018; Rivers and Schaufele, 2015) or with the price and the tax/price ratio, following the factorization suggested by

[5] The level of taxation (combining excise tax and VAT) on a litre of gasoline, more than one euro in April 2024, is second only to that of the Netherlands. In terms of the weight of the tax component in the pump price of gasoline (which also depends on the price of imported crude oil), Italy is second only to Finland (over 56% in both cases). For diesel, Italy has the highest value for both the absolute tax component and the share in the price (April 2024 data from Unione Petrolifera). According to OECD database, the effective carbon tax rates corresponding to the current excise taxes in Italy are even higher than the target carbon price (between 25 and 100 euro per ton of CO2): in 2021 the effective carbon tax rate is 322 euro per tonne of CO2-equivalent for gasoline and 231 euro for diesel.

[6] Many fuel tax increases have been linked by incumbent governments to collective traumatic events such as earthquakes and floods, or to the funding of peacekeeping missions. This was clearly a ploy to reduce the political cost of tax increases, but it never helped to raise awareness among Italian consumers of the need to correct negative externalities, and instead increased aversion to taxation. Moreover, up to 2020, Regional governments have had the power to introduce a small additional local excise tax rate to the national one.

[7] We use an OLS estimation of the first-differenced variables. We regress the first difference in consumer fuel price on international oil prices and excise taxes as follows: $\Delta CFP_t = \alpha + \beta_1 \Delta OilPrice_t + \beta_2 \Delta \tau_t + e_t$where CFP is the retail gasoline/diesel price, OilPrice is the crude oil price, and τ is the state excise taxes. We use yearly average of international oil price (euro per liter), gasoline and diesel consumer prices and excise tax rates for the 1997–2019 time span in real terms. All time series are taken from Unione Petrolifera data base (https://www.unem.it). We are aware that the use of average prices disregards potential specific effects in particular areas, but our aim is only to confirm for our time-span a result widely acknowledged in the literature. Our findings show that $\beta_2 = 1.22$ and $\beta_1 = 1.06$ with p-values 0.000. Therefore as $\beta_2 > \beta_1$ and it is higher than 1, we can argue that fuel taxes are fully shifted on consumers.

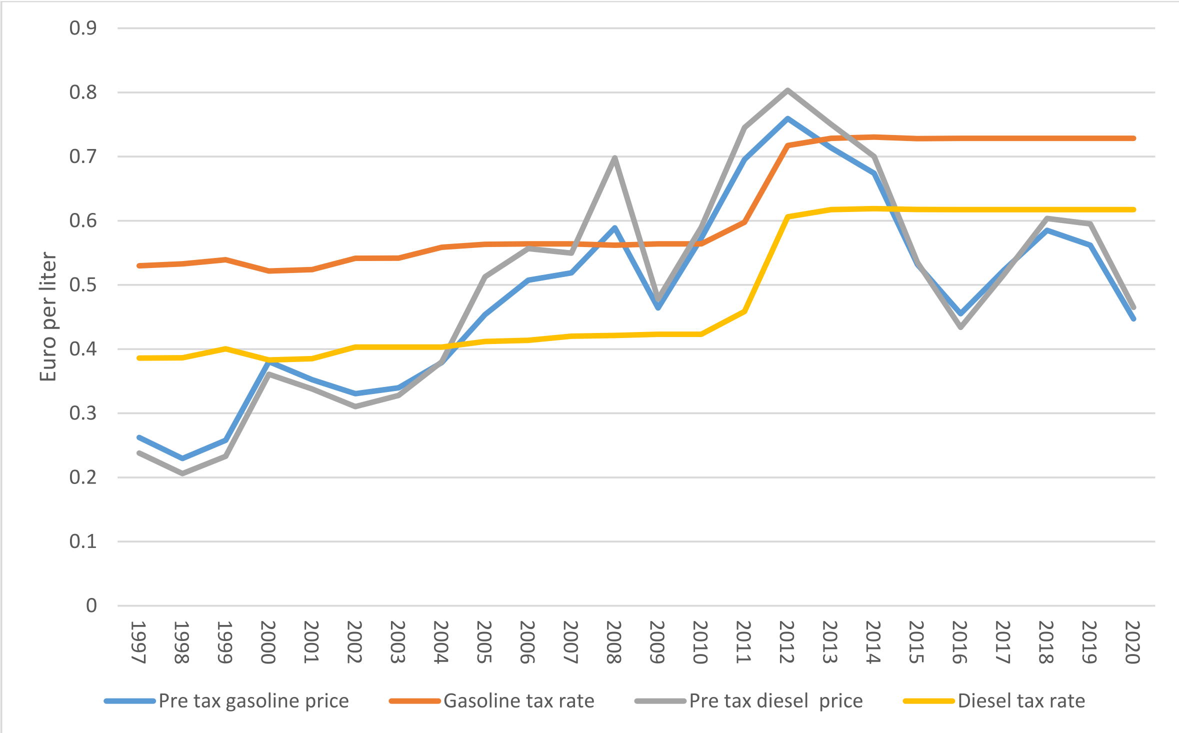

Fig. 1. Energy prices and tax rates (1997–2020) Source: Unione Petrolifera.

Muhelagger (2008) and adopted also by Li et al. (2014).[8] Whatever the chosen functional form, the available empirical results – mainly for the US, Sweden and Canada – always show that the tax elasticity is larger than the price elasticity and that the difference between the two coefficients is statistically significant. In this paper, we rely on a single equation approach and we choose the additive functional form in the log–log specification, where the parameters are easier to be discussed as elasticities. However, we also run estimations for the functional form suggested by Muhelagger – a price and a tax-price ratio – and used in several other papers and we obtain very similar results.

3.1. The data

We use survey data on household consumption including energy expenditure by type of fuel and use and sociodemographic characteristics collected by the Italian Statistical Office (ISTAT) in the annual Household Budget Survey (IHBS). The sample consists of more than 20,000 households to represent the population at the regional level for the period 1997–2019, avoiding the years of the pandemic when consumption of transport fuel was severely reduced due to lockdowns. Households are interviewed in different periods of the survey year. Data is collected through two questionnaires, administered by a data collector, and a diary completed by the family. The initial questionnaire is used to record the main socio-demographic characteristics of all household members and information on housing, possession of durable goods, means of transport and communication. On the paper diary, households must record daily, for 14 days, the expenses incurred by all members for the purchase of food and non-food consumer goods and services, including fuels, as well as the places where they most frequently purchased a selection of goods. A final interview is aimed to survey all other household expenditures. As collected data refer to different reference periods, they are all standardized by the statistical office to a common temporal reference (the month), so that all expenditures can be added together.

Energy prices and tax components (state and regional excise taxes, VAT) are added to the IHBS dataset for the entire period. In particular, consumer prices per liter of gasoline and diesel are used to calculate the quantities consumed at the household level. Excise and VAT rates for both fuels – including, when present, the regional excise surtax for gasoline – are collected to estimate the fiscal component for each unit.[9]

[8] The proposed factorisation begins by considering that excise tax rates (t) should be added to net prices (p) to obtain a gross prices (pg) if sales tax is not considered. From pg=p+t we can transform to pg=p (1+t/p). Taking the logarithm, we have ln(pg)=ln(p)+ln(1+t/p), which gives a net price and a tax/net price ratio to estimate.

[9] The source of prices and fiscal components is the database provided by Unione Petrolifera (https://www.unem.it) and the tax rates are provided by the Italian Ministry of Finance.

These survey data are used to build two datasets to answer to the research questions of this paper. Firstly, given the importance of time effects on people's decision on private transport use, we need information to identify the households' dynamics of fuel consumption. Unfortunately, our microdata are not designed as a panel, but rather as a collection of repeated cross-sections. Therefore, we build a pseudo panel dataset for the period 1997–2019, where cohorts are defined by the date of birth of the household head as an invariant characteristic of the agents (Bardazzi and Pazienza, 2017). The data set comprises only those households whose head is between 25 and 85 years old. This truncation was implemented to eliminate those below 25 years of age, as there are very few household heads in this age group, and those above 85 years of age, in order to avoid a selectivity problem. These data are used in a dynamic pseudo panel model to estimate the short- and long-run price and tax demand elasticities of transport fuels.

In a second step – and with the aim of providing a robustness check − we pool all cross sections into a unique dataset to exploit the heterogeneity across households. We estimate a double-hurdle model to investigate the energy price and the tax component taking into account household heterogeneity and, in particular, the presence of zero observations.

4. Estimating elasticities from survey data: The pseudo panel approach

Our approach aims to empirically test whether consumers respond differently to changes in tax-exclusive fuel prices and in their fiscal component, and whether estimated demand elasticities differ in the short and in the long run, as generally found in the relevant empirical literature (Espey, 1998; Labandeira et al., 2017).

Pseudo panels are constructed using repeated cross sections in which agents share some time-invariant characteristics to form cohort-level data, where units are assumed to have similar behaviour and can therefore be aggregated into an average cell. This method has been proposed by Deaton (1985) and further developed by Collado (1997) for the dynamic models of interest in this article. To our ends, the pseudo panel allows us the identification of the patterns of transport fuel consumption behaviour in each defined cohort to be examined.

In general, it is well-known that the decision to consume energy involves also a choice to invest in capital and in a specific type of capital and a choice about the utilization rate (Medlock 2009). In the case of transport, this means that there is an investment decision to buy a car involved in the attainment of private transport services. Moreover, the transport fuel demand is affected by individuals' habits of travel, inertia, imperfect information and uncertainty causing the response to system changes – such as change in policies, personal conditions, income, prices – to adjust slowly over time. Static models do not incorporate this behaviour and therefore demand elasticities capture only short-run responses to changes in variables. The investigation of fully adjusted demand in time requires dynamic modelling strategies.

Let's assume that the transport fuel demand can be expressed as a function of the form $E_t^* = \alpha_0 P_t^{\alpha_1} X_t^{\alpha_2}$ where E^* is the 'desired' long–run quantity of fuel demanded, P is fuel price and X is a set of variables influencing demand. The parameter α_1 is the demand elasticity with respect to fuel price. This function can be approximated by the following static equation model:

$$\log E_t^* = \alpha_0 + \alpha_1 \log P_t + \alpha_2 \log X_t \tag{1}$$

where the estimated coefficient of the log price is the short-term own price elasticity. In order to capture time delays in adjusting the fuel consumption due to changes in capital stock and habit persistence a partial adjustment mechanism can be assumed in the form $(\log E - \log E_{t-1}) = \theta(\log E_t^* - \log E_{t-1})$ where $\theta \in [0,1]$ is the speed of adjustment. In the Partial Adjustment Model (PAM), a change in log demand between two periods is only part of the difference between log demand at time t-1 and log long-run desired demand E^*. By substituting equation (1) in the expression above, rearranging the terms and appending an econometric error ε, we get the following equation:

$$\log E_t = \theta\alpha_0 + \theta\alpha_1 \log P_t + \theta\alpha_2 \log X_t + (1-\theta)\log E_{t-1} + \varepsilon$$

that can be rewritten as

$$\log E_t = \beta_0 + \beta_1 \log P_t + \beta_2 \log X_t + \phi \log E_{t-1} + \varepsilon \tag{2}$$

The PAM model is summarized by this equation where β_1 is the short-run price elasticity while the long-run elasticity is computed by dividing this parameter by the estimated coefficient of the lagged energy consumption. In our paper we split the fuel price in two components: the fuel production price and the fiscal component, therefore equation (2) is modified as

$$\log E_t = \beta_0 + \beta_1 \log Penergy_t + \beta_2 \log tax_t + \beta_3 \log X_t + \phi \log E_{t-1} + \varepsilon \tag{3}$$

Our main parameters of interests are the demand elasticities with respect to the pre-tax price and the tax burden on the transport fuel. This dynamic model is considered as very simple, somewhat ad hoc (Ryan and Plourde, 2009) and has been applied in several empirical analyses of energy demand since the 1970s (among others Houtthakker et al. 1974, Berndt et al. 1981). However, this approach is still widely applied in modelling the dynamics of single-equation energy demand models because of its practical advantages and parsimonious specification, allowing to represent reality with a simple empirical implementation involving few key parameters (Basso and Oum, 2007). Indeed, although more flexible specifications with multiple lags of dependent and independent variables have been implemented, in her review Espey (1998) finds that there is no significant difference between estimates of PAM and more complex dynamic models while Goodwin et al. (2004) find differences but with no systematic patterns. In the research field of transport, a dynamic pseudo panel model has been applied to study the determinants of car ownership (Dargay, 2007; Song et al.,

2021) and the demand of public transport (Tsai et al., 2014).

4.1. The dynamic pseudo panel model: Specification and econometric approach

For the dynamic pseudo panel demand model, we assume an adjustment mechanism to explain the fuel consumption of cohort c in time t for each fuel j as:

$$Fuel^{j}_{c,t} = \theta f\left(TE_{c,t}, Penergy_{t}, tax_{c,t}, X_{c,t}\right) + (1-\theta) Fuel^{j}_{c,t-1}$$

Therefore, our basic estimated equation is:

$$\log Fuel^{j}_{c,t} = \beta_0 + \beta_1 TE_{c,t} + \beta_2 \log Penergy_{t} + \beta_3 \log tax_{c,t} + \beta_4 \log X_{c,t} + \phi \log Fuel^{j}_{c,t-1} + \varepsilon_{c,t} \quad (4)$$

where β_2 and β_3 are short-term price and tax elasticities while the long-run elasticities are computed as the parameters divided by $(1-\phi)$. As for the price $Penergy_t$, we have chosen to use the oil price to avoid an endogeneity problem, while the fiscal component is the sum of regional and national excises in real terms.[10] As a proxy for income, which is not available in our data, TE in equation (5) is the total equivalent expenditure in real terms.[11] The presence of children in the family, the generation of the householder and the level of education – defined as having a university degree – are among the few variables which are relevant at the cohort level and are considered in $X_{c,t}$. Table 1 presents the descriptive statistics of the variables used in the model. Cohort means of all relevant variables by age of household head are calculated for all years and represent the elementary observations of the model.

The estimation of the dynamic pseudo panel model poses specific problems compared with genuine panel models. Indeed, in contrast to true panel data where the unobserved individual effect is fixed, the average unobserved group effect is time-varying in addition to the unobserved time-invariant variables at the cohort level. Therefore, the transformation used in the fixed effects estimation cannot eliminate the time-varying group effects, and thus the coefficients will be biased.

To address these problems, we use the system Generalised Method of Moments estimator (GMM-SYS) (Blundell and Bond, 1998) because of its ability to deal with the endogeneity between the lagged dependent variable and the error terms, and because previous studies suggest it is a suitable estimator for pseudo panels under certain conditions (Inoue, 2008). In particular, the cohort size should be large relative to the number of cohorts and the time periods in order to have adequate cohort-specific variability in the data. The GMM estimator could suffer from the proliferation of instruments and serial autocorrelation of errors. To test for over-identification of the model, we run the Hansen test and determine the appropriate set of instruments by limiting the number of lags of the endogenous independent variables. We also check the absence of second-order autocorrelation in the transformed idiosyncratic errors using the Arellano-Bond test.

4.2. Results of the dynamic pseudo panel model

Table 2 presents the results of the dynamic model following equation (4). Overall, the p-values of the Hansen test reveal that the results are statistically significant. The coefficient of the lagged dependent variable captures the temporal effects of travellers' demand adjustment: the higher the parameter, the longer the time needed for households to fully adjust their private transport behaviour. As a result, the value of the long-run elasticities will be higher because the fuel demand is largely influenced by travellers' habits, location and other factors that households cannot easily change in the short run. In our estimated model, the lagged dependent variable has a positive sign and is statistically significant only in the case of gasoline, indicating that the fuel demand dynamic is path-dependent and exhibits a consumption persistence. For the other explanatory variables, the income elasticity – measured using total equivalent expenditure as a proxy – is positive, as expected, although lower than 1 for both fuels. Faiella and Lavecchia (2023) using a similar technique on Italian data for transport fuels as a whole estimate an income elasticity of 0.547, apparently driven mainly by the demand for diesel. Demographic variables, such as the birth cohorts and the educational level of the householder, play a more (statistically) significant role for the demand of gasoline. The older generations show a higher demand with respect to younger cohorts, as found in previous studies (Bardazzi and Pazienza, 2018). The higher average educational level of the household heads has the effect of reducing the gasoline demand while having children in the family increases the use of private transport regardless of the two fuels. Finally, the age of the householder is negatively significant thus confirming the findings of the literature on the key role of this demographic variable when considering energy related choices (Chancel, 2014; Bardazzi and Pazienza, 2018).

The results concerning our variables of interest are the estimated price and tax elasticities, both in the short and in the long-run. The dynamic pseudo panel model confirms that the tax elasticities of both fuels are higher than the net-price elasticities. This result is in line with similar findings in the (sparse) literature on the price and tax elasticities of energy consumption, both for households (Labandeira et al. 2017; Rivers and Schaufele, 2015 for Canada; Davis and Kilian, 2011, Li et al., 2014, and Tiezzi and Verde, 2019 for the United States; Andersson, 2019 for Sweden) and for industry (Arnberg and Bjorner, 2007; Bardazzi et al., 2009). Therefore, also

[10] In economies where oil supply can follow changes in domestic demand, an endogeneity problem between the consumed quantity and the energy price may arise because market prices can adjust to the new equilibrium. Therefore, although we have assessed that this type of endogeneity problem is not relevant for our case, we have chosen to use international oil prices for our model.

[11] We use the square-root equivalence scale to equivalize the total expenditure and the consumption deflator (base year 2015) to deflate it.

Table 1
Pseudo panel descriptive statistics.

	Obs.	Mean	Std. Dev.	Min.	Max
Gasoline consumption (quantity per adult)	1,403	412.7	187.4	63.2	1032.4
Diesel consumption (quantity per adult)	1,403	134.0	103.1	0.0	423.0
Total household expenditure (per adult eq.) (deflated)	1,403	20685.8	2429.9	14243.2	28912.4
Oil Price, deflated	1,403	0.309	0.122	0.095	0.544
Total gasoline excise taxes, deflated	1,403	0.693	0.049	0.608	0.759
Total diesel excise taxes, deflated	1,403	0.541	0.065	0.453	0.620
Age of the household head	1,403	55	17.613	25	85
Educational level of the household head	1,403	0.108	0.060	0.000	0.298
Minors	1,403	0.342	0.380	0.000	1.334

Source: Authors'.

Table 2
Dynamic pseudo panel model – GMM.

	Gasoline	Diesel
Lagged consumption	0.410***	0.030
	(0.037)	(0.062)
Total equivalent expenditure (real, log)	0.114***	0.548***
	(0.040)	(0.095)
Oil price (real, log)	−0.073***	−0.143***
	(0.006)	(0.010)
Excise taxation (real, log)	−0.826***	−0.601***
	(0.036)	(0.055)
Birth cohort after 1990 (reference: before 1949)	−0.116***	−0.005
	(0.031)	(0.060)
Birth cohort 1970–89 (reference: before 1949)	−0.067**	0.058
	(0.027)	(0.052)
Birth cohort 1950–69 (reference: before 1949)	−0.072***	−0.054*
	(0.017)	(0.032)
Education level	−0.129***	−0.020
	(0.022)	(0.041)
Minors	0.028***	0.061***
	(0.006)	(0.013)
Age of household head	−0.016***	−0.031***
	(0.002)	(0.005)
Age of hh (squared)	0.0001***	0.0003***
	(0.000)	(0.000)
time	−0.003**	0.025***
	(0.001)	(0.003)
Constant	2.596***	0.613
	(0.412)	(0.821)
Number of observations	1,322	1,319
Number of instruments	80	80
Hansen (p-value)	60.98 (0.684)	60.80 (0.690)
AR(1) (p-value)	−6.74 (0.000)	−3.48 (0.000)
AR(2) (p-value)	−1.64 (0.100)	−2.39 (0.017)
Long-run price elasticity	−0.124	−0.147
	(0.015)	(0.011)
Long-run tax elasticity	−1.399	−0.619
	(0.046)	(0.034)

Standard errors in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Italian households exhibit a stronger behavioural response to the change in the fiscal component of the energy gross price, particularly in the case of gasoline demand. If we look at the long-run elasticities, this difference is confirmed. Moreover, as expected, the long-run parameters are significantly higher than the short-run particularly for the gasoline model as the coefficient of the lagged consumption is positive and larger than for diesel. Therefore, the gasoline demand is very elastic in the long-term to changes in the excise taxes as consumers adapt to system and capital stock changes. Similar results are obtained for Italy by Faiella and Lavecchia (2023) although they do not distinguish between transport fuels and the net price and tax elasticities. These findings have noteworthy implications for climate change policies as energy taxes show a significant potential in affecting private transport fuel consumption.

5. A robustness check using micro data: A double hurdle estimation

As a robustness check, in this section we exploit the microeconomic data to verify whether the result of higher reactivity to taxes with respect to prices is confirmed when household heterogeneity is considered. In particular, we think that the use of microdata allows us to take into account the high share of zero expenditure in transport fuel demand. In our dataset, on average, about 30 % of Italian households report a zero expenditure on transport fuels, and this share shows a vivid response to oil prices changes (Fig. 2), albeit with a slightly increasing trend over the period 1997–2019. The zero expenditure may be due to the short data collection period (14 days), the fact that the household does not own a car or, even if it does, chooses not to use it (Bardazzi and Pazienza, 2018). In fact, fuel consumption data can be considered as a zero-inflated variable and therefore requires a special treatment.

Because of this high share of zero expenditures, we use a double hurdle model (Cragg, 1971) to study the decision to buy transport fuels.[12] Therefore, there are zero observations in both steps (hurdles): in the first step (participation), when consumers decide whether to buy a vehicle, and in the second step when they can decide the intensity of use − how much to spend on buying fuel − once they are in the private mobility market. These two decision steps are formalized as in Bardazzi and Pazienza (2018): the first one is the probability of participating in the private mobility market whereas the second step is the consumption decision. The model is described in the Appendix A with the detailed tables of results. Besides several socio-economic characteristics of the households that influence their fuel consumption, the variables of interest of this paper – the tax-exclusive fuel price and its fiscal component – are included in the set of covariates. In order to appreciate the effect of a variable we should consider both stages of the estimation, so we look at the marginal effects, as shown in Table 3.

As we are interested in the valence of the fuel tax rate as a policy signal, separately from the effect of the net fuel price, we focus on the two distinct elasticities, taking in consideration the ample variability of households' characteristics. Results show that the excise marginal effect (−0.524 for gasoline and −0.079 for diesel) is higher than that of the before tax price (respectively −0.013 and −0.048) and both are negatives, as expected. This confirms our previous finding of a differentiated influence of tax policy with respect to prices, as discussed in section 4.[13] This model estimation considers several specific characteristics such as income effect (approximated by total household expenditure) and detailed socio-demographic characteristics such as gender (confirming a higher level of fuel consumption by male householder), type of family (single parent households are those who consume the most of gasoline for private mobility), education level and the condition of monthly income earner (as for pensioners and employees) exhibit a positive effect and possibly contribute also as an additional proxy of income and wealth. Other relevant characteristics for transport choices, such as living in a metropolitan area, owing a motorbike and using public transport, exert a negative influence on private mobility fuel consumption, even if less clear for the diesel case. Also cohort and age effects confirm their key role as in previous estimations on similar data (Bardazzi and Pazienza, 2017 and 2018 for Italy; Chancel, 2014 for France). As for gasoline consumption, given all other variables at mean values, age has a clear linear effect on fuel consumption (with the youngest householders consuming more), while the cohort effect is non-linear, with a peak for the baby-boom generation. For diesel, a similar but less clear pattern can be observed for age, with a peak for the post-baby-boom generation. This is consistent with the time pattern of diesel penetration in Italy for private cars, which became noticeable after 2000, and therefore this fuel is less usual among the older cohorts.[14]

6. Conclusions and policy implications

In 2022, transport accounted for 12.5 % of household total expenditure in the EU-27, more than half of which devoted to the operation of personal transport, including fuel expenditure (Eurostat, 2024). More generally, the transport sector is responsible for about 25 % of total greenhouse gas emissions in the EU and cars accounted for 43.9 % of these emissions in 2019 (EEA, 2022). Therefore, private mobility generates a cost burden for the individual but also for the society, in terms of externalities on health, emissions and pollution. Fuel taxation aims to put a price on these externalities and is one of the instruments on transport use that is considered in the literature to be more efficient than instruments limiting vehicle ownership and purchase (He and Kim, 2024). Empirical evidence indicates that consumers react more strongly to an increase in the tax component of the final fuel price, even though it has the same effect on household budgets as a similar change in the net price. This response can be rationalized because fuel tax changes may be perceived as more permanent than the oil price fluctuations, as they are implemented with a wide news coverage thus having a higher saliency and signalling effect on consumer behaviour because of a tax aversion effect. Our work gives a contribution to the empirical literature in this field as this important characteristic of differentiated behavioural reaction to price components has never been studied for Italy. We use microdata of household's expenditures enriched with information on fuel prices and taxes for the period 1997–2019 to build a pseudo panel to estimate the effect on fuel demand pattern in time. The estimated dynamic model provides robust evidence that consumers respond differently to changes in pre-tax fuel prices and in their tax component, and that the estimated long-run demand elasticities are larger than the short-run ones, as it is generally the case in the relevant empirical literature. For example, the estimated short-run elasticities indicate that a 5-cent increase in the price of gasoline reduces the demand by 2.8 per cent, while the same increase in the tax rate reduces the quantity by 5.6 per cent. These values are consistent and very similar to those highlighted in the international literature (Rivers and Schaufele, 2015). These findings are

[12] This model is suitable for our purpose because it considers that households may decide not to consume a goods for reasons not only linked to income but also to preferences.

[13] It's worth emphasizing that, similarly to the case of the pseudo panel, these results do not depend on the specification of the tax rate component or of the equation: using a log-linear equation or a definition in terms of the tax-price ratio instead of the logarithm of the tax rate leads to the same results in terms of signs and the difference between the two elasticities. Results for alternative specification are available upon request.

[14] In Italy, the share of diesel cars in the total passenger car fleet increased from 15% in 2000 to 48,8% in 2022 due to improved fuel efficiency of diesel engines and lower excise rate with respect to gasoline excise rate. However, the share of diesel cars in new car registrations is decreasing since 2015.

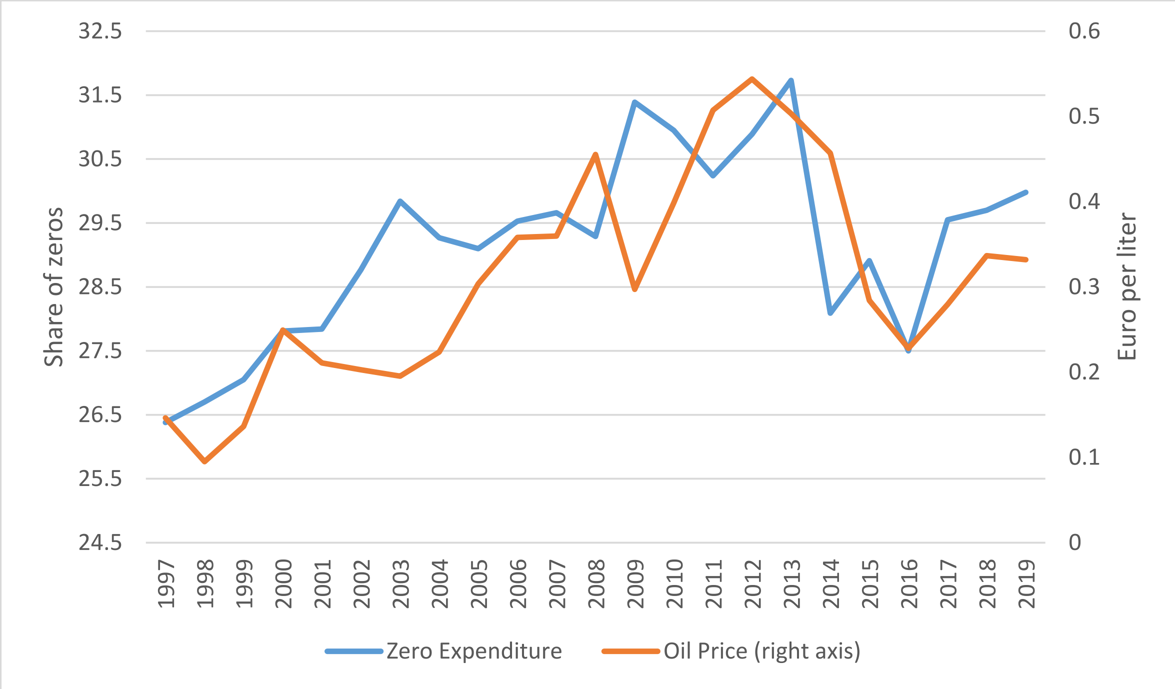

Fig. 2. Fuels zero expenditure share and oil price .
Source: IHBS and Unione Petrolifera

validated by a cross-sectional analysis that exploits the heterogeneity of the dataset by estimating a double hurdle model of gasoline and diesel household consumption. The smaller effect of fuel prices net of taxes compared to the tax components is confirmed after controlling for several socio-demographic variables and taking into account the high share of zero expenditure.

These results have very relevant implications for both scientific research and public policy. Firstly, assessing the impact of a fuel tax change on the basis of the final price elasticities may actually underestimate the behavioural response of consumers. Secondly, although some studies based on aggregate data show that fuel taxes have a moderate impact on total GHG emissions (for a recent survey and estimation see Ptak et al., 2024), empirical research using microdata at the national level suggests a higher potential of this tool to curb the negative effects of private transport, as confirmed by our estimation results for Italy. This effectiveness of environmental taxes could be crucial in accompanying consumers along the treacherous path of energy transition, which in the transport sector will require important investments in new, more efficient and less carbon-intensive vehicles. However, given the very high level of taxation on transport fuels in Italy, it is not plausible to envisage a further increase. Rather, it would be preferable to move towards a carbon tax in order to make this instrument compatible with the EU ETS in Italy. Considering the adverse distributional implications and the likelihood of increasing energy and transport poverty, a broader policy perspective is needed: this perspective should include the availability of different types of vectors in shared modes, together with significant investments in public transport. All these paths imply a major change in current consumption habits. The issue is therefore of particular interest in Italy, where the choice of vehicle for private mobility is still considered a sign of social status and self-image, and where the penetration of electric vehicles is among the lowest in Europe.

Funding

This work was supported by the Italian Ministry of University and Research (Projects of Major National Interest 2022, grant number 2022ZHR8WC) and by the European Union – NextGenerationEU, project GRINS – Growing Resilient, INclusive and Sustainable GRINS PE000018 – CUP C93C22005270001. The views and opinions expressed herein are solely those of the authors and do not necessarily reflect those of the Italian Ministry of University and Research and of the European Union, nor can they be held responsible for them.

CRediT authorship contribution statement

Rossella Bardazzi: Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maria Grazia Pazienza:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Table 3
Marginal effects of double hurdle estimation (2002–2019).

	Gasoline			Diesel		
	dy/dx	z	P>z	dy/dx	z	P>z
Oil price (deflated, log)	−0.013	−3.49	0.000	−0.048	−20.260	0.000
Tax rate (deflated, log)	−0.524	−32.32	0.000	−0.079	−9.320	0.000
Household total expenditure (equiv., defl., log)	1.654	33.57	0.000	0.573	15.930	0.000
Household total expenditure square (equiv., defl., log)	−0.071	−28.63	0.000	−0.024	−13.160	0.000
Gender (male = 1)	0.763	45.26	0.000	0.562	41.540	0.000
Type of family (ref. Couple with children)						
Single person	−0.851	−40.34	0.000	−0.597	−35.740	0.000
Couple without children	−0.103	−5.84	0.000	−0.206	−13.600	0.000
Single parent	0.402	15.21	0.000	−0.044	−1.710	0.088
Other types	−0.145	−5.07	0.000	−0.255	−0.060	0.954
University degree (yes = 1)	0.199	10.07	0.000	0.175	0.000	1.000
Employee or Pensioneer status (yes = 1)	0.022	6.19	0.000	0.013	0.000	0.997
Geographic area (ref. Centre)						
North	−0.139	−8.55	0.000	−0.138	−9.720	0.000
South	−0.128	−7.68	0.000	−0.329	−22.890	0.000
Motorbike owner (yes = 1)	−0.090	−35.8	0.000	−0.029	0.000	1.000
Public Transport expenditure (equiv., deflated)	−0.017	−40.79	0.000	−0.008	−26.570	0.000
Metropolitan Area (yes = 1)	−0.141	−10.22	0.000	−0.404	−33.750	0.000
Cohort (ref. Born before 1949)						
Cohort 1 (born > 1990)	−0.296	−2.57	0.010	0.166	1.850	0.065
Cohort 2 (born 1970–1989)	−0.050	−1.52	0.128	0.396	14.950	0.000
Cohort 3 (born 1950–1969)	0.173	7.44	0.000	0.290	15.020	0.000
Age of the householder (ref. Aged more than 75)						
Aged between 25 and 34	1.758	41.54	0.000	1.008	26.930	0.000
Aged between 35 and 59	1.498	53.81	0.000	1.043	38.860	0.000
Aged between 60 and 74	1.161	65.68	0.000	0.849	44.710	0.000

Source: Authors'.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2024.104391.

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