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# Price and income elasticities of demand for passenger transport fuels in Spain. Implications for public policies

Desiderio Romero-Jordán [a], Pablo del Río [b,*], Marta Jorge-García [c], Mercedes Burguillo [d]

[a] Universidad Rey Juan Carlos, Madrid
[b] Institute for Public Goods and Policies (IPP), Consejo Superior de Investigaciones Científicas (CSIC), C/Albasanz, 26-28, Madrid 28037, Spain
[c] Universidad de León, Spain
[d] Universidad de Alcalá, Spain

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ABSTRACT

The significant increase in passenger transport activity (cars) experienced by Spain and its associated increase in energy consumption have several associated negative aspects, including a greater dependence on foreign energy sources and higher GHG emissions. Therefore, reducing the level of transport activity would bring important socioeconomic and environmental benefits. The aim of this paper, which focuses on energy consumption in the passenger transport, is fourfold: (1) to provide a diagnostic of energy consumption in the Spanish passenger transport system and the related problems; (2) to develop a model to calculate price and income elasticities of demand for transport fuel; (3) to apply this model to the Spanish passenger transport sector; (4) to infer policy recommendations derived from the results of the diagnostic and the model. It is claimed that, in view of those low price elasticities and high income elasticities and if a reduction in the scale of transport activity is deemed socially desirable, a combination of instruments is necessary. Fuel taxes play an important role within this combination. Apart from their long-term effects, the low price elasticity of demand for transport fuel would allow the collection of a significant amount of revenues, which could eventually be earmarked to encourage reductions in private transport demand and modal shifts with other instruments.



## 1. Introduction

Passenger transport activity has its pros and cons. While mobility is a crucial feature of our modern societies and lifestyles and transport is highly relevant for economic development and individual and collective welfare, it can also be blamed for its contribution to some problems, including emissions of global and local pollutants, traffic congestion, material costs and fatalities due to accidents and foreign energy dependence.[1]

The level and trends of fuel consumption in passenger transport plus the reliance on fossil fuel energy sources for energy consumption in this sector is allegedly a major concern nowadays in many countries, especially for their contribution to the problems of security of supply and $CO_2$ emissions.

Although there are alternatives to oil, such as biofuels, they still represent a negligible fraction of total fuel consumption in this sector and they are likely to remain a small share in the near and medium term (IEA, 2008).[2] Thus, reducing oil consumption is inescapable in order to reduce the associated energy dependence and climate change problems.

Therefore, a reduction of fuel consumption in the transport sector is likely to be a policy priority for governments all over the world. This is also the case of Spain, a country which is far from complying with its Kyoto Protocol targets and whose oil dependency in the transport sector is as high as 99%.

Several policies have been suggested to encourage the technological and behavioural changes leading to a reduction in fuel consumption in transport. Economists have highlighted the role of economic instruments, namely fuel taxes, on the grounds of economic efficiency. However, their effectiveness might be limited, especially in the short term, if the price elasticity of

* Corresponding author.
*E-mail addresses:* desiderio.romero@urjc.es (D. Romero-Jordán), pablo.delrio@cchs.csic.es (P. del Río), martajorgeg@gmail.com (M. Jorge-García), mercedes.burguillo@uah.es (M. Burguillo).

[1] According to Mendiluce (2008), environmental and non-environmental externalities from transport could represent 10% of GDP in Spain. Accidents is the most expensive externality from transport (17 600 M€/year), followed by negative effects on air quality (6816 M€/year) and climate change (5993 M€/year).

[2] Biofuels represented only around 1.5% of total road transport fuel demand worldwide in 2006 and this share is expected to rise up to 5% in a reference scenario, according to IEA (2008). A target of 10% of biofuels in fuel consumption in transport has been set for 2020 in Europe.

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demand is low and the income elasticity of demand for transport fuel is high, which is generally the case. Therefore, although necessary, the price signal may be insufficient by itself to induce significant changes in passenger transport demand. This calls for a combination of instruments in order to reduce the "scale effect" of transport (i.e., the level of transport activity). Our starting point is that an analysis of elasticities is crucial to propose an appropriate combination of policy measures. We focus on passenger transport and its activity and on fuel consumption and not only GHG emissions reductions as it is frequently the case. This is so because, from the perspective of Spain, a major oil importer, reducing energy dependency is a policy goal at least as important as curbing the growth of GHG emissions. This is also the case in most European countries.

However, our analysis does not allow us to state whether reductions in transport activity or technological changes are preferable from a social perspective in order to reduce the negative externalities from private transport. In addition, if fuel taxes are deemed an appropriate instrument, we cannot tell what its level should be. The policy question this paper tries to answer is a different one: if reduction in transport activity levels is deemed socially desirable, what measures should be implemented, taking into account the aforementioned elasticities, and what should be the role of fuel taxes?

More specifically, the aim of this paper is fourfold: (1) to provide a diagnostic of energy consumption in the Spanish passenger transport system and the related problems; (2) to develop a model taking an Almost Ideal Demand System (AIDS) specification as a basis to calculate price and income elasticities of demand for transport fuel; (3) to apply this model to Spain, through the Continuous Family Budget Survey database; (4) to infer policy recommendations derived from the results of the diagnostic and the model.

Accordingly, the paper is structured as follows. Section 2 provides a brief description of the situation and trends of energy consumption in the Spanish passenger transport sector and discusses the driving factors of energy consumption in this sector. In Section 3 we develop an econometric model which allows us to identify the price and income elasticities of demand for transport fuel. This model is applied to Spain in Section 4. We then identify the policy implications of those results (Section 5). The paper closes with some concluding remarks.

## 2. Diagnosing the illness. Fuel consumption in the Spanish passenger transport sector: situation, trends, drivers and associated problems.

Spain provides a good example of the policy challenge associated to fuel demand reductions in the passenger transport sector, in a context of strong growth of this demand. This section provides an overview of the Spanish passenger transport sector with respect to energy consumption patterns and trends, including their drivers and the associated problems in terms of GHG emissions and energy dependence of the Spanish economy. The EU is used as the yardstick to which the Spanish case is compared to. Official data sources from the European Environmental Agency, Eurostat and the Spanish Ministries of the Environment and Promotion are used.

### 2.1. Trends and situation of fuel consumption in the Spanish transport sector.

The Spanish transport sector has experienced a significant increase in final energy consumption compared to the EU-27 (82% over the 1990–2005 period versus 32% in the EU). In turn, the share of transport in total final energy consumption is relatively high (41% versus 31% for the EU on average in 2006). Only 3 (very small) countries show a larger share of transport in final consumption (Luxembourg, Malta and Cyprus) (EC, 2009).

Road transport accounted for 79.7% of the 40,650 ktoe consumed in 2006 by the transport sector (versus 82% in the EU), followed by air (13.7%), sea (4.1%) and rail (2.7%). Annual average growth rates of energy consumption of different transport modes over the period 1990–2005 were: road (3.9%), air (5.3%), sea (−0.5%) and rail (5.4%) (Spanish Government, 2009).

### 2.2. Why are these trends problematic in terms of energy dependency and $CO_2$ emissions?

As a result of the increasing consumption of energy in the transport sector and its dependence on oil, this fuel has experienced a substantial increase in its share in final energy consumption (1990 = 100, 2005 = 175). Transport accounted for 45% of total oil consumption in 2005 versus 39% in 1990 (Mendiluce, 2008). Passenger transport accounts for 15% of total final energy consumption in Spain (Sauret, 2008).

Oil import dependency in Spain is high above the EU (100% versus 83%) (European Commission, 2009). Oil imports amounted to 78 million tonnes of oil equivalent (MTOE) in 2005, almost two thirds of total energy imports. This is particularly worrying in a context of increasing oil prices.

On the other hand, total GHG emissions in Spain had increased by 50.6% in 2006 with respect to 1990 levels, making it difficult to reach its Kyoto Protocol target (a 15% increase between 2008–2012 and 1990). This is partly explained by the substantial increase in GHG emissions in the transport sector (89% in 2006 with respect to 1990), which are projected to rise by 93% in 2010 (EEA, 2008). This is in sharp contrast with the EU-27 increase of 27% and expected rise by 29%. Whereas transport accounted for 25.4% of total GHG emissions in Spain in 2006, this percentage was significantly lower in the EU-27 (19.3%). Road transport accounts for 89.2% of total GHG emissions in transport. The rest is accounted for aviation (6.6%), sea (3.9%) and rail (0.3%).[3]

### 2.3. What factors are behind the trends and situation of fuel consumption in the Spanish transport sector?

This subsection provides a diagnostic on the main factors influencing energy consumption and $CO_2$ emissions in the passenger transport sector in Spain. The focus is mostly on road transport since it is relatively energy intensive, the main mode of passenger transport and the one, together with aviation, with the highest growth rates (see below).

#### 2.3.1. Drivers of energy consumption in passenger transport.

Any policy aiming to control energy consumption in the transport sector should consider the following drivers[4]:

[3] Per type of vehicle, private vehicles account for 53% of road transport $CO_2$ emissions, whereas the share of heavy vehicles (trucks and buses) and light vehicles is 33% and 13%, respectively. Per driving pattern, half of road transport emissions take place in high-speed roads (preferably interurban trips), whereas urban trips account for 36% of those emissions (Spanish Government, 2009).

[4] A useful approach in this context is the Kaya decomposition, which has been applied in the past to analyse the drivers to $CO_2$ emissions at the aggregated level (i.e., a whole economy) or in the transport sector (see Tarancón and Del Río, 2007) (see, for example, Schmutzler, 2005; Holden and Høyer, 2005). Since $CO_2$ emissions and reductions in energy consumption go in tandem, this is a useful starting point (only "the carbon intensity of fuel factor" is not relevant regarding energy consumption but only concerning $CO_2$ emissions reductions).

**Table 1**
Land passenger transport activity (thousand million pass * km).

| | | Passenger cars | Bus and coach | Railway | Tram and metro | Total |
|---|---|---|---|---|---|---|
| EU-27 | 1995 | 3863 | 504 | 351 | 71 | 4789 |
| | 2007 | 4688 | 539 | 395 | 85 | 5707 |
| | % variation | 21.36 | 6.94 | 12.54 | 19.72 | 19.2 |
| Spain | 1995 | 250.3 | 39.6 | 16.6 | 4.2 | 310.7 |
| | 2007 | 343.3 | 59.1 | 21.8 | 6.4 | 430.6 |
| | % variation | 37.16 | 49.24 | 31.33 | 52.38 | 38.6 |

*Source*: European Commission (2009).

- The *scale factor* refers to the overall level of passenger transport activity (i.e., adding all modes) and depends on several variables: car ownership and car mileage, which in turn depends on the number of trips, the distance of each trip and the occupancy levels of the vehicles travelling. The use of vehicles depends on the income of individuals. In addition, structural and geographical factors affect the demand for transport services and, thus, the scale of transport activity. For example, more densely populated cities reduce the need for transport (fewer trips and shorter distances), which highlights the role of urban planning leading to more compact cities.
- The modal factor can be disaggregated into a modal share subfactor (% share of each mode) and a modal energy intensity subfactor (energy/passenger of each mode). Some passenger transport modes have higher associated energy consumption levels (private cars) than others (rail).
- A fuel efficiency factor (technological), related to specific technologies within transport modes. Within a specific transport mode, different types of vehicles can have different levels of fuel consumption per kilometre depending on the energy efficiency of the engine, the horsepower and the vehicle weight or size. The distinction between new and existing vehicles is also relevant in this regard.
- A fuel efficiency factor (behavioural). Driving patterns and other decisions of drivers influence the energy consumption of vehicles. Less aggressive driving patterns at moderate speeds and appropriate vehicle maintenance of the vehicle are associated with lower energy consumption levels.[5]

In addition to technological and behavioural changes, changes in infrastructures might be needed to tackle those factors.

We are particularly interested in the scale factor, since it is very relevant to explain the trends in energy consumption in the Spanish passenger transport.

### 2.3.2. The scale factor

Passenger transport has grown in Spain at an average annual rate of 5.3% between 1990 and 2000 and 2.1% between 2000 and 2007 (Spanish Government, 2009).[6] The journeys/distances have almost doubled between 1990 and 2006, from 192.078 to 371.140 million (passenger/km). It is also high above the trends observed for the EU-27 (Table 1). Indeed, Spain is responsible for 12% of the absolute increase in transport activity levels related to the use of cars in the EU-27 between 1995 and 2007. Passenger cars account for more than $^3/_4$ of the increase in overall transport activity in the period which brings us to the modal factor in Section 2.3.3. Interurban trips represent 50% of all trips (passenger/km), whereas urban and rural trips account for 30% and 20%, respectively (Spanish Government, 2009).

The increase in passenger transport is high above the increase in freight transport, whereas the opposite occurs in the EU, which is an additional reason for paying attention to the passenger transport sector.

Not only a significant increase in the number of private (passenger) vehicles has occurred (from 15 million in 1990 to 27 million in 2005), but the use of the car has also increased (i.e., more and longer trips). In 1990 each car travelled about 4000 km/inhabitant. This figure was near 7000 in 2005 (Monzón, 2007). In 2000 each vehicle performed 13,650 km/yr, jumping to 16,600 km/yr in 2007 (Nombela et al., 2008).

### 2.3.3. The modal factor

Road represents 90% of overall passenger transport in Spain in 2007, whereas the shares of rail and aviation are 5% each (Spanish Government, 2009). The share of road has remained constant, that of rail has declined and the share of aviation has increased.

The share of passenger cars in land passenger transport, while high, is lower than in the EU-27 (79.7% versus 82.1%), whereas the share of rail is also lower (5.1% versus 6.9%). The number of passenger cars per thousand inhabitants has significantly increased since 1990 and it is currently similar to the EU-27 average. In 1990, this figure was 309 for Spain and 348 for the EU-27. In 2006, the numbers were, 464 for Spain and 466 for the EU as a result of a 50% increase in Spain over the period and a 35% increase in the EU, respectively.

According to the last available data, the share of modes in public investments in 2007 was: rail (50.8%), road (26.8%), air (14.7%) and sea (7.7%) (Spanish Government, 2009).

### 2.3.4. The technology factor

There are significant differences with respect to the energy consumption of different types of modes and vehicles, with passenger cars showing higher energy consumption levels. Whereas the energy consumption (kg of oil equivalent/passenger/km) of private passenger cars in Spain is between 0.03 and 0.04 in the interurban mode and between 0.05 and 0.06 in the urban mode, the energy consumption of $4 \times 4$ vehicles is much greater (between 0.04 and 0.05 in the interurban mode and between 0.07 and 0.08 in the urban mode) and that of trains and buses is much lower (between 0.01 and 0.02 in the interurban mode and between 0.01 and 0.03 in the urban mode) (Monzón, 2007).

The energy intensity of different passenger transport modes has improved, but it still differs widely, with rail being the most energy-efficient and aviation the least (Table 2).

Therefore, a comparison of this data with the data in Section 2.3.2 shows that the improvement in the average fuel efficiency of

[5] Maintaining an appropriate tyre pressure, avoiding excessive accelerations and keeping car speeds within moderate limits could improve the fuel economy of cars between 5% and 20% (Gallagher et al., 2007).

[6] In contrast to the EU-27, the growth rate of passenger transport in Spain (95% accumulated between 1990 and 2004) is higher than in the freight transport (60%). The figures for the EU are, respectively, 27% for passenger transport (passenger/km) and 41% for freight transport (tonnes/km)(Monzón, 2007).

**Table 2**
Energy intensity per passenger transport mode.

| | Energy intensity (MJ/passenger-km) | | % variation |
|---|---|---|---|
| | 1990 | 2005 | |
| Road | 2.34 | 1.98 | −16 |
| Rail | 0.45 | 0.37 | −19 |
| Airplane | 13.81 | 9.24 | −33 |

*Source*: Own elaboration from Monzón (2007).

passenger road transport vehicles has been offset by an increase in the scale of transport activity.

### *2.3.5. Drivers of the scale factor.*

The scale effect is influenced by several factors, including population and economic (income) growth, the urban model, price and transport policies.

Population has increased by 14.4% between 2007 and 1990 in Spain, high above the EU average increase (4.8%). This is mostly due to the significant increase in the number of incoming immigrants, who now represent 10% of the Spanish population.

The use of transport tends to be closely related to GDP growth rates.[7] These have been about 1.5% points higher in Spain than in the EU in the 1997–2007 period. However, although increasing, the expenditure on transport by Spanish households is still below the EU average. Spanish households spend 11.8% of their total final consumption on transport (1500 €), whereas this figure is 13.6% for the EU-27 (1800 €) (European Commission, 2009).

On the other hand, relevant national legislation and official documents regarding reduction in energy consumption and $CO_2$ emissions in the transport sector in Spain include the Spanish Energy Efficiency Strategy (2004–2012) and their corresponding Action Plans, the Strategic Plan for Transport Infrastructures 2005–2020 (PEIT), the Renewable Energy Plan and the recently approved Mobility Strategy. The measures envisaged (implemented and/or planned) include information provision and training (ecodriving), public investments in public transport and financial support (subsidies) for the purchase of more efficient vehicles (RENOVE, PREVER and PLAN 2000E).

An increase in fuel taxes is not explicitly considered and the single economic instrument envisaged is higher registration taxes for the most polluting vehicles. Indeed, the relatively low fuel taxes in Spain result in lower fuel prices on petrol and diesel for passenger cars compared to the EU average (Table 3). Spain's diesel and petrol prices are below the prices in 18 Member Status.

Fuel retail prices have significantly increased since 2001, especially for diesel (Table 4). Nevertheless, diesel prices are still below petrol prices, due to the different tax treatment (the fuel tax for petrol is currently 0.432 €/l, whereas that for diesel is 0.307 €/l). A significant increase in diesel and a substantial reduction in gasoline demand can be observed.

Taxes represent a significant share in those fuel prices, although they are lower than in other EU countries, as observed by a lower final fuel price (Table 3). Table 5 summarises the main taxes affecting the private transport sector in Spain. Arguably, their purpose has been mostly to collect money and not to encourage energy efficiency in this sector. We return to this issue in Section 5.2.

[7] As people get richer, they travel more (make more trips and travel greater distances). In addition, an increase in income leads to a shift to more energy- and carbon-intensive modes of transport (changes from train to cars and from smaller to bigger cars) (Stern, 2006).

**Table 3**
Diesel and petrol retail prices in Spain and the EU (2007).

| | Petrol* | Automotive diesel* |
|---|---|---|
| EU-27 | 1.126 | 1.030 |
| Spain | 0.950 | 0.891 |

*Source*: EC (2009).

* €/l (current prices). Diesel automotive prices and unleaded petrol (95 RON) prices, all taxes included.

**Table 4**
Evolution of retail diesel and gasoline prices and consumption.

| | Prices* | | Consumption** | |
|---|---|---|---|---|
| | Diesel | Gasoline | Diesel | Gasoline |
| 2001 | 0.725 | 0.788 | 27.8 | 9 |
| 2002 | 0.654 | 0.746 | 28.7 | 8.7 |
| 2003 | 0.687 | 0.790 | 31.1 | 8.6 |
| 2004 | 0.644 | 0.740 | 33.1 | 8.2 |
| 2005 | 0.715 | 0.747 | 34.4 | 7.7 |
| 2006 | 0.795 | 0.856 | 35.3 | 7.4 |
| 2007 | 0.742 | 0.791 | 36.5 | 7.05 |
| % variation 2001–2007 | 2.314 | 0.367 | 31.2 | −21.6 |

*Source*: Own elaboration from INE's website and European Commission (2009).

* €2001/l. Diesel automotive prices and unleaded petrol (95 RON) prices, all taxes included.
** MTOE.

**Table 5**
Main characteristics of transport taxes in Spain.

| Tax | Main characteristics |
|---|---|
| (1) Registration tax | Tax rates are set according to $CO_2$ emissions per km of the vehicles ( < 120 $gCO_2$/km: exempted, between 121 and 160 $gCO_2$/km: 4.75%, between 161 and 200 $gCO_2$/km: 9.75%, > 200 $gCO_2$/km: 14.75%). The sum collected goes to regional governments. |
| 2) Circulation tax | Annual tax on vehicle ownership collected by the municipalities, who may increase/reduce the amounts to be paid according to environmental criteria. The absolute amount to be paid depends on the type of vehicles (automobiles, buses and trucks) and their horsepower. |
| 3) Fuel taxes | Fuel tax (central administration):<br>• Different fuels are taxed differently (unleaded gasoline: 371.69 €/1000 l; diesel: 278 €/1000 l).<br>• The sum collected is shared between the central government (56.75%), regions (40%) and the local administrations (3.25%).<br><br>Tax on retail sales of certain fuels (IVMDH). The regional tax rate can be set by regions within certain limits. The sum collected goes to regional governments. |

*Source*: Own elaboration from Mendiluce (2008). *Note*: In addition, transport is subject to the value added tax and infrastructure charges.

## 3. The model

### *3.1. Links to the existing literature*

There is a long tradition in the analysis of price and income elasticities for fuel demand and several overviews of the literature on this topic are available (see Graham and Glaister, 2002; Goodwin et al., 2004; Goodwin, 1992; Oum et al., 1992; Sterner et al., 1992; Espey, 1998). Price elasticities of fuel demand

**Table 6**
Elasticities of fuel consumption with respect to fuel price and income.

| Period | Average elasticity with respect to fuel price | | | Average elasticity with respect to income | | |
|---|---|---|---|---|---|---|
| | Short | Long | Static | Short | Long | Static |
| Pre-1974 | −0.29 | −0.45 | −0.56 | 0.52 | 1.28 | 0.63 |
| 1974–81 | −0.35 | −0.93 | −0.36 | 0.37 | 1.08 | 0.43 |
| Post-1981 | −0.16 | −0.43 | −0.28 | 0.38 | 1.04 | 0.14 |

*Source*: Goodwin et al (2004).

indicate the percentage reduction in fuel demand as a result of a percentage increase in fuel prices. Income elasticities refer to the percentage increase in fuel demand due to a percentage increase in income.

The conclusions are broadly similar. They show that short-term price elasticities of demand are relatively low whereas long-term price elasticities are higher (Table 6) and probably also higher for the higher-income households.[8] Whereas short-run price elasticities normally range between −0.2 and −0.3, long-run price elasticities typically tend to fall in the −0.6 to −0.8 range.[9] A recent meta-analysis of the price elasticity of gasoline demand results in mean short-run and long-run price elasticities of −0.36 and −0.81, respectively (Brons et al., 2007). In turn, income elasticities are relatively high. Therefore, fuel demand is relatively insensitive to price changes and, thus, higher income levels significantly increase transport demand, mainly covered with private transport (IPCC, 2007a).[10]

The price elasticities for fuel consumption are higher than the elasticities for vehicle-km (Goodwin et al., 2004). Two reasons may explain this: (1) price increases trigger a more efficient use of fuel; (2) with high prices, gas-guzzlers are more likely to be left at home or scrapped (op.cit.). Thus, raising fuel prices will therefore be more effective in reducing the quantity of fuel used than in reducing traffic volumes.

Several major policy implications deriving from those analysis are: (1) the higher absolute value of the income elasticity compared to price elasticity suggests that fuel prices must rise faster than income if fuel consumption is to be kept constant (Sterner et al., 1992); (2) fuel price manipulation is more effective when the objective is to decrease fuel consumption rather than road congestion (Goodwin, 1992); (3) fuel taxes alone might not be very effective in reducing the external costs of road transport; (4) the design of long-run policy instruments should take the higher long-run price elasticities into account (Brons et al., 2007).

On the other hand, the studies on the aforementioned elasticities are scarce in Spain, in contrast to the abundance of those studies in other developed countries. This paper tries to cover this gap in the literature.

An interesting study in the Spanish context is Labandeira and López (2002). Their calculations of (short term) price and income elasticities for fuel demand are, respectively, −0.08 and 0.99. The authors claim that the relatively low price elasticity of fuel demand in Spain is due to the low fuel prices in Spain,[11] but it could also be related to the different structure of models. Our results are in line with the range of estimates in other countries.

### *3.2. Theoretical background: the AIDS model*

The analysis of fuel demand from a micro perspective has intensified in the last two decades. The growing interest of economists for this approach can be explained by the fact that microdata allow us to capture the heterogeneity of households' fuel consumption decisions and the impact of key variables (including habits, place of residence, the socioeconomic status and household size) on such decisions. One of the procedures commonly used to analyse the demand for any good or service by households is the Almost Ideal Demand System (AIDS) model proposed by Deaton and Muellbauer (1980a, 1980b), which expresses the expenditure share of good $i$, $w_i$, as a function of the prices of the goods comprising the household consumption basket, $p_i$, and real disposable income. Formally,

$$w_{iht} = \alpha_{iht} + \sum_j \gamma_{ij} \log p_{jt} + \beta_i \log(X_{ht}/P_t) \quad (1)$$

where the subindex $i$, $h$ and $t$ represent, respectively, the type of good, the household and time. Also $\alpha$, $\beta$ and $\gamma$ are the parameters of the model to be estimated. Similarly, $X$ is the total expenditure of households and $P$ is a quadratic price index defined as

$$\log P = \alpha_0 + \sum_k \alpha_k \log p_k + \frac{1}{2} \sum_j \sum_k \gamma_{kj} \log p_k \log p_j. \quad (2)$$

As an alternative to this quadratic specification, Deaton and Muellbauer (1980a) suggest a linear approximation (LA/LAIDS), where the price index $P$ is replaced by the index proposed by Stone (1954)[12]

$$\log P^* = \sum_{k=1}^{n} w_{kt} \log p_{kt}. \quad (3)$$

Substituting (3) in Eq. (1), we obtain the LAIDS

$$w_{iht} = \alpha_{iht} + \sum_j \gamma_{ij} \log p_{jht} + \beta_i \log(X_{ht}/P_t^*) \quad (4)$$

$i = 1,2, \ldots, n$

The *AIDS* model may be specified as a complete demand system (see, for example, Brännlund and Nordström, 2004; Jabarin, 2005; Romero-Jordán and Sanz-Sanz, 2009) or as a uniequational model (see, for example, Filippini, 1995; Halvorsen and Larsen, 2001 and Hondroyiannis, 2004). The LA/LAIDS option

[8] This was found out in the study by Hughes et al. (2006). Van Dender (2009) argues that the share of discretionary driving is likely higher for higher-income households, and it is easier to cut back on such driving than on "mandatory" travel.

[9] Notwithstanding, the estimates depend on the method used, particularly on whether the analysis is performed with static or dynamic models and on how the model has been specified. In addition, estimates vary greatly both between and within geographical areas of study for long- and short-run elasticities.

[10] However, the role of prices should be ascertained in this context. In fact, those countries with relatively low fuel prices are also those with lower fuel efficiency levels (USA, Canada, Australia) whereas regions with high prices are also those with greater fuel efficiencies (Japan and European countries).

[11] While Goodwin et al. (2004) do not find evidence that price elasticity is related to price level, Hanly et al. (2002) do find some evidence that price elasticities are related to price level.

[12] For a critique, see Moschini and Mielke (1989), Pashardes (1993) and Buse (1994). For a discussion on the limitations, advantages and drawbacks of the AIDS model, see Deaton and Muellbauer (1980a, 1980b), Green and Alston (1990) and Alston et al. (1994).

is chosen for this paper because it allows for a better model specification and estimation. However, the main disadvantage of uniequational models is that they do not allow us to analyse possible complementarity or substitutability between the various goods comprising the household consumption basket (for a discussion see, for example, Deaton and Muellbauer, 1980a, 1980b).

Expression (4) is defined as a demand system composed of two equations, one for fuel expenditure and another for the remaining goods. However, the second equation is not estimated (in order to avoid the singularity of the error variance–covariance matrix), and a uniequational model is the result. The homogeneity restriction is achieved automatically, as fuel price is expressed in relative terms with respect to the average weighted price of the remaining goods. Thus, we consider different assumptions of separability: between the decision to consume fuel and purchase vehicles, between the labour-leisure choice and the consumption choice and between the consumption of fuel and the remaining goods (for a discussion, see Baker et al., 1989).

The calculation of the price, $\xi_i$, and income elasticities, $\eta_i$, is performed on the basis of the following expressions (see Baker et al., 1990; Haden, 1990; Abdulai and Aubert, 2004, among others)[13]:

$$\xi_i = \frac{\gamma_i}{w_i} - 1 \tag{5}$$

$$\eta_i = \frac{\beta_i}{w_i} + 1. \tag{6}$$

### 3.3. Econometric specification

The consumption patterns of economic agents are determined by their characteristics, both observable and unobservable (see Deaton, 1997; Deaton, 1997; Calvet and Common, 2000; Christensen, 2002). Following the procedure proposed by Pollack and Wales (1981), observable heterogeneity is captured through a vector of dummy variables, which reflect the socioeconomic characteristics of households. Thus, the constant term of the LAIDS model would be modified as follows:

$$\alpha_{iht} = \alpha^*_{iht} + \sum_{k=1}^{s} \rho_{ikht} d_{kht} \tag{7}$$

where $\alpha^*$ and $\rho$ are the parameters to be estimated and $d$ are the socioeconomic variables. The dummy variables used in this study are the following: household income level, size of the municipality of residence, ownership of primary and secondary residence, educational level and occupational category of the principal breadwinner and, lastly, the size, composition and principal source of household income. Similarly, a set of seasonable variables (one dummy variable per quarter) has been incorporated into the model, as well as a discrete variable, which reflects the annual tendency.

The error term is disaggregated in two components $\varepsilon_{iht}=\theta_{ih}+u_{iht}$, where $\theta_{ih}$ represents the specific individual effect of each household and $u_{it}$ is the idiosyncratic error. Parameter $\theta_{ih}$ captures unobservable heterogeneity such as consumer tastes or preferences (for a discussion, see Deaton, 1985). Consequently, equation (4) would become

$$w_{iht} = \alpha_{iht} + \sum_j \gamma_{ij} \log p_{jht} + \beta_i \log(X_{ht}/P^*_t) + \varepsilon_{iht} \tag{8}$$

It is well-known that the fixed character of the individual effect, $\theta_{ih}$, leads to the inconsistency in the parameters estimated when using Ordinary Least Squares (OLS) (Wooldridge, 2002; Baltagi, 2005). To verify the existence of fixed effects, the Hausman (1978) and Breusch and Pagan (1980) tests have been used. In case fixed effects exist, we use the within-groups estimator (for a discussion, see Deaton, 1989, 1997).

Static models implicitly accept the highly unrealistic assumption of intertemporal separability of preferences. In other words, the consumer does not make an immediate and complete adjustment to changes in prices and income (see Deaton and Muellbauer, 1980a, 1980b; Madlener, 1996; Dynan, 2000, for example). To avoid this problem, we use two alternative procedures which explicitly incorporate household demand habits for fuel (see Anderson and Blundell, 1983; Rickertsen, 1998), firstly, by using a lagged total expenditure on fuel in the demand equation (see Chen and Veeman, 1991; Blanciforti and Green, 1983; Blanciforti et al., 1986). That is to say, $\alpha_i$ is specified as

$$\alpha_{iht} = \alpha_{ih0} + \sum_{k=1}^{s} \rho_{ikht} d_{kht} + \alpha^*_i q_{ih(t-1)} \tag{9}$$

where $q_{ih(t-1)}$ is the lag of consumption of good $i$ by household $h$.

The second alternative procedure uses a vector of lagged expenditure shares, $w_i$. Essentially, this is an extension of the aforementioned procedure proposed by Pollack and Wales (see Alessie and Kapteyn, 1991; Rickertsen, 1998). Formally

$$\alpha_{iht} = \alpha_{ih0} + \sum_{k=1}^{s} \rho_{ikht} d_{kht} + \sum_{j=1}^{n} \delta_{ij} w_{jh(t-1)} \tag{10}$$

In the case of dynamic specification where habit is incorporated via a lag of the relative expenditure on fuel. Therefore, we have used, as an alternative, the Generalised Method of Moments (GMM) proposed by Arellano and Bond (1991).

Different procedures to correct for the common problems of infrequency of purchase or non-observable heterogeneity have been used in the estimation of the model. Therefore, a range of different values for those elasticities is provided.

From an econometric point of view, infrequency of purchase implies a measurement error in the dependent variable and in total expenditure (see Heien and Wessells, 1990). For this reason, the estimation by OLS leads to inconsistent estimations of the parameters of the model. In order to circumvent this problem we use two alternative procedures. Firstly, following Keen (1986), we correct the measurement error for the totality of households, by using instrumental variables in a three-stage least squares estimation procedure (see Baker et al., 1990; Nichele and Robin, 1995; Romero and Sanz, 2003). Secondly, we correct the measurement error by reducing the gap between the expenditure observed and the latent consumption for households which display positive expenditure on fuel (see Meghir and Robin, 1992). This is done by deflating the observed expenditure by the probability of purchase. Thus

$$x_{ih} = \frac{x^*_{ih}}{P_{ih}} + v_{ih} \quad \text{if } n_i > 0 \tag{11}$$

$$x_{ih} = 0 \quad \text{if } n_i = 0$$

where $x_{ih}$ is the observed expenditure, $x^*_{ih}$ the latent consumption, $n_i$ the number of observations with positive expenditure and $p_{ih}$ the probability of purchase. The demand system to be estimated would be

$$w^k_{iht} = \frac{x^{*k}_{iht}}{X^{*k}_{ht}} = \alpha_{iht} + \sum_j \gamma_{ijht} \log p^k_{jt} + \beta_i \log(X^{*k}_{ht}/P^k_t) + \varepsilon^k_{iht} \tag{12}$$

[13] For a discussion of such expressions, see Green and Alston (1990, 1991), Alston et al. (1994) and Buse (1994).

where $k$ denotes the subsample for which $w^k_{iht} > 0$ and $\varepsilon^k_{iht}$ is the error term.[14]

## 4. The empirical study

### 4.1. Data

We use the Continuous Family Budget Survey database (ECPF, in its Spanish initials), which provides quarterly data on automotive fuel consumption by families (INE, various years). ECPF provides household socioeconomic information, such as expenditure on the consumption of goods and services, place of residence, employment status, size of the family and economic status of the principal breadwinner. The estimation period runs from the first quarter of 1998 to the fourth quarter of 2001. For this period, a rotating panel is available (e.g., households collaborate for eight consecutive quarters), which includes interviews with approximately 3200 households in each quarter.

### 4.2. Descriptive statistics

Table 7 summarises the share of fuel expenditure in total household expenditures in the aforementioned period, according to household location, expenditure deciles, number of household members, economic situation of the household, occupational category and educational level of the principal breadwinner. The table distinguishes between the totality of households (total sample) and those owning a car (positive subsample). The information allows us to infer the following conclusions:

I. As expected, the relative expenditure on fuel in rural areas is higher than in urban zones.
II. In the total sample there is a positive monotonic relation between household size and the share of fuel expenditure in total household expenditures. Such a relation does not exist in the positive subsample (i.e., individuals in the sample who own a car). In fact, households of two to six members owning a car consume, in relative terms, less fuel than single-person households.
III. The weight of fuel in the household consumption basket increases with the level of expenditure in the total sample, whereas it decreases in the positive subsample.
IV. The expenditure on fuels is quite relevant for all households. Even half of those not owning a car spend more than 1% of their budget on fuel.
V. Those owning a car spend considerably more on fuels. Thus, if provided with a cheaper alternative, which offsets the advantages in terms of comfort of the private car, those households might be willing to shift their transport mode.
VI. In relative terms (i.e., compared to their total expenditure), households whose family head is an employer or has a university degree spend less on fuel than those in which the head is an employee or has only primary or secondary education. However, the former spend more in absolute terms. The differences are, on average, statistically significant.

[14] The probability of purchase, $P_{ih}$, is defined as the quotient of the number of positive expenditures undertaken by the household multiplied by the number of quarters in which it has collaborated in the survey in annual terms (Labeaga and López, 1997).

**Table 7**
Average share of fuel expenditures in household budgets 1998–2001 (%).

| Sample | *Total sample* (a) | *Positive subsample* (b) |
|---|---|---|
| **Area of residence** | | |
| Provincial capital municipality | 1.89 | 7.63 |
| Non-capital municipality > 1,000,000 inhabitants | 2.18 | 7.88 |
| 50,000 inhabitants < non-capital municipality < 100,000 inhabitants | 2.30 | 8.46 |
| 20,000 inhabitants < Non-capital municipality < 50,000 inhabitants | 2.31 | 8.73 |
| 10,000 inhabitants < municipality < 20,000 inhabitants | 2.29 | 8.68 |
| Municipality < 10,000 inhabitants | 2.31 | 9.76 |
| **Number of household members** | | |
| 1 | 0.60 | 12.09 |
| 2 | 1.59 | 8.23 |
| 3 | 2.45 | 8.42 |
| 4 | 2.63 | 8.28 |
| 5 | 2.84 | 8.35 |
| 6 | 3.02 | 8.65 |
| 7 | 3.16 | 9.02 |
| 8 | 3.60 | 9.50 |
| **Expenditure deciles*** | | |
| 1 | 0.03 | 9.71 |
| 2 | 0.10 | 9.17 |
| 3 | 0.29 | 8.93 |
| 4 | 0.61 | 8.64 |
| 5 | 1.03 | 8.48 |
| 6 | 1.87 | 8.26 |
| 7 | 2.94 | 8.26 |
| 8 | 4.07 | 8.11 |
| 9 | 5.07 | 7.76 |
| 10 | 5.32 | 7.04 |
| **Economic situation of the household** | | |
| Principal breadwinner and partner employed, other household member employed | 3.44 | 9.38 |
| Only principal breadwinner and partner employed | 2.64 | 8.50 |
| Principal breadwinner or partner employed, other household member employed | 3.04 | 8.76 |
| Principal breadwinner or partner employed, no other household member employed | 2.34 | 8.53 |
| Neither principal breadwinner nor partner employed, at least two other household members employed | 3.02 | 8.69 |
| Neither principal breadwinner nor partner employed, other household member employed | 2.47 | 8.03 |
| No household member employed | 1.10 | 7.86 |
| **Occupational category of principal breadwinner** | | |
| Employer | 2.36 | 7.98 |
| Employee | 2.20 | 8.38 |
| **Educational level of principal breadwinner** | | |
| Primary and secondary | 2.18 | 8.55 |
| University degree | 2.28 | 7.93 |

* In ascending order with respect to the share of fuel expenditures in total expenditures.

### 4.3. Econometric estimates: main results

The following two tables show the results of the long-run price and income elasticities of demand in Spain, estimated according to the methods developed in Section 3 and using the aforementioned data (Tables 8 and 9).

The results are within the ranges of the studies found in the literature, although income elasticities are closer to the upper bound and price elasticities are lower than those ranges (i.e., greater absolute value) (see Romero-Jordán and Sanz-Sanz, 2009). Estimates vary according to the correction method used to deal

**Table 8**
Marshallian own-price elasticities

| **Model** (estimator) | **Correction method for infrequency of purchase** | |
|---|---|---|
| | **Keen** | **Meghir–Robin** |
| 1. Dynamic with lag of total expenditure on fuel (within-group) | −0.4748* | −0.6449* |
| 2. Dynamic with lagged budget shares (within-group) | −0.4561* | −0.6405* |
| 3. Dynamic with lagged budget shares (GMM) | −0.3295* | −0.7571 |

* Significant at 1% confidence level.

**Table 9**
Expenditure elasticities.

| **Model** (estimator) | **Correction method for infrequency of purchase** | |
|---|---|---|
| | **Keen** | **Meghir–Robin** |
| 1. Dynamic with lag of total expenditure on fuel (within-group) | 1.3564* | 1.05,754* |
| 2. Dynamic with lagged budget shares (within-group) | 1.36,104* | 1.05,784* |
| 3. Dynamic with lagged budget shares (GMM) | 1.45,814* | 0.92,394* |

* Significant at 1% confidence level.

with the infrequency of purchase, with lower elasticities for the Meghir–Robin method.

The lower price elasticities imply a greater responsiveness of fuel consumption to fuel price changes than those generally found in the literature, and suggests that fuel taxes can play a significant role to reduce fuel consumption. However, the high income elasticities also suggest that (in line with Sterner et al. (1992) recommendation, see Section 4.1) those price increases will need to be significantly higher than increases in income in order to achieve such result.

## 5. Policy implications

### *5.1. Addressing the transport activity factor. What role for fuel taxes?*

Although significant reductions in fuel consumption have been achieved per kilometre in Spain (see Section 2.3.4), they have been offset by transport growth (see Section 2.3.2) and increased vehicle weight and horsepower (Tarancón and Del Río, 2007). It is routinely assumed that considerable further efforts to reduce transport energy consumption are justified (Van Dender, 2009). However, the decision to tackle the aforementioned externalities related to energy consumption in transport with measures predominantly targeted at the scale factor or at technological changes would require a deeper analysis on the costs of both types of measures (technology-oriented or activity-related) as well as a valuation of the resulting avoided negative externalities.[15] This is beyond the scope of this paper. Nevertheless, since it is likely that a combination of both types of measures will be required, this section briefly discusses the role of fuel taxes in tackling the transport activity factor, taking into account the results of the elasticities in Section 4.

In general, policy instruments to reduce energy consumption in transport can be grouped into four categories (Table 10)[16].

**Table 10**
Classification and description of instruments to reduce energy consumption in the transport sector.

| **Regulatory instruments** | |
|---|---|
| **User restrictions** | They limit the access of the private vehicle to city centres |
| **Speed limits** | Substantial improvements in fuel consumption can be achieved with speeds around 100 km/h compared to higher speeds. |
| **Vehicle maintenance requirements** | Requiring vehicles to periodically pass an inspection (within ordinary technical inspection programmes) may facilitate the maintenance of optimal fuel consumption levels. |
| **High-occupancy requirements** | An entry lane reserved to vehicles with more than one occupant encourages car-sharing. |
| **Standards** | They set binding targets for vehicle manufacturers either in the form of fuel or $CO_2$ standards |
| **Economic instruments** | |
| **Price-based (fiscal) instruments** | Fuel taxes, registration taxes, circulation taxes and charges for infrastructure use (including tolls and parking fees). |
| **Subsidies** | Direct financial support, soft credits, fiscal exemptions and tax deductions for the purchase of cleaner and more energy-efficient vehicles. |
| **Information instruments** | |
| **Information/awareness raising campaigns** | They can be general (on the socioeconomic and environmental problems resulting from using the private cars) and, or more specific (showing more sustainable mobility patterns). |
| **Ecodriving campaigns** | Aim: to train drivers in more fuel-efficient practices when driving (reducing cycles of deceleration and acceleration, keeping engine revolutions low, maintaining proper tyre pressure (IEA, 2001)). |
| **Education** | Fuel saving attitude encouraged in the conventional pre-university school curricula, as an additional subject. Longer-term impact. |
| **Other instruments** | |
| **Voluntary agreements** | They involve an agreement between regulators and regulated whereby the later commit to achieve a previously agreed fuel-economy target. |
| **Land-use and transport planning** | Urban mobility should be planned in an integrated manner to facilitate the use of the non-motorised modes of mobility and public transport. |
| **Public provision** | Purchase of vehicles for the public administrations, according to environmental criteria. |
| **RD&D investments** | Funding of technologies at different maturity levels. |
| **Promotion of public transport** | Improving the quality and availability of public transport makes it more appealing for potential users. |

*Source*: Own elaboration based on del Rio and Hernández (2008).

[15] This is also related to the extent of effort that should be required from the transport sector. For example, there is widespread evidence that reducing $CO_2$ emissions in transport is more expensive than in other sectors (see IPCC, 2007b; Proost, 2008; Abrell, 2007). In addition, in the study of Proost (2008) nearly all abatement in transport is realized through the adoption of alternative technologies, not through a reduction in transport activity of passenger car transport, which entails a loss of consumer surplus (Van Dender, 2009).

[16] Different classifications of instruments have been proposed. See, for example, Bristow et al. (2004), Gallagher et al. (2007) and IPCC (2007a). The literature on GHG mitigation instruments in this sector is more abundant than that specifically related to reduction of energy consumption. Although there is a great overlap between both types of instruments, a few measures to reduce GHG

Within a specific instrument category, multiple possibilities exist, depending on the specific design elements.[17]

Within all those measures, economists tend to favour economic instruments and particularly those providing a price signal, i.e., fuel taxes, although the non-economic instruments (regulatory, information and "other" measures) also have a role to play to tackle the scale factor and/or to induce modal shifts (Table 10). Theoretically, fuel taxes are an appropriate instrument to internalise the externalities related to energy use in the fuel prices faced by transport users. An increase in fuel excise duties will influence consumers to buy more efficient vehicles, promote a fuel-efficient driving style, encourage transport users to shift to more fuel-efficient transport modes and limit transport growth rates (Markowska et al., 2009). Fuel taxes encourage behavioural as well as technological changes,[18] mitigate the rebound effect[19] and have relatively low administrative costs. Fuel taxes also raise revenue, which can be used to stimulate more energy-efficient forms of transport or for other social objectives, including the reduction in pre-existing distortionary taxes, within a broad ecological tax reform.

However, as shown in Section 4, the influence of the fuel tax on the behaviour of individual users depends on the price elasticity of fuel demand. A low elasticity means that fuel taxes have to be substantial to significantly reduce fuel demand, but the social acceptability and, thus, the political feasibility of high tax rates are generally low. In fact, strong public opposition has made this option politically unacceptable in the US and elsewhere (see Greene et al., 2005).

Nevertheless, in spite of this low price reactivity, fuel taxes are still deemed necessary (albeit not sufficient) in any strategy to reduce energy consumption in transport because

(1) As prices do not reflect the full social cost of transport, demand has been artificially high (EC, 2001). The price signal certainly encourages behavioural changes in the medium/longer term, i.e., higher gasoline taxes still provide an incentive to increase fuel economy and reduce vehicle travel.
(2) Even if taxes are not effective to reduce energy consumption in the short term, a significant amount of revenues would be collected from the fuel taxes to finance other instruments, which encourage reductions in private transport demand and modal shifts (either by investing in public transport, financing information campaigns, including ecodriving and/or the administrative costs of implementing regulations limiting the use of private cars) or be redistributed to assist low-income groups, highly affected by the fuel tax. This would make fuel taxes doubly effective in different time frames: in the short term (through the existence of a price signal and other instruments being financed with the revenues collected) and in the long term (when price elasticities are higher and a greater impact on demand can be expected).[20]

Since each instrument (and not only fuel taxes) is likely to have only a modest effect on energy consumption in this sector due to the multifaceted character of factors leading to this consumption, the appropriate policy approach involves the combination of different instruments in a coherent and coordinated manner.

The complementarity between instruments has different sides. It might be related to their different time horizons: some would have an impact in the short term (i.e., user restrictions), whereas others cannot be expected to have an immediate effect (i.e., information provision, urban planning and price instruments). It might also be related to the fact that some instruments may target technological changes (fuel economy standards), whereas others aim at changing driving behaviours (ecodriving) or modality patterns (investments in public transport). In addition, as already mentioned, the revenues from a fuel tax can provide financing for other measures. In turn, the other instruments increase the price reactivity of fuel taxes. For example, information measures may address information failures and increase the price elasticity of fuel demand. They add short-term effectiveness to the economic instrument (regulations and information measures), long-term effectiveness (land-use planning, R&D support) or social acceptability/political feasibility (informational measures).[21] Nevertheless, the Environmental Tax Reform would suggest that it should be assessed whether dedicating the revenues from those taxes to finance the "other" instruments is welfare-improving with respect to reducing social security contributions and taxes on labour.

### 5.2. Discussing the environmental and energy consumption effects of transport taxes on private transport in Spain

The incentives provided by taxes to encourage lower energy consumption levels in the private passenger transport sector (i.e., cars) in Spain are currently weak. Its intention was mainly to collect revenue. This situation will continue in the future since economic instruments play a residual role in the recently approved Sustainable Mobility Strategy (see Spanish Government, 2009).

Whereas the level of the registration tax is on the EU average, the circulation and the fuel tax are lower (Espasa et al., 2006 and Section 2.3.5). Although politically attractive (given the low perception of its existence by tax payers), the vehicle registration tax does not have any influence on car use. Albeit more energy-efficient cars are taxed at lower rates, its effect on fuel use, is likely to be limited. The high income elasticity of demand has pushed for the purchase of gas-guzzler cars. The circulation tax is also quite unrelated to energy use and to the externalities caused by this consumption.

We thus propose a revenue-neutral fiscal reform of car taxation aimed at reducing energy consumption. This would involve sustained increases in fuel taxes, together with the gradual phase-out of the registration and circulation taxes.[22] Nevertheless, further studies should identify the appropriate level

(*footnote continued*)
emissions without necessarily leading to a reduction in energy consumption (i.e., measures to encourage the uptake of biofuels).

[17] A detailed description of these instruments is clearly beyond the scope of this paper. See IPCC (2007a) for further details.

[18] Higher fuel taxes help manufacturers attain the fuel economy standard (as they narrow the gap between consumers' aspiration and the requirement of the standard) and provide an incentive for the development of low-carbon technologies (Van Dender, 2009). Markowska et al. (2009) observe that the relatively high level of taxes on vehicles and fuels in Europe has convincingly led to a more fuel-efficient vehicle fleet compared to e.g. the USA and other countries.

[19] With very fuel-efficient vehicles, there is a high chance for rebound effects. Although they can be limited by very strong infrastructure, spatial and pricing policies (Markowska et al., 2009), a low price elasticity and high income elasticity of demand for fuel makes it difficult that rebound effects can be mitigated through pricing mechanisms (since increase in fuel prices as a result of higher fuel taxes would not have an influence on fuel demand).

[20] Several papers show that the combination of fuel taxes with other instruments is welfare-improving with respect to the isolated utilization of each policy: Fullerton and West (2002) (tax on gasoline and subsidies to newer cars), Agras and Chapman (1999) and Innes (1996) (gasoline taxes and fuel economy standards).

[21] As noted throughout this paper, we focus on the scale factor, but the combination of instruments is relevant to induce, both, technological and behavioural changes, which are needed to substantially reduce energy consumption.

[22] The 2005 Proposal for a Directive on passenger car-related taxes (European Commission 2005) recommended a phase-out of registration taxes in the EU. In addition, the International Energy Agency (IEA, 2001) already urged the Spanish

of the fuel tax according to estimates of avoided externalities and to preserve revenue-neutrality, taking into account that transport is already a heavily taxed activity.

It might be argued that the removal of the registration and circulation taxes would also reduce the incentive to buy more energy-efficient cars. However, the higher fuel taxes would not only reduce the incentive to use the car, but would also maintain some incentive to buy more fuel-efficient cars because drivers would pay less each time they drive. Probably a better alternative would be to transform the registration tax into a true feebate system, which combine rebates on vehicles with higher fuel economy with fees on vehicles with lower fuel economy (Gallagher et al., 2007), remove the circulation tax and increase the fuel taxes to compensate the revenue loss due to such removal.

This fiscal reform should be part of a wider, integrated strategy, which would include a package of measures (promotion of public transport, information instruments, R&D investments, etc.) aimed at reductions of energy consumption by private cars. The low (but not insignificant) price elasticity and high income elasticity of fuel demand is unlikely to result in a significant behavioural change in the short term but part of the revenues from an increase in fuel taxes could be earmarked to finance the other "non-price" measures, although this would put revenue neutrality at risk.[23]

In contrast to this proposal centred on the use of fiscal instruments, and for reasons of social acceptability and political feasibility, "soft" instruments rather than hard measures in the form of high fuel taxes and regulations restricting the use of private cars have been the norm. As shown in Section 2.3.5, domestic policies to reduce energy consumption and/or $CO_2$ emissions associated to the scale factor have mostly relied on investments in public transportation and information/education.[24]

The implementation of a policy aimed at reducing energy consumption by car users based on a strong price signal, which directly affects the pocket of fuel users will continue to be missing in the future. The Sustainable Mobility Strategy is oriented to encourage investments in public transport and technological innovation,[25] provide information to transport users, reduce speed limits, raise awareness, provide information (ecodriving) and undertake transport and urban planning, but there is only a generic mention to the use of "economic instruments".

## 6. Concluding remarks, limitations and suggestions for further research

The analysis of price and income elasticities carried out in this paper is useful to identify appropriate instrument combinations in Spain, which tackle the transport-activity factor and lead to effective reductions in energy consumption by cars and the most appropriate role of economic instruments within those policy mixes. Whether those instruments should be targeted at short-term energy consumption reductions or rather be part of a package of policies in which its main role is to provide a long-term price signal and revenues to finance the other instruments depends on the results of such analysis. This paper has provided a set of policy recommendations in this direction. Although they relate to the Spanish case, they could be extrapolated to other countries.

Our analysis suggests that, although necessary, the price signal provided by fuel taxes may be insufficient to induce significant changes in private passenger transport demand in Spain, given the low price elasticities and the high income elasticities of fuel demand. This would require very high levels of fuel tax, which are hardly politically feasible. Our analysis does not allow us to identify the level of those fuel taxes, however. If estimates of marginal external costs and elasticities provide guidance on appropriate fuel tax levels (Van Dender, 2009), we do not provide an estimate of the former. Furthermore, whether reductions in transport activity should be prioritised (in contrast to technological changes) is beyond the scope of this analysis. However, if such reductions are deemed recommendable as part of an integrated strategy in which they are combined with technological changes (which is likely), then our analysis provides some policy-relevant insights.

In view of those results, a combination of instruments at different levels and with different scopes (short term and long term, carrots and sticks) is necessary to reduce the scale of transport activity and fuel use in this sector. Fuel taxes have an important role to play in this combination. Different instruments have different time horizons after which they can be expected to be effective. Whereas regulations are probably better at inducing reductions in transport demand in the short term, fuel taxes are effective in longer time frames. Notwithstanding, fuel taxes also have a role to play to reduce transport fuel demand in the short term. The low short-term price elasticity of fuel demand allows for the collection of revenues, which could be earmarked to finance other instruments in order to reduce energy consumption in transport (public transport, information provision, regulations or R&D).

However, given that cars are already heavily taxed, we recommend that the gradual increase in fuel taxes is combined with the removal of the circulation tax and that the registration tax is transformed into a feebate system that encourages the purchase of more energy-efficient cars, in the context of a revenue-neutral fiscal reform of car taxation. In contrast, the implementation of high fuel taxes within a combination of instruments aimed at reducing energy consumption in the passenger transport sector has been missing in Spain. The government relies (and will rely) on soft measures (public transport investments and information).

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## References

Abdulai, A., Aubert, A., 2004. A cross-section analysis of household demand for food and nutrients in Tanzania. Agricultural Economics 31, 67–79.

(*footnote continued*)
government in 2001 to substantially increase energy taxes in order to comply with its Kyoto target.

[23] The fuel tax already generates a substantial amount of revenue (about 11 thousand million € in 2004, according to Espasa et al. (2006). An increase in fuel taxes would be used to compensate for the reduction in the circulation or the registration tax (which amounted to 1.6 and 1.9 million thousand € in the same year, respectively).

[24] Of course, other policy initiatives at the EU level have tackled the technological factor, mainly the voluntary agreements with the Japanese, Korean and European vehicle manufacturers.

[25] However, all the measures proposed in the Strategy to encourage technological changes are of a supply-push kind (technology policy instruments, such as R&D and deployment subsidies) and not of a demand-pull type (economic instruments). This amounts to renewing the vehicle stock, supporting RD&D of more energy-efficient and cleaner vehicles (hybrids, hydrogen, CNG, LNG, …) (see Spanish Government, 2009).

Abrell, J., 2007. Transportation and emission trading—a CGE analysis for the EU 15. Economics of Global Warming Working Paper WP-EGW-01, Dresden University of Technology.

Agras, J., Chapman, D., 1999. The Kyoto Protocol, CAFE standards, and gasoline taxes. Contemporary Economic Policy 17 (3), 296–307.

Alessie, R., Kapteyn, A., 1991. Habit formation, interdependent preferences and demographic effects in the almost demand system. The Economic Journal 101, 404–419.

Alston, J.M., Foster, K.A., Green, R.D., 1994. Estimating elasticities with the linear approximate almost ideal demand system: some Monte Carlo results. Review of Economics and Statistcs 76, 351–356.

Anderson, G., Blundell, R., 1983. Testing restrictions in a flexible dynamic demand system: an application to consumers' expenditure in Canada. Review of Economic Studies 50, 397–410.

Arellano, M., Bond, S., 1991. Some especification tests for panel data: Monte Carlo evidence and an application to employment equations. Review of Economic Studies 58, 277–298.

Baker, P., Blundell, R., Micklewright, J., 1989. Modelling household energy expenditures using micro-data. The Economic Journal 99, 720–738.

Baker, P., McKay, S., Symons, E. 1990. The simulation of indirect tax reforms: the IFS simulation program for indirect taxation (spit). Working Paper Institute for Fiscal Studies, 90/11.

Baltagi, B.H., 2005. Econometric Analysis of Panel Data. John Wiley & Sons, West Sussex, UK.

Wooldridge, J.M., 2002. Econometric Analysis of Cross Section and Panel Data. The MIT Press, Cambridge, UK.

Blanciforti, L.A., Green, R.D., 1983. An almost ideal demand system incorporating habits: an analysis of expenditures on food and aggregate commodity groups. Review of Economics and Statistics 65, 511–515.

Blanciforti, L.A., Green, R.D., King, G.A., 1986. U.S. consumer behaviour over the postwar period: an almost ideal demand system analysis. Giannini Foundation Monograph, 40.

Brännlund, R., Nordström, J., 2004. Carbon tax simulations using a household demand model. European Economic Review 48, 211–233.

Breusch, T.S., Pagan, A.R., 1980. The Lagrange multiplier test and its applications to model specification in econometrics. Review of Economic Studies 47, 239–253.

Bristow, A., Pridmore, A., Tight, M., May, M., Berkhout, F., Harris, M., 2004. How can we reduce carbon emissions from transport?. Tyndall Centre for Climate Change Research. Technical Report 15, London.

Brons, M., Nijkamp, P., Pels, E., Rietveld, P., 2007. A meta-analysis of the price elasticity of gasoline demand—a SUR approach. Energy Economics 30, 2105–2122.

Buse, A., 1994. Evaluating the linear almost ideal demand system. American Journal of Agricultural Economics 76, 781–793.

Calvet, L.E., Common, E., 2000. Behavioral heterogeneity and the income effect. Harvard Institute of Economic Research DP 1892.

Chen, P., Veeman, M.M., 1991. An almost ideal demand system analysis for meats with habit formation and structural change. Canadian Journal of Agricultural Economics 39, 223–235.

Christensen, M.L., 2002. Heterogeneity in Consumer Demands and the Income Effect. Institute of Economics, University of Copenhagen, Mimeo.

Deaton, A., 1985. Panel data from time series of cross-section. Journal of Econometrics 30, 109–126.

Deaton, A., 1989. Demand analysis. In: Griliches, ZyMD Intriligator (Ed.), Handbook of Econometrics. pp. 1768–1829.

Deaton, A., 1997. The Analysis of Household Surveys, a Microeconometric Approach to Development Policy. The World Bank, Washington.

Deaton, A., Muellbauer, J., 1980a. An almost ideal demand system. American Economic Review, 312–316.

Deaton, A., Muellbauer, J., 1980b. Economics and Consumer Behaviour. Cambridge University Press, Cambridge.

Dynan, K.E., 2000. Habit formation in consumer preferences: evidence from panel data. American Economic Review 90 (3), 391–406.

European Commission (EC), 2001. European Transport Policy for 2010: Time to Decide—White Paper. European Commission, Brussels.

EC 2009. Energy and Transport in figures. Statistical Pocketbook.

EEA 2008. Climate for a transport change—TERM 2007: indicators tracking transport and environment in the European Union, Copenhagen, European Environment Agency, 2008.

Espasa, M.,Lladó, A., Nadal, M., 2006. Propuesta de reforma de la fiscalidad sobre el automóvil. RACC automóvil club.

Espey, M., 1998. Gasoline demand revisited: an international meta-analysis of elasticities. Energy Economics 20, 273–295.

European Commission 2009. EU Energy and Transport in Figures. Statistical Pocketbook, Brussels.

Filippini, M., 1995. Electricity demand by time of use: An application to the household AIDS demand. Energy Economics 17 (3), 197–204.

Fullerton, D., West, S., 2002. Can taxes on cars and on gasoline mimic an unavailable tax on emissions? Journal of Environmental Economics and Management 43 135–157.

Gallagher, K.S., Collantes, G., Holdren, J.P., Lee, H., Frosch, R., 2007. Policy options for reducing oil consumption and greenhouse-gas emissions from the US, Harvard (Massachussets), Transportation Sector. Discussion Paper July 27, 2007. John F. Kennedy School of Government, Harvard University.

Goodwin, P., 1992. A review of new demand elasticities with special reference to short and long run eVects of price changes. Journal of Transport Economics and Policy 26, 155–163.

Goodwin, P., Dargay, J., Hanly, M., 2004. Elasticities of road traffic and fuel consumption with respect to price and income: a review. Transport Reviews 24 (3), 275–292.

Graham, D.J., Glaister, S., 2002. The demand for automobile fuel—a survey of elasticities. Journal of Transport Economics and Policy 36, 1–26.

Green, R., Alston, J.M., 1990. Elasticities in AIDS models. American Journal of Agricultural Economics 72 (2), 442–445.

Green, R., Alston, J.M., 1991. Elasticities in AIDS models: A clarification and extension. American Journal of Agricultural Economics 73 (3), 874–875.

Greene, D., Patterson, P., Singh, M., Li, J., 2005. Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy. Energy Policy 33, 757–775.

Haden, K., 1990. The demand for cigarettes in Japan. American Journal of Agricultural Economics 72 (2), 446–450.

Halvorsen, B., Larsen, B.M., 2001. The flexibility of household electricity demand over time. Resource and Energy Economics 23, 1–18.

Hanly, M., Dargay, J., Goodwin, P., 2002. Review of income and price elasticities in the demand for road traffic—ESRC TSU publication 2002/13, ESRC Transport Studies Unit Centre for Transport Studies, University College, London.

Hausman, J.A., 1978. Specification test in econometrics. Econometrica 46, 1251–1271.

Heien, D., Wessells, C.R., 1990. Demand systems estimation with microdata: a censored regression approach. Journal of Business and Economic Statistics 8 (3), 365–371.

Holden, E., Høyer, K.G., 2005. The ecological footprints of fuels. Transportation Research Part D10, 395–403.

Hondroyiannis, G., 2004. Estimating residential demand for electricity in Greece. Energy Economics 26, 319–334.

Hughes, J.E., Knittel, C., Sperling, D., 2006. Evidence of a shift in the short-run price elasticity of gasoline demand. Institute of Transportation Studies, University of California, Davis, Research Report UCD- ITS-RR-06-16.

Innes, Robert., 1996. Regulating automobile pollution under certainty, competition, and imperfect information. Journal of Environmental Economics and Management 31, 219–239.

Instituto Nacional de Estadística (various years). Encuesta Continua de Presupuestos Familiares, Madrid, Instituto Nacional de Estadística.

Intergovernment Panel on Climate Change 2007a. Transport chapter. Fourth Assessment Report. Working Group III. Ginebra.

Intergovernment Panel on Climate Change 2007b. Mitigation in an intersectoral perspective chapter. Fourth Assessment Report. Working Group III. Ginebra.

International Energy Agency (IEA) 2001. Saving Oil and Reducing $CO_2$ Emissions in Transport, Paris.

IEA 2008. World Energy Outlook, Paris.

Jabarin, A.S., 2005. Estimation of meat demand system in Jordan: an almost ideal demand system. International Journal of Consumer Studies 29 (3), 232–238.

Keen, M., 1986. Zero expenditures and the estimation of Engel curves. Journal of Applied Econometrics 1, 277–286.

Labandeira, X., López, A., 2002. La imposición de carburantes de automoción en España: Algunas observaciones teóricas y empíricas. Hacienda Pública Española/Revista de Economía Pública 160 (1), 177–210.

Labeaga, J.M., López, A., 1997. A study of petrol consumption using Spanish panel data. Applied Economics 29, 795–802.

Madlener, R., 1996. Econometric analysis of residential energy demand: a survey. The Journal of Energy Literature II 2, 3–32.

Markowska, A., van Essen, H., Kampman, B., 2009. Transport chapter on RECIPE project. The Economics of Decarbonisation. Potsdam Institute for Climate (PIK). Potsdam, Germany.

Meghir, C., Robin, J.M., 1992. Frequency of purchase and the estimation of demand systems. Journal of Econometrics 53, 53–58.

Mendiluce, M., 2008. La fiscalidad del transporte rodado como instrumento para desvincular el transporte del crecimiento económico. In: Becker, F., Cazorla, L.M., Martínez-Simancas, J. (Eds.), Tratado de Tributación Medioambiental, vol. 2; 2008, pp. 1329–1366.

Monzón, A., 2007. La contribución del transporte a la emisión de gases de efecto invernadero en España. VII Seminario Internacional Transporte y Cambio Climático, Madrid.

Moschini, G., Mielke, K.D., 1989. Modelling the pattern of structural change in U.S. meat demand. American Journal of Agricultural Economics 71, 253–261.

Nichele, V., Robin, J.-M., 1995. Simulation of indirect tax reforms using pooled micro and macro French data. Journal of Public Economics 56, 225–244.

Nombela, G., del Río, P., Mendiluce, M., 2008. Economic aspects of climate change. Transport and GHG emissions in Spain. Presentation at FEDEA, Madrid.

Oum, T.H., Waters II, W.G., Yong, J.S., 1992. Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey. Journal of Transport Economics and Policy 23, 163–187.

Pashardes, P., 1993. Bias in estimating the almost ideal demand system with the stone index approximation. The Economic Journal 103, 908–915.

Pollack, R.A., Wales, J.W., 1981. Demographic variables in demand analysis. Econometrica 49 (6), 1533–1551.

Proost, S., 2008. Full account of the costs and benefits of reducing $CO_2$ emissions in transport, JTRC Discussion Paper No 2008-3, ITF/OECD, Paris.

Del Rio, P., Hernández, F., 2008. Análisis de los procedimientos de reducción de emisiones de CO2 en el sector del transporte de pasajeros por carretera. Ekonomiaz 67, 234–261.
Rickertsen, K., 1998. The demand for foods and beverages in Norway. Agricultural Economics 18, 89–100.
Romero, D., Sanz, J.F., 2003. El impuesto sobre las ventas minoristas de determinados hidrocarburos. Una evaluación de sus efectos económicos. Hacienda Pública Española/Revista de Economía Pública 164-(1/2003). pp. 49–74.
Romero-Jordán, D., Sanz-Sanz, J.F., 2009. Energy taxes and household compliance with the Kyoto Protocol. Public Finance Review 37, 142–169.
Sauret, 2008. El Automóvil, el Medio Ambiente y el Usuario. Conferencia sobre Combustibles y Sistemas de Propulsión Alternativas. November 27th, 2008.
Schmutzler, A., 2005. Transportation and the environment—perspective for future research. In: Böhringer, C., Lange, A. (Eds.), Applied Research in Environmental Economics, vol. 31. Springer, Heidelberg.
Stern, N., 2006. The Economics of Climate Change: The Stern Review. HM Treasury, London.
Spanish Government 2009. Estrategia Española de Movilidad Sostenible, Madrid.
Sterner, T., Dahl, C., FranzeÂ, M., 1992. Gasoline tax policy: carbon emissions and the global environment. Journal of Transport Economics and Policy 26, 109–119.
Stone, J.R.N., 1954. The Measurement of Consumers' Expenditure and Behaviour in the United Kingdom, 1. Cambridge University Press, Cambridge, pp. 1920–1938.
Tarancón, M.A., Del Río, P., 2007. Structural factors affecting land-transport $CO_2$ emissions: a European comparison. Transportation Research D: Transport and the Environment 12, 239–253.
Van Dender, K., 2009. Energy policy in transport and transport policy. Energy Policy, 37 (10), 3842–3862.