The Distributional and Environmental Dilemma of Energy Price Shocks

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Abstract

Energy price shocks pose complex challenges for climate policy, combining efficiency concerns with distributional tensions. We develop a micro-founded method to estimate the behavioral and environmental effects of energy price changes, combining household expenditure microdata, a structural demand system (EASI), and supply-use tables with production-based GHG inventories. The approach enables consistent attribution of emissions to household demand and captures heterogeneous responses across income groups. Applying the method to a national case study, we simulate price shocks in electricity, heating, and transport fuels. Results reveal asymmetrical and regressive impacts, especially for essential goods with low price elasticity. Emission effects are highly dependent on substitution patterns, with some shocks triggering rebound effects. A lump-sum transfer mitigates welfare losses for electricity and heating, but not for fuels. Comparing predicted and observed aggregate responses during recent crises highlights the limits of elasticity-based instruments in practice. Our findings underscore the need for flexible, context-sensitive compensation mechanisms in carbon pricing design and illustrate a transferable method applicable across national settings.

Keywords: Energy prices, Distributional effects, Carbon pricing, VAT, Household welfare, EASI demand system

JEL codes: D12, D63, H23, Q52, Q41, C52

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1. Introduction

Energy price volatility and climate policy reforms pose significant challenges for households, especially in terms of affordability, inequality, and emissions. Residential energy consumption—through electricity, heating, and transport fuels—is both a key driver of greenhouse gas (GHG) emissions and a central component of household welfare (Belaïd, 2022; Guan et al., 2023). As governments increasingly rely on carbon pricing and tax-based instruments to meet climate targets, understanding the behavioral and distributional consequences of energy price changes become essential for effective and equitable policy design.

These tensions are particularly salient when viewed through a national lens, as countries face varying degrees of exposure to external shocks and overlapping structural transitions. In Spain, for example, residential energy use accounts for nearly 20% of final energy consumption and remains heavily reliant on fossil fuels, especially for heating (MITERD, 2023; de Arriba Segurado, 2025). In response to the 2022 energy crisis (IEA, 2022), temporary fiscal measures, including VAT reductions and fuel subsidies, were introduced to contain rising household energy costs. However, structural reforms are expected to intensify these pressures: VAT on electricity returned to 21% in 2025 in Spain, and the extension of the EU Emissions Trading System (ETS-2) to buildings and transport from 2027 will further increase household exposure to carbon pricing (European Commission, 2024). Despite the widely acknowledged need for global carbon pricing mechanisms to address climate externalities efficiently (Stiglitz et al., 2017), these developments highlight the need to anticipate the socio-environmental effects of energy price reforms, particularly for vulnerable groups.

A substantial literature has examined household energy demand and its responsiveness to prices and income (Labandeira et al., 2017). Existing studies rely on either aggregate data (Blázquez et al., 2013a, 2013b) or household microdata (Labandeira et al., 2006), using models ranging from single-equation (Filippini & Pachauri, 2004) to discrete-continuous frameworks (Dubin & McFadden, 1984; Hanemann et al., 2024). Demand systems such as AIDS, QUAIDS, and EASI (Deaton & Muellbauer, 1980; Banks et al., 1997; Lewbel & Pendakur, 2009, respectively) have gained traction for their flexibility in capturing cross-price and income effects. Recent applications have emphasized distributional impacts and associated carbon emissions (Tovar-Reaños & Wölfing, 2018; van der Ploeg et al., 2022; Levell et al., 2024; Bonnet et al., 2025).

This paper simulates the effects of a stylized 20% increase in energy prices, reflecting the combined influence of market dynamics and forthcoming policy changes. Using 2017–2022 microdata from the Spanish Household Budget Survey and a flexible EASI demand system, we estimate price and expenditure elasticities for electricity, heating fuels, and motor fuels by income group. We assess the distributional impact of price shocks and evaluate the mitigating effect of a revenue-neutral lump-sum rebate. To validate the behavioral predictions, we compare simulated outcomes with aggregate expenditure and emissions data, accounting for deviations observed during crises such as COVID-19 and the 2021–2022 energy price surge.

Our findings reveal significant heterogeneity in elasticities and welfare effects. Electricity demand is inelastic (–0.90 to –0.82), especially among low-income groups. Heating and motor fuels are more elastic, with stronger substitutions among wealthier households. Price increases in electricity and heating are regressive; motor fuels are less so but impose larger aggregate welfare losses. Environmentally, electricity shocks raise emissions (+1.14%) via substitution toward heating (+1,121 tCO_2e), while gas shocks reduce them (–0.85%), i.e., –1,463 tCO_2e. Fuel taxes generate marginal gains (+0.34%) but also trigger behavioral rebounds.

The lump sum revenue-neutral rebate partially mitigates electricity losses (61% net winners) and gas (54%) but proves inadequate for fuels (≈80% net losers). Moreover, demand reactions during crises diverge from model predictions, underscoring the limits of elasticity-based approaches when non-price constraints dominate (e.g., lockdowns, precautionary behavior, and supply constraints). These findings stress the need for differentiated context-sensitive instruments to design effective and equitable carbon pricing policies.

The remainder of the paper is structured as follows: Section 2 reviews the literature; Section 3 presents the theoretical model; Section 4 describes the data and results; and Section 5 concludes.

2. Literature Review

Understanding residential energy demand is crucial for evaluating the equity and effectiveness of climate policy, particularly in the context of carbon pricing. A growing body of research stresses the importance of simulating realistic price scenarios and incorporating behavioral responses to assess welfare and distributional impacts (Evald et al., 2022). Within ex-ante evaluation frameworks, microsimulation models based on household budget surveys are especially suited to capturing heterogeneous responses across income groups (Köppl & Schratzenstaller, 2023).

Recent empirical work increasingly relies on flexible demand systems to estimate price and income elasticities of energy goods. While the QUAIDS model (Banks et al., 1997) remains widely used (e.g., Douenne, 2020), growing evidence suggests that the Exact Affine Stone Index (EASI) model by Lewbel and Pendakur (2009) provides greater flexibility in capturing nonlinear Engel curves and heterogeneous preferences, especially at the distribution's tails (Jacksohn et al., 2023; Wang et al., 2024). Applications of the EASI model have addressed energy price shocks (Tovar-Reaños & Wölfing, 2018), compensatory policy design (van der Ploeg et al., 2022), and unobserved heterogeneity (Ramírez-Hassan & López-Vera, 2024).

Beyond elasticity estimation, recent EASI-based studies emphasize the distributional impacts of energy price reforms and the effectiveness of compensation mechanisms. In Germany, Tovar-Reaños and Wölfing (2018) find stronger regressive effects for heating than for electricity and highlight the superiority of targeted transfers. Eisner et al. (2021) simulate a carbon tax in Austria, showing that regressivity varies by region, household type, and dwelling characteristics, suggesting the need for tailored instruments. In Ireland, Tovar-Reaños and Lynch (2022) document vertical and horizontal inequalities, particularly affecting rural and elderly households, and recommend income-based transfers. Van der Ploeg et al. (2022) further integrate labor supply responses, comparing lump-sum transfers, tax cuts, and hybrid strategies, and find that policy combinations improve both equity and political acceptability.

At the EU level, large-scale analyses (Maier et al., 2024; Immervoll et al., 2023) underscore the importance of behavioral responses and redistribution to ensure fairness and legitimacy. Feindt et al. (2021), using an input–output model with household microdata, simulate the incidence of a €25/tCO_2 tax in 23 EU countries. While the tax appears distributionally neutral at the EU level, many countries show regressive effects, prompting the authors to recommend targeted redistribution to enhance fairness and political feasibility.

3. Theoretical framework

3.1. The demand system, specification and estimation

To align with recent empirical evidence advocating flexible demand systems, we estimate household energy demand using the Exact Affine Stone Index (EASI) model proposed by Lewbel and Pendakur (2009).[1] The EASI model constitutes a major advancement in demand modelling, as it allows for highly flexible Engel curves and captures nonlinear income effects more effectively than earlier systems. Crucially, its structure permits the interpretation of error terms as random utility components, incorporating unobserved household heterogeneity. The model is grounded in a cost function that flexibly models nonlinear income-consumption relationships while preserving analytical tractability. Formally, the model assumes the following cost function:

$$\log[C(p,y)] = y + \sum_i m_i(y,z)\log(p_i) + \frac{1}{2}\sum_i\sum_j a_{ij}\log(p_i)\log(p_j) + \sum_i \epsilon_i \log(p_i) \quad (1)$$

where p_i, p_j are commodity prices, y denotes implicit household utility, m_i is a function which can parametrise the model assuming specific functional forms. ε_i is defined by Lewbel and Pendakur (2009) as parameters which model unobserved preference heterogeneity, with the assumption $E[\varepsilon_i] = 0$. We follow the original proposal of Lewbel and Pendakur (2009) with the following specifications for y and m_i:

$$y = \log(x) + \sum_j w_j \log(p_j) - \frac{1}{2}\sum_i\sum_j a_{ij}\log(p_i)\log(p_j), \quad (2)$$

$$m_i = \sum_{r=0}^{R} b_r \log(y)^r + \sum_l g_{il} z_l \quad (3)$$

This specification permits highly flexible Engel curves while maintaining a transparent and tractable functional form. A key feature of the EASI system is its ability to model interactions between prices and total expenditure, further enhancing its flexibility—though at the cost of less interpretable coefficients and increased computational demands. In addition to its flexibility, the EASI model is structurally related to the Almost Ideal (AI) demand system, which facilitates direct comparisons with results derived from QUAIDS.

r ranges from 0 to R, and R is the maximum degree of the polynomial chosen by the modeller. The variables z_l, $l = 1, \ldots, L$, represent demographic characteristics, and b_r, d_{il} and g_{il} are the parameters to be estimated. This specification permits highly flexible Engel curves while maintaining a transparent and tractable functional form. A key feature of the

[1] Since we need to obtain robust results for our microsimulation analysis, we provide in the Appendix B elasticities obtained though the estimation of the Quadratic Almost Ideal Demand System (QUAIDS, Banks et al., 1997) for comparison.

EASI system is its ability to model interactions between prices and total expenditure, further enhancing its flexibility, though at the cost of less interpretable coefficients and a higher computational burden. In addition to its flexibility, the EASI model is structurally related to the Almost Ideal (AI) demand system, which facilitates direct comparisons with results derived from QUAIDS.

Applying Shephard's lemma to equation (1) and using equations (2) and (3), we obtain the following set of equations for the budget shares:

$$w_i = \sum_{r=0}^{R} b_r \log(y)^r + \sum_j a_{ij} \log(p_j) + \sum_l g_{il} z_l + \epsilon_i \quad (4)$$

To ensure that equation (4) is homogeneous of degree one in prices and satisfies Slutsky symmetry, the following restrictions must hold:

$$\sum_j a_{ij} = \sum_i a_{ij} = \sum_i b_{ir} = 0, \sum_l g_{il} z_l = 0, a_{ij} = a_{ji} \quad (5)$$

Note that $\sum_i b_{ir} = 0$ must hold only for r ≠ 0 whereas $\sum_i b_{i0} = 1$. Once these constraints are introduced in the system, the final restricted specification to estimate is:

$$w_i = b_{i0} + \sum_{r=1}^{R} b_r \log(y)^r + \sum_{j=1}^{J-1} a_{ij} \log\left(\frac{p_j}{p_J}\right) + \sum_l g_{il} z_l + \epsilon_i \quad (6)$$

The Marshallian own-price and total expenditure elasticities are expressed as:

$$e_{ii}^{u} = \left[\frac{\partial w_i}{\partial log p_i}\right] \frac{1}{w_i} - 1$$

$$e_i = \left[\frac{\partial w_i}{\partial log x}\right] \frac{1}{w_i} + 1$$

With *x* total expenditure.

Equation (6) shares the core structure of the QUAIDS model, incorporating commodity prices and sociodemographic variables. A key distinction, however, is the inclusion of the implicit utility term *y*, which introduces two econometric challenges. First, *y* is a function of the budget shares, it gives rise to an endogeneity problem. Second, because *y* also depends on the parameters to be estimated, the system becomes non-linear in parameters. To address both issues, we follow Lewbel and Pendakur (2009) and estimate the system using iterated Three-Stage Least Squares (3SLS). This approach instruments *y* with all available exogenous variables and applies iterative linear approximations to solve the non-linearity. To account for potential heteroscedasticity, we compute standard errors using a non-parametric bootstrap.

As a preliminary step, Figure 1 presents non-parametric kernel regressions of Engel curves for selected goods. Marked non-linear patterns emerge for categories such as food, motor fuels, and leisure, highlighting the risk of bias when income non-linearities are omitted. Other aggregates, like housing, exhibit more linear trends. While these curves are illustrative and do not control demographics or prices, they underscore the relevance of a flexible specification.

In the EASI model, we include log-income terms up to the fourth order (i.e., r=4) in the expansion $\sum_{r=1}^{4} b_r \log(y)^r$. Although we tested a fifth-order term, its high correlation with the fourth introduced multicollinearity; thus, we retained the fourth-order specification. Tables 3 and B.1 (Appendix) confirm the statistical significance of higher-order income terms in key categories, including heating, motor fuels, and leisure.

While non-parametric methods offer visual insight, they are sensitive to unobserved heterogeneity and prone to bias (Blundell et al., 2007). Following Tovar-Reaños and Wölfing (2018), we therefore adopt a parametric approach that allows for rich behavioral heterogeneity and demographic controls, while maintaining tractability for simulation and welfare analysis.

3.2. Welfare analysis

The estimated parameters of the model enable the computation of welfare measures like the Equivalent Variation (EV) (see Tovar-Reaños & Wölfing, 2018, and Ramírez-Hassan & López-Vera,2024). The EV is defined as $C(p^1, U) - C(p^0, U)$ where U represents the level of household utility. Tovar-Reaños & Wölfing (2018) derive a measure for EV that can be expressed as:

$$EV = x - \exp\left\{\log(x) - \sum_{i=1}^{I}(\log(p_i^1 w_i^1) - \log(p_i^0 w_i^0)) + \frac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} a_{ij}\left[\log\left(p_i^1 p_j^1\right) - \log\left(p_i^0 p_j^0\right)\right]\right\}, \quad (7)$$

where superscripts 0 and 1 refer to prices **p** before and after the price change, respectively. We can define x^e such that $v(p^1, x^e) = v(p^0, x)$ with v(.) being the indirect household utility (King, 1983; Tovar-Reaños & Wölfing, 2018). If we assume y = v, then:

$$x^e = \exp\left\{\log(x) - \sum_{i=1}^{I}(\log(p_i^1 w_i^1) - \log(p_i^0 w_i^0)) + \frac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} a_{ij}\left[\log\left(p_i^1 p_j^1\right) - \log\left(p_i^0 p_j^0\right)\right]\right\} \quad (8)$$

x^e refers to the income level which gives the same utility as the current income level, but under a different regime of prices, i.e., the equivalent income (King, 1983).

We compute the budget shares for new prices as:

$$w_i^1 = w_i^0 \left(1 + e_{ij}^y \Delta p_j\right),$$

Where e_{ij}^y is the Marshallian price elasticity for good *i* when price of good *j* changes, and Δp_j is the variation of good *j* price. w_i^0 is the pre-change in price budget share for good *i*.

To assess the impact of a carbon tax on Spanish households, we simulate four scenarios, including separate 20% price increases for electricity, heating fuels, and transport fuels (Scenarios 1-3).[2] Results are reported as equivalent variation relative to household expenditure, averaged by income quintile. This allows for a clear interpretation of the distributional burden across the income spectrum.

We compute a metric for social welfare following Creedy and Sleeman (2006) parametrisation of Sen (1976) index:

$$Social\ Welfare = \frac{\sum_{h=1}^{H} x^e \,/\, \sqrt{hsize_h}}{H} \,.\,(1 - G)\,,$$

Where G is the Gini index, hsize is the size of household *h* and there are H households in our sample.

3.3. Effects on emissions

To evaluate the welfare effects of price changes and their implications for emissions, we use the following standard expenditure share equation:

$$w_i^1 = w_i^0 \left(1 + e_{ij}^y \Delta p_j\right),$$

Where w_i^1 represents the predicted expenditure share under new price conditions, w_i^0 is the observed expenditure share, e_{ij}^y denotes the estimated price elasticity, and Δp_j is the percentage change in price for good *j*.

[2] The 20% price increase is not arbitrarily chosen but reflects plausible future price developments based on recent regulatory changes. First, the Spanish government reduced the VAT on electricity to 5% during the energy crisis but reinstated the standard 21% rate as of January 2025. This policy change directly raises household electricity costs, contributing significantly to potential price increases. Second, the European Union's upcoming Emissions Trading System 2 (ETS 2), set to take effect in 2027, will introduce a carbon pricing mechanism for fuels used in buildings and road transport.

$$w_i^0 = \frac{p_i^0 q_i^0}{\sum_i p_i^0 q_i^0},$$

Given the observed values, we can derive q_i^0. Then, using the estimated elasticities $\left(e_{ij}^{y}\right)$, we predict new expenditure shares under the revised price scenario:

$$w_i^1 = \frac{p_i^1 q_i^1}{\sum_i p_i^1 q_i^1},$$

Where we obtain the new consumption quantities q_i^1, which allow us to estimate the impact of price changes on total emissions.

The Spanish National Statistics Institute (INE) provides GHG emissions by production branch, following the CNAE-2009 classification, and disaggregates emissions attributable to households (INE, 2023). The Annual National Accounts of Spain (INE 2024) provides the share of each production branch's output that is allocated to household final demand. By multiplying this share by the total GHG emissions of each branch, we estimate the emissions attributable to households from each production activity.

Each ECOICOP aggregate *i* is linked to one or more production branches *c* in the Spanish supply-use tables (CNAE classification). For each branch, we take total emissions E_c from the official 2022 greenhouse gas inventory (INE, 2023). To allocate emissions to consumption aggregates, we compute the share of each branch's output that is absorbed by household demand for aggregate *i*. Formally:

$$GHG_{ic}^0 = E_c \frac{g_{ic}}{\sum_c g_{kc}}$$

where g_{ic} is total expenditure by households on goods from branch c within aggregate *i*. Summing across branches yields the emissions attributable to each consumption aggregate:

$$GHG_i^0 = \sum_c GHG_{ic}^0,$$

This approach accounts for the composition of each aggregate's supply sources and ensures consistency with the structure of the input-output system. In practice, we proxy g_{ic} using national household expenditure microdata merged with product-branch mapping based on ECOICOP–CNAE concordance. After the price shock, the new branch-level emissions are obtained:

$$GHG_i^1 = GHG_i^0 \frac{w_i^1}{w_i^0},$$

Summing over all goods yields household emissions before and after the shock:

$$GHG_i^0 = \sum_i GHG_i^0, GHG_i^1 = \sum_i GHG_i^1,$$

The current approach assumes that changes in emissions are proportional to changes in expenditure shares. This assumption holds only under two conditions:

1. There is no substitution between goods within the same aggregate.
2. Emission intensities remain constant along the period of analysis

3.4. Welfare framework and compensation design

Given that we observe both pre-tax and post-tax consumption values—denoted as $p_i^0 q_i^0$ and $p_i^1 q_i^1$, respectively—we can estimate the tax revenue before and after the price change. This is possible because we also have information on indirect tax rates, including not only VAT but also other effective excise-equivalent rates.

We assume that the full price increase is attributable to the introduction of a tax. Accordingly, the tax revenue for each good *i* before and after the price change is computed as follows:

$$T_i^0 = p_i^0 q_i^0 \tau_i,$$

$$T_i^1 = p_i^1 q_i^1 \tau_i,$$

Where τ_i represents the effective tax rate applied to good *i*. The change in tax revenue per good is then computed as:

$$\Delta T_n = \sum_i (T_i^1 - T_i^0),$$

To estimate the aggregate tax revenue at the population level, we apply an uplifting factor (f_h) to scale household-level estimates to the national population. The total additional tax revenue is then given by:

$$\Delta T_{Total} = \sum_h f_h \ \Delta T_n,$$

By aggregating across all goods, we obtain both the overall tax revenue increase and the contribution of each good to this increase.

We implement a revenue-neutral compensation scheme based on a uniform lump-sum transfer. Under this approach, the total tax revenue is redistributed equally across all households, ensuring that each receives the same absolute amount, regardless of income or consumption levels.

To assess whether households gain or lose under the compensation mechanism, we compute the following equation for each income quintile:

$$\Delta W_h = (p_i^1 q_i^1 + S_h) - (p_i^0 q_i^0 + VE_h),$$

Where S_h is the subsidy received under the compensation scheme and VE_h is the equivalent variation.

4. Data and sources

Our analysis uses data from the Spanish Household Budget Survey (EPF), conducted annually by the Spanish Statistical Office (INE) since 2006. We pool the six most recent waves (2017–2022), covering 123,403 households. The survey provides detailed expenditure and sociodemographic data via face-to-face interviews over two consecutive years.

Following the ECOICOP classification, we group expenditure into nine categories: 1. Food and beverages, 2. Housing expenses,[3] 3. Electricity, 4. Heating,[4] 5. Motor fuels, 6. Transport, 7. Communications, 8. Leisure, and 9. Other non-durable goods and services (see Table 1). Unlike most studies, which aggregate all energy-related items into a single category, our disaggregated structure allows for identifying potential substitution effects between energy goods. This is particularly important, as household energy needs relate to functions (e.g. heating or mobility), not specific fuels. Household-specific prices are computed using Lewbel's methodology (Lewbel, 1989, see Appendix C.1) and Consumer Price Indexes (CPIs) from INE, improving precision relative to aggregate indices (Hoderlein & Mihaleva, 2008). To reduce outlier influence, we trim households below the 1st or above the 99th percentiles in income, expenditure, and budget shares.

[3] This section on housing expenses does not include imputed rents for owner-occupied housing.

[4] To ensure that the expenditure refers to the aggregate of heating fuels, we perform the following steps. We remove households that primarily use electricity and solid fuels as their main source of heating and retain those that use liquefied natural gas or other fossil fuels as their primary source. We keep households where the most significant energy good within the aggregate matches the primary energy source used.

To ensure consistency in the heating fuel aggregate, we retain households whose main reported heating source aligns with the dominant expenditure item. We exclude those using electricity or solid fuels, given the lack of consistent CPI micro-indices. The resulting subsample, focused on fossil fuels (natural gas, LPG, liquid fuels), improves the interpretability of price elasticities and welfare simulations. We also exclude households with zero expenditure in any category to ensure strictly positive budget shares, a requirement for consistent demand estimation. The final sample includes 12,047 households, representing a behaviorally consistent set of energy consumers. To account for climatic variation, we merge heating and cooling degree days (HDD and CDD) at the NUTS-3 level from Eurostat.[5]

Table 2 presents descriptive statistics for the weighted sample.[6] On average, households allocate 23.3% of non-durable spending to food, 9.0% to housing, and 3.0%, 2.7%, and 7.9% to electricity, heating fuels, and motor fuels, respectively. Log prices and total expenditures show moderate household-level variation.

Additional descriptive statistics outline the socio-demographic profile of the sample. The average household head is 52 years old; 28.5% are male. Regarding education, 34.5% hold an undergraduate degree, 12.6% a postgraduate degree, and 20.6% only primary education. Most households are couples with children (53.7%), followed by childless couples under 65 (14.3%) and lone parents (6.9%). Elderly single-adult households represent 1.6%. Climate variation is captured via HDD (141) and CDD (23) per year. The sample is balanced across years and concentrated in Madrid (35.5%), Catalunya (19.4%), and País Vasco (9.2%). Canarias, Ceuta, and Melilla are excluded.

5. Results

5.1. Baseline results

Table 4 reports uncompensated own-price elasticities. Electricity demand ranges from -0.90 to -0.82, confirming its inelastic nature in Spain. Elasticity declines (in absolute terms) with income, indicating greater price responsiveness among lower-income households. This reflects not greater adjustment capacity but tighter budget constraints; electricity represents a larger share of their spending, leaving them with little choice but

[5] https://ec.europa.eu/eurostat/databrowser/bookmark/af12da61-61d6-40a1-ac74-7d404350c1d6?lang=en – downloaded 01/07/2024. Methodological details are presented in Appendix C.2.

[6] All descriptive statistics are computed using household survey weights provided by INE to ensure population representativeness.

to reduce consumption.[7] Thus, the observed elasticity signals necessity rather than flexibility: while wealthier households can absorb price hikes with minimal impact, lower-income groups face substantial sacrifices in essential energy use.

For heating fuels, estimated price elasticities range from -1.05 to -1.15, indicating elastic demand. Elasticities rise with income, suggesting greater responsiveness among higher-income households. This can reflect non-essential consumption (e.g., for comfort), easier access to alternatives (e.g., renewables or efficient systems), and lower welfare impacts, as heating comprises a smaller budget share. Wealthier households are also better positioned to adopt energy-saving technologies or behaviours, enhancing flexibility. In contrast, lower-income households may lack such options, making their demand less responsive despite potentially greater vulnerability to energy price increases.

Motor fuel elasticities range from -1.30 to -1.37, with no clear pattern across income levels. The highest responsiveness appears in the top quintile, the lowest in the third. Wealthier households may adjust more due to discretionary use and urban access to transport alternatives.[8]

Tables A.1 to A.5 reveals notable substitution effects between electricity and heating fuels across all income quintiles, intensifying with income. Higher-income households respond to electricity price increases by raising heating fuel use, reflecting greater flexibility. In contrast, lower-income groups show limited substitution capacity. Similar patterns emerge for motor fuels, with higher-income households displaying stronger substitutions with both electricity and heating. These results suggest that wealthier households are better able to adapt energy use or invest in alternatives when relative prices shift.

Table 5 presents expenditure elasticities by quintile from the EASI demand system, with bootstrap standard errors (500 replications). A key result is that motor fuels exhibit declining expenditure elasticities with income. For lower-income households, motor fuels

[7] In our sample, the first quintile households spend 4.43% of their budget in electricity on average while top income households devote to electricity services 1.90% of total expenditure.

[8] This result is consistent with evidence from the *Encuesta de Características Esenciales de la Población y Viviendas* conducted by the Spanish National Statistics Institute (INE), which shows that vehicle ownership increases with income: low-income households (under €1,000) are more likely to own no vehicle (10.5%), while high-income households (over €3,000) are more likely to own two or more vehicles (6.8% for three or more). This suggests that higher-income households can adjust motor fuel use both on the intensive margin (reduced use or switching to efficient vehicles) and on the extensive margin (vehicle ownership). In contrast, low-income households devote a higher share of their total budget to fuel—8.82% for the lowest quintile versus 7.25% for the highest—limiting their flexibility to reduce consumption without affecting essential travel.

behave as luxuries, while for higher-income groups they are necessities, reflecting more regular car use. In contrast, electricity and heating are necessities across quintiles, with no clear income gradient. This suggests that, although essential, wealthier households may adjust consumption more easily, potentially due to access to energy-efficient technologies or alternatives. While the model controls for urban–rural residence, simulations are not disaggregated by geography, and exploring this source of heterogeneity is an avenue for future research.

Overall, these findings suggest that motor fuel taxes may disproportionately affect lower-income households, for whom such fuels are a luxury. In contrast, electricity and heating policies impact all income groups, though higher-income households may have greater capacity to adjust consumption in response to price changes.

5.2. Welfare simulations

Table 6 reports the equivalent variation (EV) as a share of total expenditure by income quintile under three policy scenarios: price increases in electricity, heating fuels, and motor fuels.

Scenario 1*: Increase in electricity prices*

Under the electricity price increase scenario, the equivalent variation declines with income: the lowest quintile faces a burden of 0.804% of expenditure, while the highest sees only 0.347%. This has a regressive impact, as lower-income households spend a larger share of their budget on electricity.

Scenario 2*: Increase in heating fuel prices*

A similar regressive pattern emerges under heating fuel price increases: the lowest-income quintile bears a 0.697% burden, compared to 0.324% for the highest. The smaller gap suggests heating expenditures are more evenly distributed or that higher-income households also devote a notable share of their budget to heating.

Scenario 3*: Increase in motor fuel prices*

In the motor fuel price scenario, equivalent variation is higher across all quintiles: 1.588% for the lowest-income group and 1.309% for the highest. Unlike electricity and heating, the burden does not decline uniformly with income. Middle-income households face slightly lower impacts, but welfare losses remain substantial even for wealthier groups, possibly reflecting differences in car ownership, fuel use, and commuting patterns across income distribution.

Table 8 presents Sen index results across scenarios. In the no-tax baseline, the Gini is 0.2712, mean equivalent income €20,162.24, and the Sen index €15,223.54. Under the electricity tax, the Gini rises slightly to 0.2718 and mean income falls to €20,064.49, reducing the Sen index by €86.81. The heating tax similarly increases the Gini (0.2717) and lowers mean income to €20,072.63, with a Sen index drop of €77.56. Both policies slightly reduce welfare without significantly worsening inequality.

The motor fuels tax scenario results in the largest welfare loss, with the Sen index falling by €216.85, despite a slight Gini decline to 0.2711. This stems from a sharper drop in mean equivalent income (€19,860.63), which outweighs the marginal equity gain. Although the income quintile ratio remains stable across scenarios, these results show that moderate income changes can significantly affect welfare. Thus, the fuel tax has the most adverse impact, highlighting the need to jointly assess efficiency and equity in tax reform design.

5.3. Emissions effects of price-induced demand changes

Simulation results (Table 7) reveal asymmetric behavioral and environmental responses to energy price shocks across expenditure categories. A 20% increase in electricity prices raises the electricity budget share (+2.29%) and, more notably, heating-fuel expenditure (+3.55%), while food (-0.22%) and leisure (-0.29%) contract slightly. This reallocation, consistent with electricity's inelasticity and substitution toward complementary energy sources, leads to a net rise in emissions (+0.75%). Only 25% stems from electricity itself (+304 tCO_2e); the remainder originates from heating (+418 tCO_2e), illustrating a rebound effect (Chitnis & Sorrell, 2015).

This pattern aligns with earlier findings: high-income households substitute electricity and heating in response to relative prices, unlike lower-income groups. A similar gradient appears for motor fuels. Thus, emission rebounds are largely driven by wealthier households shifting toward more carbon-intensive energy. These results underscore the need for integrated carbon pricing or complementary measures to prevent environmentally counterproductive substitution.

In contrast, the gas price shock is the only scenario that reduces emissions (–0.40%), largely due to a sharp contraction in heating-related demand (–4.63%), cutting 546 tCO_2e.

While electricity use increases modestly (+0.88%), the offsetting emissions remain relatively small (+117 tCO_2e). The fuel shock, meanwhile, fails to deliver environmental benefits: although motor fuel use declines (–6.94%; –343 tCO_2e), emissions increase overall (+0.64%) due to compensatory rises in heating (+511 tCO_2e) and transport-related emissions (+262 tCO_2e).

These findings highlight the central role of heating in household emissions, i.e., small expenditure shifts can produce sizable emission effects. Electricity contributes both directly and indirectly, amplifying the rebound through substitution toward more polluting energy uses. Limited behavioral responses in essential categories like food and housing (share changes < ±0.5%) suggest that price instruments alone are insufficient for deep decarbonization without structural support. Our assumption of proportionality between spending and emissions (i.e., $GHG_i^1 = GHG_i^0 \times w_i^1/w_i^0$) likely overstates impacts, as intra-aggregate substitution and efficiency gains remain unobserved. Households may adopt cleaner fuels or more efficient appliances, reducing actual emissions. Since the simulation applies pre-shock emission factors to post-shock spending, results should be interpreted as upper-bound estimates. Overall, uniform price signals risk unintended outcomes unless accompanied by targeted support and access to cleaner alternatives—key considerations for effective and equitable climate policy.

5.4. Distributional results under compensation

Figure 2 illustrates significant heterogeneity in household outcomes across income quintiles under different energy price scenarios. Under the electricity tax, 61.02% of households are net winners and 38.98% losers. Although relatively balanced overall, low-income households face a higher incidence of losses, while high-income groups may also incur net losses due to high absolute consumption only partially offset by uniform transfer.

For the heating tax, outcomes are more evenly distributed: 54.39% winners and 45.61% losers. This reflects that heating expenditure depends more on dwelling characteristics (e.g., insulation, system efficiency) than income alone. However, the lump-sum transfer still fails to fully compensate many low-income households with greater heating needs.

In contrast, the fuels tax is markedly regressive: 79.86% of households are net losers, and only 20.14% benefit. Although the lowest quintile includes a slightly higher share of winners, it is likely due to lower car ownership—middle- and upper-income households absorb most losses given higher, less flexible fuel use. These results emphasize the inadequacy of uniform compensation in the context of transport fuels and underscore the need for targeted mechanisms that reflect actual energy needs and mobility constraints.

5.5 On the evaluation of behavioral responses and policy implications

To evaluate the alignment between our empirical model and aggregate behavior, we implement a national-level validation exercise. Annual household energy expenditures are constructed by multiplying budget shares (electricity, heating, fuels) by total household expenditure and a grossing-up factor, yielding aggregate figures for the EPF sample. Since the EPF excludes certain groups (e.g., institutional households), we apply a correction factor, computed as the ratio between total national expenditure reported in the Spanish National Accounts (INE, 2024) and the EPF aggregate. Table 9 summarizes this adjustment.

To capture price dynamics, we use monthly averages for Gasoline 95 E5, Diesel A, and compressed natural gas (Ministry for the Ecological Transition), and the electricity CPI (INE, base 2021). We then compare observed changes in energy demand with counterfactuals derived from: (i) our model-based elasticities and (ii) meta-analysis estimates from Labandeira et al. (2017).

Table 10 presents annual prices and demand variations. Two episodes dominate. First, during the COVID-19 crisis (2020-21), electricity prices rose sharply (+35.6%), yet demand fell only -20.9%, below both model (-30.7%) and literature-based (-25.1%) predictions. Heating demand rose (+8.3%), and fuel use increased slightly (+0.9%), likely due to more time spent at home, teleworking, and private vehicle reliance. Second, during the 2021-22 energy crisis following Russia's invasion of Ukraine, heating prices surged (+127.8%), along with electricity (+26.8%) and fuel (+36.3%). Still, observed demand reductions were far milder than predicted: electricity fell -13.7% (vs. -23.2% and -18.9%); heating -53.5% (vs. -193.6% and -158.1%); and fuels -6.1% (vs. -48.8% and -29.7%). These gaps highlight how, in crisis contexts, effective elasticities shrink as non-price constraints, precautionary motives, supply restrictions, and limited short-run flexibility, dominate behavior. This reflects the well-established divergence between micro-econometric estimates (typically more elastic) and muted aggregate responses in turbulent conditions (Labandeira et al., 2017).

Table 11 compares observed and predicted changes in household GHG emissions. For electricity, the model captures the direction of change annually but consistently overstates the magnitude. For example, it overshoots the 2017-18 decline (-5.3% vs. -3.9% observed), underpredicts the 2019-20 rebound (+1.1% vs. +3.7%), and again exaggerates the 2020-21 drop (-2.0% vs. -1.3%). Heating emissions display major sign mismatches: emissions increased in both 2017-18 and 2020-21 (+4.2% and +3.9%), while models predicted declines. Fuel emissions show similar discrepancies: 2019-20 predicted a -12% fall (vs. -1% observed), and 2020-21 predicted a +11% rise (vs. a slight -0.5% fall), likely due to mobility collapse during lockdowns, an effect unrelated to prices.

Overall, elasticity-based counterfactuals tend to overstate both declines (e.g., 2019-20: -3.6% estimated vs. -0.6% observed) and rebounds (e.g., 2021-22: +1.4% vs. +0.1%). These findings confirm that during health or geopolitical crises, non-price forces dominate. To further illustrate, we approximate the effects of the standardized 20% price increase for each energy aggregate by linearly scaling the average annual variations observed in Table 11. These back-of-the-envelope calculations show that elasticity-based counterfactuals tend to significantly overstate both reductions (e.g., electricity: –2.32% estimated vs. –0.30% observed) and increases (e.g., fuels: +4.70% estimated vs. +0.44% observed). This confirms that during periods of external shocks—such as health or geopolitical crisis-price determinants overwhelmingly drive household consumption patterns. Elasticity-based models, while useful, may substantially exaggerate actual behavioral responses, underscoring the need to contextualize their predictions when assessing the climate impact of price-based interventions.

Table 12 compares observed annual price elasticities with estimates from our model and Labandeira et al. (2017), revealing strong year-to-year variation. In 2017-18, heating demand rose despite price increases (+2.14), likely due to an unusually cold winter. In 2018-19, elasticities for all energy types were around -1.5, suggesting greater substitution under mild conditions. Electricity and heating remained price-sensitive in 2019-20 (-2.37 and -1.51), while fuel demand was largely unresponsive (-0.11). In 2020-21, elasticities for heating and fuels turned positive, reflecting lockdown-induced increases in home energy use and car reliance. By 2021-22, elasticities returned to negative signs but remained low (-0.51 to -0.17), well below model and literature benchmarks. On average, electricity is more elastic (-1.13) than expected, whereas heating (+0.10) and fuel (-0.39) are far less so. These findings reinforce that micro-level elasticities may overstate aggregate responsiveness, especially during crises.

On average, electricity demand appears more elastic (-1.13) than both model (–0.86) and literature (–0.71) suggest, while heating (+0.10) and fuels (–0.39) are markedly less elastic. These deviations underscore a broader point: micro-based elasticities, while informative, often overstate short-run aggregate responsiveness, especially during crises when household decisions are shaped by non-price constraints.

These discrepancies between observed and predicted responses suggest that price-based energy policies may be less effective than expected during periods of economic or geopolitical turmoil. In such contexts, households face rigidities—technological, behavioral, or contextual—that limit their ability to adjust consumption, even in the face of large price swings. This has two key implications: first, relying solely on carbon pricing may not deliver the intended environmental outcomes unless complemented by measures that facilitate substitution (e.g., building retrofits, public transport access, or clean heating alternatives). Second, policymakers must anticipate the limited behavioral responsiveness during crises and design compensation schemes accordingly, to avoid regressive impacts without overestimating environmental gains.

6. Conclusion

This study examines the distributional and environmental effects of energy price changes in Spain using a flexible demand system (EASI) and microsimulation techniques. Our results highlight the heterogeneous behavioral responses across income groups: electricity demand is inelastic but more responsive among low-income households, while heating and motor fuels are more elastic, especially for wealthier groups. Cross-price effects, particularly substitution between electricity and heating fuels, play a central role in shaping both welfare and emissions outcomes.

Price increases in electricity and heating are regressive, disproportionately affecting lower-income households. Motor fuel taxes are less clearly regressive but generate the largest aggregate welfare losses. Lump-sum transfers partially offset these impacts for electricity and heating, but are insufficient in the case of transport fuels, where nearly 80% of households experience net losses—especially those with high mobility needs. More targeted compensation schemes may be needed to ensure fairness and political viability.

On the environmental side, substitution patterns can undermine climate goals. Electricity price hikes increase emissions due to shifts toward more carbon-intensive heating, while only gas price shocks reduce emissions meaningfully. These findings underscore the importance of accounting for behavioral substitutions when designing price-based instruments.

Finally, comparing model predictions with aggregate data during recent crises reveals that real-world responses are often weaker than elasticities suggest, due to non-price constraints. Policymakers must therefore consider household heterogeneity, substitution effects, and structural barriers when designing equitable and effective carbon pricing.

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Table 1. Aggregation of COICOP categories

COICOP category	Description	Aggregate
011	Food	Food and beverages
012	Non-alcoholic beverages	Food and beverages
021	Alcoholic beverages	Food and beverages
022	Tobaccco	Food and beverages
041	Actual rents for housing	Housing
043	Maintenances and repair of the dwelling	Housing
044	Water supply and miscellaneous services related to the dwelling	Housing
0451	Electricity	Electricity
0452	Natural gas and town gas	Heating
0453	Liquefied hydrocarbons (butane, propane, etc)	Heating
0454	Lyquid fuels	Heating
0455	Solid fuels	Heating
07221	Diesel	Motor fuels
07222	Petrol	Motor fuels
07211	Accesories and parts for personal transport equipment	Transportation
12541	Motor vehicle insurances	Transportation
07230	Maintenance and repair of personal transport equipment	Transportation
07241	Hire of garages, parking spaces and personal transport equipment	Transportation
07242	Toll facilities and paarking meters	Transportation
07243	Driving schools, tests, licenses and road worthiness tests (ITV)	Transportation
073	Transport services	Transportation
082	Telephone and telefax equipment	Communication
083	Telephone and fax services	Communication
091	Audio-visual, photographic and information processing equipment	Leisure
093	Other recreational items and equipment for gardens and pets	Leisure
094	Recreational and cultural services	Leisure
095	Newspapers, books and stationary	Leisure
096	Package holidays	Leisure
06	Health	Other non durable goods
10	Education	Other non durable goods
11	Restaurants and hotels	Other non durable goods
12	Other goods and services	Other non durable goods

Table 2. Descriptive statistics

VARIABLES	Mean	SD
Budget shares		
Budget share: Food and beverages	0.233	0.103
Budget share: Housing	0.090	0.086
Budget share: Electricity	0.030	0.016
Budget share: Heating	0.027	0.021
Budget share: Motor fuels	0.079	0.058
Budget share: Transport	0.044	0.062
Budget share: Communication	0.047	0.024
Budget share: Leisure	0.080	0.068
Budget share: Other non durable goods	0.369	0.121
Log Prices		
Price: Food and beverages	4.450	0.264
Price: Housing	4.093	0.268
Price: Electricity	4.500	0.197
Price: Heating	3.810	0.118
Price: Motor fuels	4.105	0.314
Price: Transport	3.964	0.359
Price: Communication	4.505	0.276
Price: Leisure	3.756	0.399
Price: Other non durable goods	4.331	0.237
Log Total Expenditure	10.144	0.434
Household characteristics		
No. household members	2.991	1.166
Single-family house	0.179	0.384
Rural environment	0.046	0.209
25 or more years ago	0.575	0.494
Less than 25 years old	0.425	0.494
Over 100k inhabitants	0.528	0.499
100k - 20k inhabitants	0.266	0.442
Below 20k inhabitants	0.206	0.404

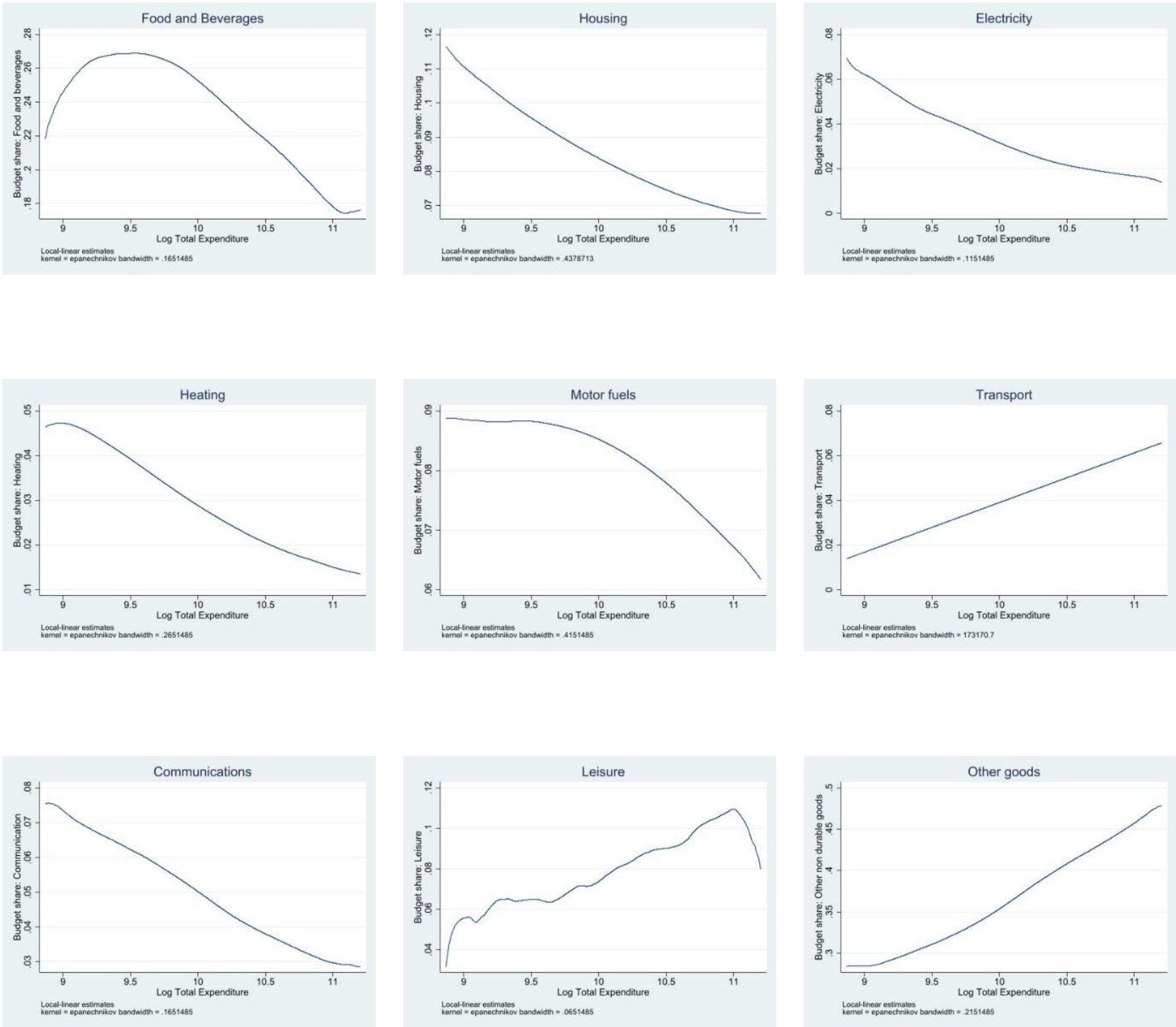
Table 2. Descriptives (cont.)

VARIABLES	Mean	SD
Household head sociodemographics		
Household head: Age	51.944	12.614
Elementary school or less	0.206	0.404
High school	0.055	0.228
Vocational	0.189	0.391
Undergraduate	0.345	0.475
Postgraduate	0.126	0.332
Household Head: Male	0.285	0.451
Household type		
Single adult household. One person aged 65 or over.	0.016	0.127
Single adult household. A person under 30 to 64 years old.	0.067	0.250
Single adult household. One adult with children under 16 years old.	0.011	0.107
Childless couple with at least one member aged 65 or older.	0.089	0.284
Childless couple with both members under 65 years of age.	0.143	0.350
Couple with children.	0.537	0.499
Lone parent with at least one child aged 16 or over	0.069	0.253
Other households	0.068	0.252
Climatic variables		
Heating degree days	141.264	134.236
Cooling degree days	22.997	45.419
Years		
Year 2017	0.158	0.365
Year 2018	0.202	0.401
Year 2019	0.192	0.394
Year 2020	0.145	0.352
Year 2021	0.148	0.355
Year 2022	0.156	0.363

Table 2. Descriptives (cont.)

VARIABLES	Mean	SD
Regions		
Region: Andalucia	0.014	0.118
Region: Aragon	0.046	0.208
Region: Asturias	0.026	0.159
Region: Islas Baleares	0.012	0.108
Region: Canarias	0.000	0.000
Region: Cantabria	0.019	0.138
Region: Castilla y Leon	0.070	0.256
Region: Castilla-La Mancha	0.040	0.195
Region: Catalunya	0.194	0.396
Region: Comunitat Valenciana	0.039	0.193
Region: Extremadura	0.011	0.105
Region: Galicia	0.036	0.187
Region: Comunidad de Madrid	0.355	0.479
Region: Region de Murcia	0.009	0.093
Region: Comunidad Foral de Navarra	0.026	0.160
Region: Pais Vasco	0.092	0.290
Region: La Rioja	0.010	0.102
Region: Ceuta	0.000	0.000
Region: Melilla	0.000	0.000

Figure 1. Non-parametric Engel curves



Note: Nonparametric Engel curves for nine consumption categories estimated using kernel regressions of budget shares on log household income. The figures depict the relationship between income and expenditure shares for food, housing, electricity, heating, motor fuels, transport, communications, leisure, and other goods. Estimates are based on data from the Spanish Household Budget Survey (2017–2022)

Table 3. EASI implicit Marshallian demand system

Variable	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Log price food	0.025***	-0.015***	-0.003***	-0.003***	0.006***	-0.003**	-0.004***	-0.005***	0.001
	(0.003)	(0.001)	(0.000)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.003)
Log price housing	-0.015***	0.046***	-0.001***	-0.003***	0.005***	-0.001	-0.004***	-0.008***	-0.019***
	(0.001)	(0.002)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Log price electricity	-0.003***	-0.001***	0.003***	0.006***	0.003***	0.000	-0.001***	-0.001***	-0.005***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log price heating	-0.003***	-0.003***	0.006***	-0.003**	0.006***	0.001*	0.001	-0.001***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Log price motor fuels	0.006***	0.005***	0.003***	0.006***	-0.028***	0.006***	0.003***	-0.013***	0.012***
	(0.002)	(0.001)	(0.000)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Log price transport	-0.003**	-0.001	0.000	0.001*	0.006***	-0.021***	-0.001***	0.001	0.018***
	(0.002)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Log price communication	-0.004***	-0.004***	-0.001***	0.001	0.003***	-0.001***	0.019***	-0.002***	-0.011***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Log price leisure	-0.005***	-0.008***	-0.001***	-0.001***	-0.013***	0.001	-0.002***	0.025***	0.004**
	(0.002)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.002)	(0.002)
Log price other goods	0.001	-0.019***	-0.005***	-0.004***	0.012***	0.018***	-0.011***	0.004**	0.004
	(0.003)	(0.002)	(0.000)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.004)
ln (y)	11.618*	1.364	-0.156	2.81*	-8.999**	-0.851	-1.208	-11.999**	7.42
	(6.700)	(4.639)	(1.058)	(1.527)	(3.657)	(3.515)	(1.766)	(4.685)	(8.158)
$\ln(y)^2$	-2.668	-0.380	0.008	-0.713*	2.361**	0.160	0.308	3.089**	-2.165
	(1.716)	(1.200)	(0.27)	(0.389)	(0.939)	(0.917)	(0.449)	(1.218)	(2.12)
$\ln(y)^3$	0.270	0.044	0.001	0.079*	-0.272**	-0.011	-0.036	-0.352**	0.277
	(0.195)	(0.138)	(0.03)	(0.044)	(0.107)	(0.106)	(0.051)	(0.140)	(0.244)
$\ln(y)^4$	-0.010	-0.002	-0.000	-0.003*	0.012**	0.000	0.002	0.015**	-0.013
	(0.008)	(0.006)	(0.001)	(0.002)	(0.005)	(0.005)	(0.002)	(0.006)	(0.01)

Table 4. Own price elasticities by quintile in EASI demand systems

Quintiles	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Quintile 1	-0.898***	-0.480***	-0.896***	-1.052***	-1.343***	-1.770***	-0.652***	-0.609***	-1.063***
	(0.012)	(0.018)	(0.017)	(0.031)	(0.023)	(0.058)	(0.011)	(0.026)	(0.015)
Quintile 2	-0.843***	-0.419***	-0.882***	-1.075***	-1.339***	-1.570***	-0.607***	-0.670***	-1.097***
	(0.011)	(0.021)	(0.022)	(0.039)	(0.023)	(0.039)	(0.013)	(0.023)	(0.013)
Quintile 3	-0.822***	-0.386***	-0.866***	-1.092***	-1.331***	-1.527***	-0.556***	-0.719***	-1.112***
	(0.012)	(0.022)	(0.027)	(0.044)	(0.024)	(0.035)	(0.014)	(0.020)	(0.012)
Quintile 4	-0.807***	-0.336***	-0.847***	-1.120***	-1.335***	-1.455***	-0.496***	-0.746***	-1.118***
	(0.013)	(0.025)	(0.032)	(0.055)	(0.025)	(0.030)	(0.016)	(0.019)	(0.011)
Quintile 5	-0.793***	-0.341***	-0.824***	-1.153***	-1.374***	-1.405***	-0.407***	-0.788***	-1.103***
	(0.015)	(0.027)	(0.039)	(0.066)	(0.027)	(0.025)	(0.019)	(0.018)	(0.010)

Table 5. Expenditure elasticities by quintile. EASI demand system

Quintiles	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Quintile 1	0.968***	0.468***	0.251***	0.424***	1.218***	1.861***	0.514***	1.488***	1.237***
	(0.024)	(0.037)	(0.021)	(0.036)	(0.045)	(0.137)	(0.025)	(0.070)	(0.025)
Quintile 2	0.770***	0.490***	0.229***	0.277***	1.077***	1.794***	0.459***	1.518***	1.313***
	(0.019)	(0.031)	(0.022)	(0.037)	(0.034)	(0.071)	(0.023)	(0.043)	(0.016)
Quintile 3	0.696***	0.536***	0.206***	0.280***	0.939***	1.749***	0.392***	1.422***	1.331***
	(0.016)	(0.028)	(0.019)	(0.031)	(0.027)	(0.063)	(0.019)	(0.035)	(0.013)
Quintile 4	0.639***	0.588***	0.208***	0.295***	0.794***	1.615***	0.323***	1.367***	1.319***
	(0.021)	(0.042)	(0.027)	(0.046)	(0.034)	(0.070)	(0.026)	(0.042)	(0.015)
Quintile 5	0.598***	0.719***	0.311***	0.422***	0.636***	1.441***	0.272***	1.398***	1.258***
	(0.031)	(0.050)	(0.040)	(0.070)	(0.046)	(0.070)	(0.037)	(0.045)	(0.017)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at each expenditure quintile.

Table 6. Equivalent variation as percentage of total expenditure

Scenario 1: Increase in electricity price	
Equivalent variation: Policy 1 quintile 1	0.804
Equivalent variation: Policy 1 quintile 2	0.615
Equivalent variation: Policy 1 quintile 3	0.508
Equivalent variation: Policy 1 quintile 4	0.423
Equivalent variation: Policy 1 quintile 5	0.347
Scenario 2: Increase in heating fuels price	
Equivalent variation: Policy 2 quintile 1	0.697
Equivalent variation: Policy 2 quintile 2	0.394
Equivalent variation: Policy 2 quintile 3	0.481
Equivalent variation: Policy 2 quintile 4	0.389
Equivalent variation: Policy 2 quintile 5	0.324
Scenario 3: Increase in motor fuels price	
Equivalent variation: Policy 3 quintile 1	1.588
Equivalent variation: Policy 3 quintile 2	1.087
Equivalent variation: Policy 3 quintile 3	1.541
Equivalent variation: Policy 3 quintile 4	1.467
Equivalent variation: Policy 3 quintile 5	1.309

Note: Equivalent variation (EV) is expressed as a percentage of total household expenditure and represents the welfare loss from a 20% price increase in electricity, heating fuels, or motor fuels. Estimates are based on simulations using the EASI demand system and reflect average losses by income quintile. Welfare measures are computed following the methodology of Tovar-Reaños & Wölfing (2018), with price scenarios applied separately for each energy good.

Table 7. Estimated Effects of Energy Price Increases on Household Emissions

Aggregate Category	Baseline Expenditure Share	Electricity Shock	Gas Shock	Fuels Shock	Δ % (Electricity)	Δ % (Gas)	Δ % (Fuels)	Emissions (tCO_2e)	Δ Emissions (Electricity)	Δ Emissions (Heating)	Δ Emissions (Fuels)
Food and Beverages	0.2339	0.2334	0.2334	0.2353	-0.22%	0.02%	0.80%	23903.2	-52.587	4.781	191.226
Housing	0.0898	0.0895	0.0893	0.0906	-0.38%	-0.19%	1.42%	6254.701	-23.768	-11.884	88.817
Electricity	0.0301	0.0308	0.0311	0.0306	2.29%	0.88%	-1.53%	13291.12	304.367	116.962	-203.354
Heating	0.0271	0.0281	0.0268	0.0279	3.55%	-4.63%	4.34%	11784.72	418.358	-545.633	511.457
Motor Fuels	0.0792	0.0797	0.0800	0.0744	0.61%	0.43%	-6.94%	4944.952	30.164	21.263	-343.180
Transport	0.0438	0.0439	0.0440	0.0449	0.02%	0.42%	2.03%	12930.09	2.586	54.306	262.481
Communication	0.0470	0.0469	0.0472	0.0476	-0.24%	0.50%	0.83%	82.19694	-0.197	0.411	0.682
Leisure	0.0796	0.0793	0.0792	0.0772	-0.29%	-0.12%	-2.52%	1466.989	-4.254	-1.760	-36.968
Other Non-Durable Goods	0.3695	0.3686	0.3690	0.3715	-0.26%	0.13%	0.66%	11471.8	-29.827	14.913	75.714
Total								86129.769	644.841	-346.640	546.874
Emission Variation									0.749%	-0.402%	0.635%

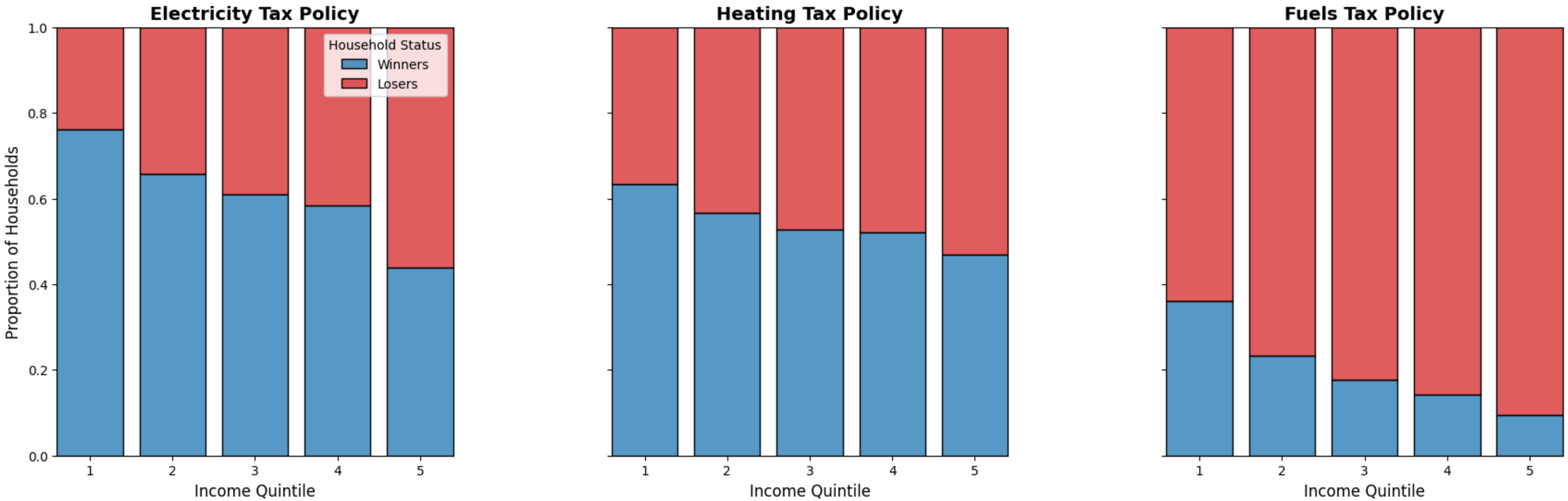
Note: This table presents the estimated effects of a 20% price increase in electricity, heating (gas), and motor fuels on household expenditure shares and associated CO_2-equivalent emissions. Budget shares are based on observed expenditure patterns and adjusted using a matrix of compensated price elasticities. Emissions are attributed to consumption categories using official production-based GHG inventories (INE, 2023), mapped to household consumption aggregates via the Spanish supply-use tables. The analysis assumes constant emission intensities and no substitution within aggregates. Emission variations are computed proportionally to changes in predicted expenditure shares. Results are reported in metric tons of CO_2 equivalent (tCO_2e).

Table 8. Inequality and sen’s index for Social Welfare over different scenarios

	Gini		Mean equivalent income		Sen's index (€)	
Scenario	**Level**	**Δ in %**	**Level**	**1st quintile / 5 quintile in %**	**SW**	**Δ SW**
Reference	0.2712		20162.24	47.416%	15223.54	
Electricity	0.2718	0.221%	20064.49	47.213%	15136.73	-86.81
Heating	0.2717	0.184%	20072.63	47.248%	15145.98	-77.56
Fuels	0.2711	-0.037%	19860.63	47.236%	15006.69	-216.85

Note: The Gini index and Sen’s social welfare measure are computed using household-level equivalent incomes (adjusted by household size) and weighted by sampling factors. Welfare losses are calculated via equivalent variation (EV). Calculations follow the approach of Tovar-Reaños & Wölfing (2018).

Figure 2: Winners and Losers by Income Quintile Under Different Scenarios



Note: Based on simulations using EASI model estimates and equivalent variation (EV) measures. Households are classified as *winners* if the flat compensation exceeds their welfare loss, and *losers* otherwise. The lump-sum transfer is financed by the additional tax revenue generated under each scenario and distributed equally across households.

Table 9. Corrected National Aggregated Expenditure (thousand euros)

Year	Electricity expenditure	Heating expenditure	Fuels expenditure	Energy expenditure	Aggregate household expenditure	Correction factor	Total electricity expenditure (Corrected)	Total heating expenditure (Corrected)	Total fuels expenditure (Corrected)
2017	1098054.915	984643.6157	3195359.043	5278057.574	23384000	4.430	4864841.992	4362382.56	14156775.45
2018	1442425.72	1384707.465	4448728.971	7275862.156	24755000	3.402	4907631.279	4711253.81	15136114.91
2019	1406355.5	1306655.668	4184668.495	6897679.664	24803000	3.596	5057039.059	4698533.725	15047427.22
2020	1030032.602	879099.6014	2517762.265	4426894.469	23998000	5.421	5583761.385	4765560.233	13648678.38
2021	1101227.824	992534.8564	2945686.393	5039449.074	27402000	5.437	5987925.346	5396907.427	16017167.23
2022	1353175.059	1179635.8	4233832.54	6766643.4	32773000	4.843	6553855.966	5713350.298	20505793.74

Note: The national-level corrected expenditures for electricity, heating, and fuels were obtained by multiplying the expenditure estimates from the Household Budget Survey (EPF) by a correction factor, calculated as the ratio between the aggregate expenditure on electricity, gas, and other fuels reported in the National Accounts and the corresponding total observed in the EPF, thereby adjusting for coverage discrepancies such as the exclusion of institutional households.

Table 10. Annual and average anually price and quantity variation according to observed, estimated and literature elasticities

Years	Price electricity	Price heating	Price fuels	Electricity demand	Estimated electricity demand	Literature electricity demand	Heating demand	Estimated heating demand	Literature heating demand	Fuels demand	Estimated fuels demand	Literature fuels demand
2017/2018	2.460%	2.504%	7.405%	-1.542%	-2.123%	-1.734%	5.360%	-3.794%	-3.098%	-0.454%	-9.955%	-6.068%
2018/2019	-6.702%	0.521%	0.865%	10.447%	5.784%	4.725%	-0.787%	-0.789%	-0.644%	-1.439%	-1.163%	-0.709%
2019/2020	-9.000%	-3.064%	-10.285%	21.336%	7.767%	6.345%	4.632%	4.642%	3.791%	1.102%	13.826%	8.428%
2020/2021	35.589%	4.591%	16.286%	-20.909%	-30.713%	-25.090%	8.277%	-6.957%	-5.681%	0.918%	-21.895%	-13.347%
2021/2022	26.840%	127.779%	36.284%	-13.709%	-23.163%	-18.922%	-53.524%	-193.619%	-158.118%	-6.061%	-48.780%	-29.734%
Mean	9.837%	26.466%	10.111%	-0.875%	-8.489%	-6.935%	-7.208%	-40.103%	-32.750%	-1.187%	-13.593%	-8.286%

Note: This table presents the annual and average yearly variations in energy prices and household energy demand (electricity, heating, and fuels) for the period 2017–2022. It includes the observed demand changes and two sets of counterfactual estimates derived from applying observed and literature-based price elasticities. Estimated demand changes are calculated as the product of annual price variation and the corresponding elasticity. This allows a comparison between actual consumption behavior and expected reactions based on economic theory and previous empirical findings.

Table 11: Inter-annual and average variations in prices and household demand for electricity, heating, and transport fuels

Years	Emissions electricity	Estimated emissions elecricity	Literature emissions electricity	Emissions heating	Estimated emissions heating	Literature emissions heating	Emissions fuels	Estimated emissions fuels	Literature emissions fuels	Total emissions	Estimated total variation	Literature emission variation
2017/2018	-3.858%	-5.311%	-4.338%	4.160%	-0.074%	-2.404%	-0.036%	-0.793%	-0.483%	-0.14%	-2.552%	-2.960%
2018/2019	0.717%	0.397%	0.324%	-0.211%	-0.212%	-0.173%	0.970%	0.784%	0.478%	0.39%	0.216%	0.150%
2019/2020	3.717%	1.106%	1.106%	-5.219%	-5.230%	-4.271%	-0.949%	-11.907%	-7.258%	-0.62%	-3.577%	-2.425%
2020/2021	-1.341%	-1.970%	-1.609%	3.883%	-3.264%	-2.665%	-0.461%	10.991%	6.700%	0.79%	-0.324%	-0.641%
2021/2022	0.039%	0.066%	0.054%	-0.509%	-1.841%	-1.504%	1.590%	12.799%	7.802%	0.08%	1.392%	0.705%
Mean	-0.145%	-1.142%	-0.893%	0.421%	-2.124%	-2.204%	0.223%	2.375%	1.448%	0.098%	-0.969%	-1.034%

Note: This table presents the annual variation in GHG emissions from household consumption of electricity, heating, and fuels, disaggregated by energy type. The first column for each energy source shows the observed emission change based on actual consumption variation; the second reflects the estimated variation using the price elasticities derived in this study; and the third column uses elasticity values drawn from a meta-analysis of existing literature. The last three columns aggregate these changes to reflect total annual household emissions variation under each of the three approaches. This comparison enables an assessment of how closely behavioral responses align with theoretical and empirical benchmarks.

Table 12: Annual and Average Observed, Model-Estimated, and Literature-Based Price Elasticities of Energy Demand by Source

Year	Electricity elasticity	Heating elasticity	Fuels elasticity
2017 -2018	-0.627	2.141	-0.061
2018 -2019	-1.559	-1.511	-1.663
2019 - 2020	-2.371	-1.512	-0.107
2020 - 2021	-0.588	1.803	0.056
2021 -2022	-0.511	-0.419	-0.167
Mean	-1.131	0.100	-0.388
Estimated	-0.863	-1.098	-1.344
Literature	-0.705	-0.897	-0.820

Note: This table presents annual estimates of price elasticity of demand for electricity, heating, and fuels, calculated based on observed variations in expenditure, prices, and quantities. These observed elasticities are compared to elasticities estimated using our econometric model, as well as values drawn from a meta-analysis of the existing literature. Positive values may appear in heating elasticities due to specific external conditions (e.g. temperature anomalies or policy effects), and zero values reflect periods where no change in quantity was observed despite price changes.

Appendix A. Uncompensated cross-price elasticities

Table A1. Uncompensated price elasticities for quintile 1. EASI demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.898***	-0.006	0.138***	0.085***	0.013	-0.342***	0.063***	-0.208***	-0.063***
	(0.012)	(0.018)	(0.011)	(0.017)	(0.021)	(0.066)	(0.012)	(0.032)	(0.011)
Housing	-0.051***	-0.480***	0.041***	-0.018	0.032**	-0.115***	-0.010	-0.187***	-0.084***
	(0.006)	(0.018)	(0.009)	(0.016)	(0.015)	(0.043)	(0.010)	(0.018)	(0.006)
Electricity	-0.009***	0.009**	-0.896***	0.176***	0.020***	-0.032**	0.005	-0.045***	-0.027***
	(0.002)	(0.004)	(0.017)	(0.018)	(0.006)	(0.013)	(0.006)	(0.006)	(0.002)
Heating	-0.009***	-0.009	0.162***	-1.052***	0.059***	0.002	0.028***	-0.040***	-0.021***
	(0.002)	(0.006)	(0.016)	(0.031)	(0.008)	(0.020)	(0.009)	(0.008)	(0.003)
Motor fuels	0.026***	0.095***	0.125***	0.202***	-1.343***	0.143***	0.096***	-0.253***	0.018***
	(0.006)	(0.014)	(0.010)	(0.018)	(0.023)	(0.046)	(0.010)	(0.020)	(0.006)
Transport	-0.010*	0.006	0.024***	0.041***	0.063***	-1.770***	-0.008	-0.005	0.052***
	(0.006)	(0.011)	(0.007)	(0.014)	(0.014)	(0.058)	(0.008)	(0.019)	(0.005)
Communication	-0.013***	-0.004	0.023***	0.049***	0.023***	-0.099***	-0.652***	-0.061***	-0.050***
	(0.003)	(0.007)	(0.008)	(0.014)	(0.008)	(0.021)	(0.011)	(0.009)	(0.003)
Leisure	-0.015**	-0.053***	0.013*	0.003	-0.156***	-0.033	-0.002	-0.609***	-0.001
	(0.006)	(0.011)	(0.007)	(0.012)	(0.014)	(0.043)	(0.008)	(0.026)	(0.006)
Other goods	0.012	-0.026	0.119***	0.090***	0.071***	0.387***	-0.034**	-0.081**	-1.063***
	(0.012)	(0.021)	(0.013)	(0.022)	(0.025)	(0.071)	(0.015)	(0.035)	(0.015)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table A2. Uncompensated price elasticities for quintile 2. EASI demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.843***	-0.040**	0.117***	0.096***	0.054***	-0.286***	0.063***	-0.201***	-0.080***
	(0.011)	(0.018)	(0.013)	(0.020)	(0.020)	(0.042)	(0.013)	(0.025)	(0.008)
Housing	-0.037***	-0.419***	0.024**	-0.035*	0.049***	-0.090***	-0.020*	-0.165***	-0.082***
	(0.006)	(0.021)	(0.011)	(0.020)	(0.015)	(0.030)	(0.011)	(0.015)	(0.005)
Electricity	-0.003*	0.001	-0.882***	0.219***	0.028***	-0.023***	0.000	-0.038***	-0.025***
	(0.002)	(0.005)	(0.022)	(0.023)	(0.005)	(0.009)	(0.007)	(0.005)	(0.002)
Heating	-0.004	-0.019***	0.196***	-1.075***	0.067***	0.002	0.027***	-0.033***	-0.020***
	(0.002)	(0.007)	(0.021)	(0.039)	(0.008)	(0.014)	(0.010)	(0.006)	(0.002)
Motor fuels	0.044***	0.099***	0.142***	0.258***	-1.339***	0.090***	0.107***	-0.227***	0.009
	(0.006)	(0.015)	(0.014)	(0.023)	(0.023)	(0.032)	(0.012)	(0.017)	(0.005)
Transport	-0.003	0.010	0.034***	0.060***	0.067***	-1.570***	-0.004	-0.012	0.041***
	(0.006)	(0.013)	(0.010)	(0.018)	(0.014)	(0.039)	(0.009)	(0.017)	(0.005)
Communication	-0.004	-0.014**	0.012	0.056***	0.033***	-0.076***	-0.607***	-0.055***	-0.049***
	(0.003)	(0.007)	(0.011)	(0.018)	(0.008)	(0.014)	(0.013)	(0.007)	(0.002)
Leisure	-0.002	-0.062***	0.011	0.009	-0.152***	-0.041	0.002	-0.670***	-0.009*
	(0.006)	(0.012)	(0.009)	(0.015)	(0.014)	(0.031)	(0.009)	(0.023)	(0.005)
Other goods	0.081***	-0.045**	0.117***	0.133***	0.117***	0.201***	-0.025	-0.116***	-1.097***
	(0.012)	(0.021)	(0.016)	(0.027)	(0.024)	(0.048)	(0.016)	(0.028)	(0.013)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table A3. Uncompensated price elasticities for quintile 3. EASI demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.822***	-0.071***	0.094***	0.072***	0.090***	-0.257***	0.061***	-0.161***	-0.080***
	(0.012)	(0.019)	(0.016)	(0.023)	(0.020)	(0.039)	(0.015)	(0.021)	(0.008)
Housing	-0.036***	-0.386***	0.012	-0.054**	0.061***	-0.080***	-0.028**	-0.138***	-0.078***
	(0.006)	(0.022)	(0.014)	(0.023)	(0.015)	(0.027)	(0.013)	(0.013)	(0.005)
Electricity	-0.003*	-0.005	-0.866***	0.244***	0.032***	-0.017**	-0.004	-0.030***	-0.023***
	(0.002)	(0.005)	(0.027)	(0.027)	(0.005)	(0.008)	(0.008)	(0.004)	(0.001)
Heating	-0.003	-0.024***	0.231***	-1.092***	0.072***	0.004	0.028**	-0.026***	-0.018***
	(0.002)	(0.008)	(0.025)	(0.044)	(0.008)	(0.013)	(0.012)	(0.006)	(0.002)
Motor fuels	0.051***	0.099***	0.160***	0.286***	-1.331***	0.082***	0.121***	-0.193***	0.005
	(0.007)	(0.016)	(0.016)	(0.026)	(0.024)	(0.030)	(0.014)	(0.015)	(0.005)
Transport	0.000	0.009	0.039***	0.068***	0.074***	-1.527***	-0.003	-0.011	0.036***
	(0.006)	(0.014)	(0.012)	(0.020)	(0.015)	(0.035)	(0.011)	(0.015)	(0.004)
Communication	-0.003	-0.023***	0.002	0.054***	0.041***	-0.066***	-0.556***	-0.043***	-0.046***
	(0.003)	(0.007)	(0.013)	(0.020)	(0.007)	(0.012)	(0.014)	(0.006)	(0.002)
Leisure	0.006	-0.068***	0.012	0.011	-0.144***	-0.048*	0.008	-0.719***	-0.015***
	(0.007)	(0.013)	(0.011)	(0.018)	(0.014)	(0.028)	(0.011)	(0.020)	(0.005)
Other goods	0.114***	-0.067***	0.111***	0.131***	0.167***	0.160***	-0.019	-0.101***	-1.112***
	(0.012)	(0.022)	(0.018)	(0.030)	(0.023)	(0.044)	(0.017)	(0.024)	(0.012)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table A4. Uncompensated price elasticities for quintile 4. EASI demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.807***	-0.110***	0.056***	0.031	0.124***	-0.201***	0.051***	-0.134***	-0.071***
	(0.013)	(0.021)	(0.019)	(0.030)	(0.021)	(0.035)	(0.017)	(0.020)	(0.007)
Housing	-0.039***	-0.336***	-0.005	-0.084***	0.073***	-0.062***	-0.038***	-0.121***	-0.070***
	(0.007)	(0.025)	(0.016)	(0.029)	(0.016)	(0.024)	(0.014)	(0.012)	(0.004)
Electricity	-0.004**	-0.010**	-0.847***	0.288***	0.037***	-0.011	-0.008	-0.025***	-0.020***
	(0.002)	(0.005)	(0.032)	(0.034)	(0.006)	(0.007)	(0.009)	(0.004)	(0.001)
Heating	-0.004*	-0.031***	0.271***	-1.120***	0.078***	0.007	0.028**	-0.022***	-0.016***
	(0.003)	(0.008)	(0.030)	(0.055)	(0.009)	(0.011)	(0.013)	(0.005)	(0.002)
Motor fuels	0.057***	0.099***	0.176***	0.331***	-1.335***	0.075***	0.134***	-0.172***	0.005
	(0.007)	(0.017)	(0.020)	(0.032)	(0.025)	(0.027)	(0.016)	(0.014)	(0.005)
Transport	0.004	0.008	0.045***	0.080***	0.084***	-1.455***	0.001	-0.012	0.030***
	(0.007)	(0.015)	(0.014)	(0.025)	(0.015)	(0.030)	(0.012)	(0.014)	(0.004)
Communication	-0.004	-0.032***	-0.010	0.054**	0.048***	-0.052***	-0.496***	-0.036***	-0.041***
	(0.003)	(0.008)	(0.016)	(0.025)	(0.008)	(0.011)	(0.016)	(0.006)	(0.002)
Leisure	0.012	-0.078***	0.008	0.006	-0.137***	-0.044*	0.013	-0.746***	-0.017***
	(0.007)	(0.014)	(0.013)	(0.021)	(0.015)	(0.025)	(0.012)	(0.019)	(0.005)
Other goods	0.146***	-0.096***	0.097***	0.119***	0.233***	0.128***	-0.008	-0.098***	-1.118***
	(0.014)	(0.026)	(0.022)	(0.039)	(0.026)	(0.044)	(0.021)	(0.024)	(0.011)

Note: Key: Significance levels *($p < 0.10$), **($p < 0.05$), ***($p < 0.01$). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table A5. Uncompensated price elasticities for quintile 5. EASI demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.793*** (0.015)	-0.149*** (0.021)	-0.010 (0.023)	-0.039 (0.037)	0.161*** (0.024)	-0.144*** (0.031)	0.024 (0.020)	-0.125*** (0.018)	-0.051*** (0.007)
Housing	-0.045*** (0.007)	-0.341*** (0.027)	-0.025 (0.020)	-0.121*** (0.035)	0.093*** (0.018)	-0.047** (0.020)	-0.051*** (0.017)	-0.112*** (0.011)	-0.062*** (0.004)
Electricity	-0.007*** (0.002)	-0.015*** (0.005)	-0.824*** (0.039)	0.340*** (0.040)	0.043*** (0.006)	-0.006 (0.006)	-0.015 (0.011)	-0.022*** (0.003)	-0.017*** (0.001)
Heating	-0.007** (0.003)	-0.036*** (0.009)	0.318*** (0.037)	-1.153*** (0.066)	0.090*** (0.010)	0.010 (0.010)	0.029* (0.016)	-0.019*** (0.005)	-0.013*** (0.002)
Motor fuels	0.060*** (0.008)	0.086*** (0.018)	0.184*** (0.024)	0.372*** (0.039)	-1.374*** (0.027)	0.080*** (0.024)	0.146*** (0.019)	-0.154*** (0.012)	0.010** (0.005)
Transport	0.007 (0.008)	0.003 (0.015)	0.046*** (0.017)	0.087*** (0.029)	0.104*** (0.017)	-1.405*** (0.025)	0.001 (0.015)	-0.016 (0.012)	0.028*** (0.004)
Communication	-0.007** (0.003)	-0.039*** (0.008)	-0.027 (0.019)	0.050* (0.030)	0.057*** (0.009)	-0.039*** (0.009)	-0.407*** (0.019)	-0.032*** (0.005)	-0.035*** (0.002)
Leisure	0.018** (0.008)	-0.088*** (0.015)	-0.006 (0.016)	-0.010 (0.026)	-0.140*** (0.016)	-0.035 (0.022)	0.017 (0.015)	-0.788*** (0.018)	-0.016*** (0.004)
Other goods	0.176*** (0.017)	-0.141*** (0.029)	0.034 (0.028)	0.053 (0.047)	0.329*** (0.031)	0.145*** (0.044)	-0.017 (0.024)	-0.129*** (0.025)	-1.103*** (0.010)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Appendix B. QUAIDS results

Table B1. QUAIDS demand system

Variable	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Log price food	0.028***	-0.015***	-0.003***	-0.003***	0.008***	-0.000	-0.004***	-0.006***	-0.005*
	(0.003)	(0.001)	(0.000)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.003)
Log price housing	-0.015***	0.046***	-0.002***	-0.003***	0.004***	-0.002	-0.003***	-0.007***	-0.019***
	(0.001)	(0.002)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Log price electricity	-0.003***	-0.002***	0.004***	0.005***	0.003***	0.000	-0.001*	-0.001***	-0.005***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log price heating	-0.003***	-0.003***	0.005***	-0.002	0.005***	0.001*	0.001	-0.002***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Log price motor fuels	0.008***	0.004***	0.003***	0.005***	-0.026***	0.006***	0.003***	-0.013***	0.011***
	(0.002)	(0.001)	(0.000)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Log price transport	-0.000	-0.002	0.000	0.001*	0.006***	-0.02***	-0.001***	0.001	0.016***
	(0.002)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.002)
Log price communication	-0.004***	-0.003***	-0.001*	0.001	0.003***	-0.001***	0.02***	-0.002***	-0.012***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
Log price leisure	-0.006***	-0.007***	-0.001***	-0.002***	-0.013***	0.001	-0.002***	0.025***	0.006***
	(0.002)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.002)	(0.002)
Log price other goods	-0.005*	-0.019***	-0.005***	-0.003***	0.011***	0.016***	-0.012***	0.006***	0.011***
	(0.003)	(0.002)	(0.000)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.004)
ln (y)	0.353***	-0.156***	-0.112***	-0.065***	0.207***	0.003	-0.065***	-0.018	-0.148***
	(0.045)	(0.026)	(0.007)	(0.01)	(0.025)	(0.026)	(0.011)	(0.031)	(0.053)
Ln $(y)^2$	-0.035***	0.010***	0.008***	0.004***	-0.018***	0.002	0.003***	0.004	0.021***
	(0.004)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.003)	(0.005)

Table B2. Own price elasticities by quintile in QUAIDS demand systems

Quintiles	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Quintile 1	-0.878***	-0.468***	-0.883***	-1.023***	-1.311***	-1.763***	-0.651***	-0.629***	-1.047***
	(0.011)	(0.018)	(0.017)	(0.031)	(0.023)	(0.058)	(0.010)	(0.026)	(0.014)
Quintile 2	-0.849***	-0.419***	-0.863***	-1.038***	-1.302***	-1.555***	-0.600***	-0.675***	-1.066***
	(0.011)	(0.020)	(0.022)	(0.038)	(0.023)	(0.039)	(0.013)	(0.023)	(0.012)
Quintile 3	-0.826***	-0.390***	-0.842***	-1.049***	-1.299***	-1.510***	-0.548***	-0.721***	-1.078***
	(0.012)	(0.022)	(0.027)	(0.044)	(0.023)	(0.035)	(0.014)	(0.020)	(0.011)
Quintile 4	-0.801***	-0.355***	-0.819***	-1.066***	-1.307***	-1.457***	-0.490***	-0.746***	-1.089***
	(0.012)	(0.025)	(0.032)	(0.055)	(0.025)	(0.030)	(0.016)	(0.019)	(0.010)
Quintile 5	-0.764***	-0.334***	-0.788***	-1.086***	-1.334***	-1.393***	-0.402***	-0.779***	-1.106***
	(0.014)	(0.027)	(0.039)	(0.066)	(0.027)	(0.025)	(0.019)	(0.018)	(0.010)

Table B3. Uncompensated price elasticities for quintile 1. QUAIDS demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.878***	-0.024	0.129***	0.090***	0.035*	-0.265***	0.076***	-0.211***	-0.086***
	(0.011)	(0.017)	(0.010)	(0.016)	(0.020)	(0.063)	(0.012)	(0.029)	(0.009)
Housing	-0.048***	-0.468***	0.025***	-0.018	0.028*	-0.149***	-0.005	-0.156***	-0.085***
	(0.006)	(0.018)	(0.009)	(0.016)	(0.015)	(0.043)	(0.010)	(0.018)	(0.005)
Electricity	-0.007***	0.002	-0.883***	0.163***	0.021***	-0.041***	0.013**	-0.039***	-0.028***
	(0.002)	(0.004)	(0.017)	(0.018)	(0.005)	(0.013)	(0.006)	(0.005)	(0.002)
Heating	-0.007***	-0.011*	0.146***	-1.023***	0.044***	0.001	0.031***	-0.045***	-0.018***
	(0.002)	(0.006)	(0.016)	(0.031)	(0.008)	(0.020)	(0.009)	(0.007)	(0.002)
Motor fuels	0.035***	0.087***	0.123***	0.169***	-1.311***	0.133***	0.092***	-0.237***	0.011*
	(0.006)	(0.013)	(0.010)	(0.018)	(0.023)	(0.045)	(0.010)	(0.020)	(0.006)
Transport	0.001	-0.003	0.020***	0.042***	0.062***	-1.763***	-0.009	-0.003	0.043***
	(0.006)	(0.011)	(0.007)	(0.014)	(0.014)	(0.058)	(0.008)	(0.019)	(0.005)
Communication	-0.010***	-0.006	0.030***	0.054***	0.020***	-0.112***	-0.651***	-0.053***	-0.054***
	(0.003)	(0.006)	(0.008)	(0.014)	(0.008)	(0.020)	(0.010)	(0.008)	(0.003)
Leisure	-0.019***	-0.047***	0.016**	-0.011	-0.157***	-0.041	0.005	-0.629***	0.001
	(0.006)	(0.011)	(0.007)	(0.012)	(0.014)	(0.043)	(0.008)	(0.026)	(0.006)
Other goods	0.005	-0.043**	0.105***	0.115***	0.060**	0.281***	-0.028*	-0.043	-1.047***
	(0.012)	(0.020)	(0.012)	(0.021)	(0.023)	(0.065)	(0.015)	(0.032)	(0.014)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table B4. Uncompensated price elasticities for quintile 2. QUAIDS demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.849***	-0.054***	0.118***	0.082***	0.077***	-0.195***	0.073***	-0.196***	-0.089***
	(0.011)	(0.017)	(0.013)	(0.020)	(0.019)	(0.041)	(0.013)	(0.023)	(0.008)
Housing	-0.042***	-0.419***	0.010	-0.039*	0.044***	-0.103***	-0.016	-0.139***	-0.079***
	(0.006)	(0.020)	(0.011)	(0.020)	(0.015)	(0.029)	(0.011)	(0.015)	(0.005)
Electricity	-0.005***	-0.007	-0.863***	0.195***	0.029***	-0.024***	0.008	-0.032***	-0.025***
	(0.002)	(0.004)	(0.022)	(0.023)	(0.005)	(0.009)	(0.007)	(0.004)	(0.002)
Heating	-0.004*	-0.019***	0.179***	-1.038***	0.051***	0.005	0.031***	-0.038***	-0.016***
	(0.002)	(0.007)	(0.021)	(0.038)	(0.008)	(0.014)	(0.010)	(0.006)	(0.002)
Motor fuels	0.045***	0.088***	0.145***	0.204***	-1.302***	0.092***	0.103***	-0.215***	0.006
	(0.006)	(0.015)	(0.013)	(0.023)	(0.023)	(0.032)	(0.012)	(0.017)	(0.005)
Transport	0.006	-0.001	0.030***	0.058***	0.066***	-1.555***	-0.006	-0.008	0.035***
	(0.006)	(0.013)	(0.010)	(0.017)	(0.014)	(0.039)	(0.009)	(0.017)	(0.005)
Communication	-0.006**	-0.016**	0.022**	0.056***	0.030***	-0.076***	-0.600***	-0.046***	-0.050***
	(0.003)	(0.007)	(0.011)	(0.018)	(0.007)	(0.013)	(0.013)	(0.007)	(0.002)
Leisure	-0.012*	-0.054***	0.016*	-0.015	-0.150***	-0.038	0.008	-0.675***	-0.004
	(0.006)	(0.012)	(0.009)	(0.015)	(0.013)	(0.031)	(0.009)	(0.023)	(0.005)
Other goods	0.041***	-0.063***	0.108***	0.133***	0.107***	0.167***	-0.029**	-0.064**	-1.066***
	(0.011)	(0.020)	(0.015)	(0.025)	(0.022)	(0.044)	(0.015)	(0.026)	(0.012)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table B5. Uncompensated price elasticities for quintile 3. QUAIDS demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.826***	-0.079***	0.098***	0.066***	0.101***	-0.172***	0.066***	-0.171***	-0.084***
	(0.012)	(0.018)	(0.015)	(0.022)	(0.019)	(0.037)	(0.014)	(0.020)	(0.007)
Housing	-0.040***	-0.390***	-0.003	-0.053**	0.052***	-0.093***	-0.024*	-0.122***	-0.074***
	(0.006)	(0.022)	(0.014)	(0.023)	(0.015)	(0.027)	(0.013)	(0.013)	(0.005)
Electricity	-0.004**	-0.012**	-0.842***	0.218***	0.032***	-0.018**	0.004	-0.027***	-0.022***
	(0.002)	(0.005)	(0.027)	(0.027)	(0.005)	(0.008)	(0.008)	(0.004)	(0.001)
Heating	-0.004	-0.024***	0.210***	-1.049***	0.054***	0.006	0.032***	-0.033***	-0.015***
	(0.002)	(0.008)	(0.025)	(0.044)	(0.008)	(0.013)	(0.012)	(0.006)	(0.002)
Motor fuels	0.053***	0.088***	0.164***	0.228***	-1.299***	0.083***	0.115***	-0.190***	0.004
	(0.007)	(0.016)	(0.016)	(0.026)	(0.023)	(0.029)	(0.014)	(0.015)	(0.005)
Transport	0.009	-0.002	0.035***	0.066***	0.071***	-1.510***	-0.005	-0.010	0.031***
	(0.006)	(0.014)	(0.012)	(0.020)	(0.015)	(0.035)	(0.011)	(0.014)	(0.004)
Communication	-0.005*	-0.023***	0.015	0.057***	0.035***	-0.066***	-0.548***	-0.039***	-0.046***
	(0.003)	(0.007)	(0.013)	(0.020)	(0.007)	(0.012)	(0.014)	(0.006)	(0.002)
Leisure	-0.006	-0.057***	0.020*	-0.015	-0.145***	-0.043	0.013	-0.721***	-0.009*
	(0.007)	(0.013)	(0.011)	(0.017)	(0.014)	(0.028)	(0.011)	(0.020)	(0.005)
Other goods	0.072***	-0.076***	0.110***	0.146***	0.141***	0.127***	-0.028*	-0.074***	-1.078***
	(0.011)	(0.021)	(0.017)	(0.028)	(0.022)	(0.041)	(0.016)	(0.022)	(0.011)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table B6. Uncompensated price elasticities for quintile 4. QUAIDS demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.801***	-0.107***	0.067***	0.048*	0.128***	-0.147***	0.055***	-0.157***	-0.078***
	(0.012)	(0.020)	(0.018)	(0.028)	(0.020)	(0.033)	(0.016)	(0.019)	(0.007)
Housing	-0.040***	-0.355***	-0.019	-0.077***	0.062***	-0.081***	-0.033**	-0.112***	-0.069***
	(0.006)	(0.025)	(0.016)	(0.028)	(0.016)	(0.023)	(0.014)	(0.012)	(0.004)
Electricity	-0.004**	-0.016***	-0.819***	0.263***	0.036***	-0.014**	0.000	-0.023***	-0.020***
	(0.002)	(0.005)	(0.032)	(0.033)	(0.006)	(0.007)	(0.009)	(0.003)	(0.001)
Heating	-0.004	-0.029***	0.244***	-1.066***	0.059***	0.008	0.032**	-0.029***	-0.013***
	(0.003)	(0.008)	(0.030)	(0.055)	(0.009)	(0.011)	(0.013)	(0.005)	(0.002)
Motor fuels	0.062***	0.087***	0.182***	0.271***	-1.307***	0.075***	0.125***	-0.176***	0.003
	(0.007)	(0.017)	(0.020)	(0.032)	(0.025)	(0.026)	(0.016)	(0.014)	(0.005)
Transport	0.015**	-0.002	0.041***	0.082***	0.080***	-1.457***	-0.004	-0.012	0.026***
	(0.007)	(0.014)	(0.014)	(0.025)	(0.015)	(0.030)	(0.012)	(0.014)	(0.004)
Communication	-0.004	-0.029***	0.007	0.062**	0.041***	-0.056***	-0.490***	-0.035***	-0.042***
	(0.003)	(0.008)	(0.016)	(0.025)	(0.008)	(0.011)	(0.016)	(0.006)	(0.002)
Leisure	0.002	-0.064***	0.017	-0.021	-0.144***	-0.044*	0.016	-0.746***	-0.012***
	(0.007)	(0.014)	(0.013)	(0.021)	(0.014)	(0.025)	(0.012)	(0.019)	(0.005)
Other goods	0.114***	-0.091***	0.103***	0.172***	0.189***	0.086**	-0.023	-0.087***	-1.089***
	(0.012)	(0.022)	(0.020)	(0.034)	(0.023)	(0.038)	(0.018)	(0.021)	(0.010)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table B7. Uncompensated price elasticities for quintile 5. QUAIDS demand system

Aggregates	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Food	-0.764***	-0.141***	0.003	0.005	0.173***	-0.117***	0.033*	-0.138***	-0.073***
	(0.014)	(0.021)	(0.023)	(0.035)	(0.024)	(0.029)	(0.020)	(0.017)	(0.007)
Housing	-0.037***	-0.334***	-0.046**	-0.106***	0.081***	-0.069***	-0.047***	-0.102***	-0.065***
	(0.007)	(0.027)	(0.020)	(0.035)	(0.018)	(0.020)	(0.017)	(0.011)	(0.004)
Electricity	-0.004**	-0.020***	-0.788***	0.310***	0.043***	-0.010*	-0.004	-0.020***	-0.018***
	(0.002)	(0.005)	(0.039)	(0.040)	(0.006)	(0.006)	(0.011)	(0.003)	(0.001)
Heating	-0.004	-0.034***	0.290***	-1.086***	0.068***	0.008	0.034**	-0.025***	-0.011***
	(0.003)	(0.009)	(0.037)	(0.066)	(0.010)	(0.010)	(0.016)	(0.005)	(0.002)
Motor fuels	0.074***	0.081***	0.193***	0.307***	-1.334***	0.066***	0.137***	-0.156***	0.003
	(0.008)	(0.018)	(0.024)	(0.039)	(0.027)	(0.023)	(0.019)	(0.012)	(0.004)
Transport	0.026***	-0.005	0.043**	0.098***	0.100***	-1.393***	-0.001	-0.015	0.020***
	(0.008)	(0.015)	(0.017)	(0.030)	(0.017)	(0.025)	(0.015)	(0.012)	(0.004)
Communication	-0.003	-0.037***	-0.008	0.064**	0.050***	-0.045***	-0.402***	-0.030***	-0.038***
	(0.003)	(0.008)	(0.019)	(0.030)	(0.009)	(0.009)	(0.019)	(0.005)	(0.002)
Leisure	0.017**	-0.072***	0.004	-0.031	-0.144***	-0.045**	0.022	-0.779***	-0.017***
	(0.008)	(0.015)	(0.016)	(0.026)	(0.016)	(0.021)	(0.014)	(0.018)	(0.004)
Other goods	0.189***	-0.125***	0.040	0.168***	0.289***	0.045	-0.030	-0.101***	-1.106***
	(0.016)	(0.026)	(0.027)	(0.043)	(0.029)	(0.039)	(0.022)	(0.022)	(0.010)

Note: Key: Significance levels *(p < 0.10), **(p < 0.05), ***(p < 0.01). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at the first total expenditure quintile.

Table B8. Expenditure elasticities by quintile. QUAIDS demand system

Quintiles	Food	Housing	Electricity	Heating	Motor fuels	Transport	Communication	Leisure	Other goods
Quintile 1	0.927***	0.513***	0.289***	0.418***	1.198***	1.958***	0.475***	1.416***	1.262***
	(0.019)	(0.027)	(0.016)	(0.027)	(0.035)	(0.113)	(0.020)	(0.055)	(0.019)
Quintile 2	0.825***	0.545***	0.234***	0.363***	1.049***	1.727***	0.429***	1.414***	1.287***
	(0.012)	(0.021)	(0.015)	(0.024)	(0.020)	(0.045)	(0.015)	(0.027)	(0.009)
Quintile 3	0.750***	0.574***	0.193***	0.336***	0.958***	1.687***	0.376***	1.385***	1.292***
	(0.010)	(0.018)	(0.013)	(0.022)	(0.016)	(0.040)	(0.013)	(0.022)	(0.008)
Quintile 4	0.661***	0.606***	0.177***	0.264***	0.857***	1.630***	0.322***	1.377***	1.294***
	(0.013)	(0.023)	(0.016)	(0.027)	(0.019)	(0.044)	(0.015)	(0.026)	(0.009)
Quintile 5	0.504***	0.687***	0.269***	0.271***	0.672***	1.558***	0.260***	1.365***	1.306***
	(0.026)	(0.042)	(0.033)	(0.053)	(0.037)	(0.051)	(0.031)	(0.035)	(0.013)

Note: Key: Significance levels *($p < 0.10$), **($p < 0.05$), ***($p < 0.01$). Bootstrap standard errors in brackets. Elasticities are evaluated at the mean budget shares for households at each expenditure quintile.

Appendix C.

C1. Stone-Lewbel prices

The main challenge in working with survey data and estimating demand systems comes from the lack of observability of prices. In other words, prices are not observable in household budget surveys. An alternative would be to introduce changes in the consumer price indexes of each aggregate to incorporate these prices, at the cost of not having enough variation. To increase the variability of prices we construct the Stone-Lewbel indices (see Lewbel, 1989). This index uses the consumption system generated in our model to obtain personalised prices per household. For each household, and for each good it consumes, we match the prevailing monthly price index of the Spanish statistical institute (INE) according to the period of the survey. The price indices are national. For a household i consumed by household h, the Stone-Lewbel price index is written:

$$\ln(p_{ih}) = \sum_{l=1}^{N_i} \frac{w_{lh}}{w_{ih}} \ln(p_{lh})$$

Where w_{lh} is the budget share on good l belonging to aggregate i for household h, w_{ih} is the budget share on aggregate i to total consumption in household h, p_{lh} and p_{ih} are the respective national monthly price indices. We do not impose any additional assumptions on the between aggregates utility function, this method constructs the indices according to the heterogeneity in consumer preferences within aggregates. Such heterogeneity serves to increase the variability in prices. This method has been widely used in the demand systems literature, where its usefulness in producing better empirical results has been proved (Hoderlein and Mihaleva, 2008). However, we should mention the potential endogeneity problems that this type of indices may suffer from. If the between aggregates utility functions are of Cobb-Douglas type, the budget shares used in the price index correspond to the parameters of the household's exogenous preferences. However, if this assumption is not met, as expenditure is used in the construction of the indices, this may lead to an error in the identification of the consumption ration prices in basket i for total consumption in household h, p_{lh} and p_{ih} are the respective price indices.

C2 Heating degree days and cooling degree days indexes

Heating degree day (HDD) index is a weather-based technical index designed to describe the need for the heating energy requirements of buildings. Cooling degree day (CDD) index is a weather-based technical index designed to describe the need for the cooling (air-conditioning) requirements of buildings.

The Heating Degree Days (HDD) index measures the severity of cold during a specific period, considering both outdoor temperature and the average indoor temperature, which reflects the need for heating. The calculation of HDD relies on a base temperature, which is defined as the lowest daily mean air temperature that does not result in indoor heating. This base temperature can be influenced by various factors related to the building and its surroundings. In a general climatological approach, however, the base temperature is commonly set at 15°C to calculate HDD.

The formula for calculating HDD is as follows:

If Tm ≤ 15°C, then:

$HDD = \sum_i 18°\text{C} - \text{Tim}$, Else [HDD = 0], where Tim is the mean air temperature on day i.

The Cooling Degree Days (CDD) index, on the other hand, measures the severity of heat during a specific period, considering both outdoor temperature and the average indoor temperature, which reflects the need for cooling. Like HDD, CDD is calculated based on a base temperature, but in this case, it represents the highest daily mean air temperature that does not lead to indoor cooling. This base temperature is also influenced by several factors associated with the building and its environment, but in a general climatological approach, the base temperature is set at 24°C for the calculation of CDD.

The formula for calculating CDD is:

If Tm ≥ 24°C, then

$CDD = \sum_i \text{Tim} - 21°\text{C}$, Else [CDD = 0], where Tim is the mean air temperature on day i.