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Demand for Gas: Evidence from the 2022 Energy Crisis

Master's Thesis

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Declaration of Authorship

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Jan Stuchlík

Abstract

This thesis analyzes the effects of the 2022 energy crisis on changes in consumption patterns among Czech households, with the main focus on natural gas and other energy sources. We captured the effects using income and cross-price elasticity of expenditure shares of various goods. We calculated these elasticities from estimated parameters of a quadratic almost ideal demand system. The system parameters were estimated using the iterated feasible generalized nonlinear least squares method on household-level data collected by PAQ Research. Demand for gas is income-elastic during the energy crisis, contrasting with other energy sources. Households made significant adjustments to their consumption of luxury goods and necessities in response to the high energy prices. The cross-price elasticity estimates show a decrease in expenditure shares of luxury goods and distant heat in relation to higher gas prices. Reduced healthcare and transport expenditure shares and increased solid fuels expenditure shares are related to higher electricity prices. In response to rising prices of necessities, households generally decrease expenditure shares of luxury goods. Households' reactions to the energy crisis are heterogeneous among socio-economic groups.

JEL Classification	C33, D12, Q41
Keywords	energy crisis, households, Czechia, QUAIDS, elasticity of demand
Title	Demand for Gas: Evidence from the 2022 Energy Crisis

Abstrakt

Tato práce analyzuje dopady energetické krize z roku 2022 na změny ve spotřebním chování českých domácností s hlavním zaměřením na zemní plyn a další zdroje energie. Dopady jsme zachytili pomocí příjmových a křížových cenových elasticit výdajových podílů různého zboží. Tyto elasticity jsme získali z odhadovaných parametrů kvadratického téměř ideálního poptávkového systému. Parametry systému jsme odhadli pomocí iterované proveditelné zobecněné nelineární metody nejmenších čtverců na datech na úrovni domácností sbíraných společností PAQ Research. Poptávka po plynu je během energetické krize příjmově elastická na rozdíl od jiných zdrojů energie. Domácnosti významně upravily svou spotřebu luxusního i nezbytného zboží v reakci na vysoké ceny energií. Odhady křížové cenové elasticity ukazují pokles podílu výdajů na luxusní zboží a dálkové teplo v souvislosti s vyššími cenami plynu. Snížený podíl výdajů na zdravotní péči a dopravu a zvýšený podíl výdajů na tuhá paliva souvisí s vyššími cenami elektřiny. V reakci na rostoucí ceny nezbytného zboží domácnosti obecně snižují podíly výdajů na luxusní zboží. Reakce domácností na energetickou krizi jsou různorodé mezi socioekonomickými skupinami.

Klasifikace JEL C33, D12, Q41

Klíčová slova energetická krize, domácnosti, Česko, QUAIDS, elasticita poptávky

Název práce Poptávka po plynu: Důkazy z energetické krize z roku 2022

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Contents

1 Introduction

The energy crisis, which began in Europe in the first half of 2022, was a major economic event that severely affected households and firms. It showed the vulnerability of the European energy markets, especially the dependence of European countries on imports of energy. The limited supply of oil and gas led to record-high prices. According to the data from the Czech Statistical Office, energy consumption constitutes between 8 and 14 percent of households' budgets in Czechia. When a significant price shock happens, such as the one in 2022, it severely affects households. Knowing how households respond to increasing energy prices and the threat of limited energy supply is helpful so that policymakers can adequately react when such a situation occurs. Therefore, we decided to estimate the income elasticity and cross-price elasticity of demand for various categories of goods among Czech households. The main focus is on natural gas (henceforth referred to as "gas") and other energy sources. It is essential to have these estimates because then we know how people change their demand for various goods in response to price changes, how much money people can save, and where they can save. Furthermore, we now have an excellent opportunity to estimate the above mentioned elasticities of demand because of the unexpected and large price shock that triggered significant household reactions. Specifically, we concentrate on the demand for gas because gas prices were affected the most and some of the government's interventions, such as price caps and subsidies, were aimed at households that used gas heating. Thus, the first research question of our thesis is whether households' demand for gas and other energy sources was income- and price-elastic during the energy crisis. The second research question is if households reacted to the steep increase in prices of gas and other energy sources by reducing their demand for other goods. Because households are heterogeneous in many ways, we also estimate to what extent the consumption adjustments differed among various socio-economic groups. These estimates allow us to answer the third research question: whether any socio-economic factors significantly affected households' income elasticity of demand for various categories of goods. We build on available academic literature about previous energy crises and the elasticity of demand for energy. We follow with empirical estimates of the 2022 energy crisis' consequences using current household-level data.

The thesis is structured as follows: First, we provide a summary of relevant academic literature on suitable microeconomic models that can be used for approximating the household demand system, followed by appropriate econometric estimation methods. Then, we review available literature dealing with the energy crisis and its effects. We pay special attention to articles from PAQ Research, an organization that closely monitors the energy crisis, and we obtained data for our analysis from them. This information can be found in the section Literature Review. In the next section, which is called Theoretical Background, we present theoretical concepts for explaining households' economic behavior and a detailed description of the energy crisis, including expected changes in households' behavior during the energy crisis. The section also covers the context that led us to form this thesis's research questions. The practical part of the thesis consists of the sections Data, Methodology, and Empirical Results. They introduce the data that we used for the analysis, the econometric methods that we applied to the data, and we present our findings. The main results and their interpretation are summarized in the final section Conclusion.

The key findings are that demand for gas was income-elastic during the energy crisis, households did make significant adjustments to their consumption as a consequence of the high energy prices, and they decreased their expenditure shares of not only luxury goods but also goods considered to be necessities, such as healthcare. Households' reactions to the energy crisis were significantly heterogeneous among socio-economic groups.

2 Literature Review

The following section presents an overview of academic literature related to our research. The discussed papers mainly focus on household demand modeling, calculating income and cross-price elasticity of demand, and household economic behavior during energy crises.

Modeling of household demand has been an essential topic in economic research. As households play a central role in the consumption of goods and services, understanding their demand behavior is crucial for various policy and business decisions. Researchers have introduced various theoretical frameworks, empirical methodologies, and data sources over the years. In the first part of this section, we present a summary of the most important academic papers that have contributed to our understanding of household demand modeling. We examine different modeling approaches that have been proposed, summarize which methods of estimation have been used, and discuss how the mentioned options can be beneficial for our analysis.

Since the 2022 energy crisis (henceforth referred to as the "energy crisis") has seriously affected multiple countries, not only Czechia, much academic research has been conducted to understand various aspects of the crisis better. Hence, the second part of this section introduces sources related to current knowledge of households' economic behavior during the energy crisis with a primary focus on Czech households.

2.1 Modeling Household Demand

2.1.1 Suitable Types of Models

The consumer choice theory is the fundamental theoretical framework for demand modeling at the microeconomic level. It provides fundamental economic concepts, such as the role of utility maximization and the law of demand, as described by Deaton and Muellbauer (1980), who introduced the Almost Ideal Demand System (AIDS) model. The AIDS model captures relationships between consumption, prices, and income elasticities of demand. The authors describe the model as representing market demands as if they were the outcomes of decisions by a rational representative consumer. Consumer preferences are summarized by an expenditure function, which can be derived from a utility function, and we can use prices as inputs for the expenditure function. Parameters of this demand system can be retrieved using individual and aggregate-level data, and the demand system allows for an explicit estimation of cross-price elasticities that help us find substitutability and complementarity among various goods. Rimmer and Powell (1992) pointed out a problem of the AIDS model that budget shares of various goods can reach values outside the [0,1] interval when there are significant changes in real incomes. To fix this problem, they specified and estimated An Implicitly Directly Additive Demand System (AIDADS), which has similar properties to AIDS.

Another microeconomic model suitable for studying individual household behavior is the BLP (Berry, Levinsohn, and Pakes) demand model. It was introduced by Berry et al. (1995), taking advantage of unobserved product characteristics and consumer heterogeneity. Models from this family allow for the estimation of demand elasticities and provide insights into market competition and consumer preferences. However, these models can only be estimated using product-level and aggregate consumer-level data.

A further type of model for estimating households' demand was proposed by Banks et al. (1997), who built a Quadratic Almost Ideal Demand System (QUAIDS) to model consumer demand for multiple commodities. The QUAIDS model is a generalization of the AIDS model with a quadratic income term, which provides more flexibility than traditional models using expenditure share equations linear in the logarithm of income. The flexibility is claimed to have a positive effect on the quality of model outcomes. It can be used for analyzing demand for individual goods and account for heterogeneous characteristics of households. Household preferences are represented by an indirect utility function, which takes households' expenditures and commodity prices as inputs. The model assumes prices to be exogenous, which is a reasonable assumption for the energy crisis. The estimated parameters of such a model can be used to calculate income and cross-price elasticities of demand.

Cranfield et al. (2003) compared the predictive power of structural demand systems using cross-sectional data from countries with varying per capita expenditure levels. Demand systems with less restrictive income responses were proven better to predict demand than those with more restrictive income effects. AIDADS and QUAIDS were identified as the best.

Dybczak et al. (2014) employed the QUAIDS model to estimate income and price elasticities, which helped them uncover structural changes in demand for various goods in Czechia. They used aggregate data from the period between 2000 and 2008. Their estimates indicate that the commodity bundles of energy, food, and healthcare are necessities because their budget elasticity was positive and smaller than one. In contrast, they found education, transportation, leisure and clothing to be luxury goods with income elasticity larger than one. Transportation and communication were reportedly the most sensitive group to income changes, and energy was the least sensitive one. The own-price elasticities were negative among all commodity groups. The cross-price elasticities were slightly smaller than the own-price elasticities, which they claimed to be natural given their high level of data aggregation. The results showed that the analyzed commodity groups had no strong substitutes or complements among the other ones. According to the size of the estimated own-price elasticities, energy, transportation, and communication expenditures were found to be the most affected by price changes. The authors also noted that in the QUAIDS model they employed, prices are assumed to be predetermined, so the model is most applicable for simulating the effects of exogenous price shocks unrelated to demand and supply dynamics. They recommended using the model for analyzing events, such as regulated prices, indirect tax rates, or changes in world oil prices, which perfectly fits our situation. This paper is a departing point for our analysis. Like Dybczak et al. (2014), we employ the QUAIDS model to estimate income and cross-price elasticities of demand. However, we work with more recent data to account for the 2022 energy crisis and household-level data that allow controlling for heterogeneity.

The QUAIDS model was also applied by Abdulai (2002) to estimate a complete demand system for Switzerland with a focus on the food commodity group. They used household-level data, which allows for analyzing demographic effects.

The author found out that the quadratic terms in the QUAIDS were empirically important in describing household budget behavior in Switzerland. The results suggested that price policy is crucial as an agricultural policy instrument. Most commodity groups showed inelastic demand, suggesting limited possibilities for substitution between goods. When examining different income groups, the estimated own-price and expenditure elasticities consistently attained higher values for the lower-income group. All food groups seemed to be necessities, while the non-food group was consistently classified as a luxury good. Larger families often adjusted their consumption towards relatively inexpensive commodities and away from expensive ones.

Another use of the QUAIDS was described by Moro and Sckokai (2000). Taking advantage of disaggregated data, they included demographic effects, which were found to play an essential role in food consumption in Italy. They compared the QUAIDS estimates to those obtained from the traditional AIDS approach, and the QUAIDS estimates were superior in quality. Food commodities were necessity goods, while the non-food aggregate was a luxury good. Even though its expenditure shares were the lowest, the highest income group showed the highest income elasticity for all food items. Households with elderly members had both the highest food expenditure shares and elasticities.

Cross-price elasticities of demand were also examined in a study by Regmi and Seale (2010), where they used a simple method based on parameter estimates of the Florida model that was developed by Theil et al. (1989) and real per capita income. They calculated Slutsky and Cournot cross-price elasticities for 2-good and 9-good demand systems from data covering 114 countries. The Slutsky cross-price elasticities indicated that luxury items like recreation have higher magnitudes than necessities like food and clothes. When prices change relative to food and clothes, the cross-price elasticities are the greatest for low-income countries and decrease with increasing wealth of countries. However, when prices change relative to other goods, the cross-price elasticities are smaller for low-income countries and highest for the wealthiest countries, except for food, where the lowest elasticities are observed in the high-income group. Regarding Cournot cross-price elasticities, when relative price changes for necessities occur, large income effects dominate the substitution effects, resulting in negative elasticities for all goods across all income-level groupings. For changes in other goods, such as rent, fuel, power, housing operations, and transportation, the substitution effects are claimed to outweigh the income effects for many low-income countries. However, the opposite is true for higher-income groups. The substitution effects are generally more extensive for medical care and other goods than the income effect, which results in positive elasticities except for a few wealthy countries. In the case of recreation, all cross-price elasticities are positive across all income groups. Overall, the cross-price elasticities tend to be most prominent for the poorest countries and decrease in magnitude with increasing wealth of countries.

2.1.2 Methods for Empirical Estimation

A wide range of methods can be used for an empirical estimation of a demand model. A commonly used approach is maximum likelihood estimation (MLE). Poi (2002*b*) explained that MLE is useful for estimating a system of household demand equations subject to a set of constraints imposed by the expenditure minimization problem. Beenstock et al. (1999) compared the Dynamic Regression Model (DRM), ordinary least squares (OLS), and MLE when they estimated the demand for electricity in the industrial and household sectors in Israel. They found that price elasticities, calculated based on DRM and MLE, were similar, but the elasticities obtained using OLS were significantly lower. To deal with endogeneity and non-linearity of regressors, which are frequent issues when estimating demand models, Banks et al. (1997) proposed a two-stage GMM (generalized method of moments) estimation procedure to estimate the system of non-linear equations in a QUAIDS model. Further, Poi (2008) presented that demand can be estimated as a system of non-linear SUR (seemingly unrelated regressions) using iterated feasible generalized least squares. The non-linear SUR method was also later used by Dybczak et al. (2014).

In a study by Hoderlein and Mihalevava (2008), the authors discussed a common problem when applying consumer demand models - insufficient price variation. They evaluated the performance of individual specific price indices for bundles of goods, which were first constructed by Lewbel (1989). These individual-specific price indices allow for a population with heterogeneous preferences for goods within a given bundle of goods. Their results showed that the price indices produce better empirical results, in terms of precision of estimates and economic plausibility than the ones obtained through the traditional way of using aggregate price indices, regardless of whether parametric or non-parametric models were employed.

Lastly, advancements in computational capabilities and the availability of large-scale datasets have enabled the application of machine learning techniques to household demand modeling. Transaction data, web scraping techniques, and sentiment analysis reportedly allow for more comprehensive and accurate analyses (Einav and Levin, 2014). Researchers have also recently used decision trees, neural networks, and support vector machines to capture complex demand patterns and accurately predict consumer behavior (Xu et al., 2017).

2.2 Existing Literature about the Energy Crisis

Coyle et al. (2014) summarized their findings on energy crises in general terms. They discussed geopolitical and economic implications, the influence of energy sources on political relationships, conflicts, and economic stability, which are also relevant topics today. Potential solutions to energy crises are adopting energy efficiency measures, reducing energy waste, and promoting conservation practices. They also emphasized the significance of diversifying energy sources and investing in research and development of clean and renewable technologies.

McWilliams and Zachmann (2023) published an article about the turmoil in the European gas market in 2022 that followed a significant decline in gas supplies from Russia and discussions about the possibility of a complete stop to Russian gas flows to the EU. The uncertainty increased gas prices in the first quarter of 2022 compared to the previous year. The high prices increased LNG imports to Europe and a significant reduction in gas demand. The reduction was estimated at around 7%, compared to the same period in 2021. Evidence suggested that industrial companies had reduced natural gas consumption by around a fifth. Gas-to-coal switching in the power sector did not contribute to reduced demand because gas-fired generation increased due to lower nuclear and hydro production.

Household and other gas demand had reportedly also decreased by about 5% compared to the previous year.

Sperber et al. (2022) analyzed thermostat adjustments and tried to find ways to reduce natural gas consumption and alleviate consumer costs. They used an example of single-family house buildings in Germany. They discovered that about 14 to 30 TWh/a of gas, corresponding to 3-6% of Russian gas imports to Germany as of 2020, could be saved if the temperature was reduced by 2-4°C. As one would expect, the biggest absolute savings are claimed to be possible for old and large buildings. They also showed that thermostat adjustments could cut households' CO_2 emissions by 3-6%, which is a promising change, regardless of the energy crisis. Lowering the temperature from 21 to 20°C could reduce the consumers' gas bill by 4-9% depending on the building type. However, they acknowledged that the financial burden due to increased gas prices outweighs the savings. The burden is supposed to be even more vital for older buildings.

Ruhnau et al. (2023) analyzed the response of natural gas consumers in Germany, what used to be the largest export market for Russian gas for decades before the war in Ukraine, to the current energy crisis, and assessed the effectiveness of various measures implemented to conserve energy. They built a multiple regression model to empirically estimate the responses of small consumers, industry, and power stations. Significant gas savings were found among all consumer groups, but the timing of changes in consumer behavior was different. While the industry started saving even before the war began (in September 2021), smaller consumers were claimed to have started saving in March 2022. The delay was explained by the lagged pass-through of wholesale prices to retail tariffs and by non-financial motives to reduce gas consumption after Russia invaded Ukraine. Small German natural gas consumers reached their maximum relative reduction of consumption by 28% in September 2022.

2.2.1 Articles from PAQ Research

The data we use for our empirical estimation has been collected by the Czech agency PAQ Research, a sociological research organization concentrating on finding data-based solutions to critical social problems. The latest contribution comes from the cooperation between Český rozhlas (Czech Public Radio) and the PAQ Research agency. Their joint project is called ”Česko 2022: Život k nezaplacení” (”Czechia 2022: Priceless Life”) (Prokop and Röschová, 2023). It is based on a detailed questionnaire survey and aims to provide insights into the socio-economic situation of Czech households in 2022. That is associated with extremely high inflation rates that resulted from the energy crisis.

The researchers involved in this project have already published several articles related to the consequences of the energy crisis. Their main emphasis is on households' expenditures on energy, housing, and food. Frequently ascertained information is what share of the budget households spend and how much they can save. For example, Prokop (2023) presented a summary of the data collected as part of the project to show how the high inflation rate affected various types of households. Poorer people are supposedly more likely to face existential problems, and part of the middle class is said to be losing their savings. According to the study, the number of unstable and highly vulnerable households, unable to save anything from their income and having minimal savings, increased from 16% to 28% in one year. The total share of households losing their savings now stands at 36%. Even if some people can save something each month, more than their savings is needed to offset inflation, which reduces the actual value of their savings.

Dvořáková (2023) claimed that the financial situation among Czech households, especially those with children, has significantly worsened in comparison to autumn 2021. After all expenses are paid, Czech households are said to have half as much left at the end of the month as in November 2021. The leading causes of the financial problems are reportedly a lower growth of households' income than inflation and high housing expenses (mainly caused by an increase in energy prices), which account for more than 30 percent of income. One of the suggested solutions to the problem is a social energy tariff.

Korbel (2023) found out that around 20 percent of Czech families with children cut back on education spending or free time activities. Poorer families, who are, naturally, hit harder by rising housing and food prices, were said to cut their expenses much more often. Inflation can thus reinforce inequalities in education. The author argued that various local and state-wide measures were already in place, such as subsidized or even fully covered lunches for schoolchildren. However, only a minority of those in need get access to help.

A more recent article by Vokurková (2023), which is based on data from May 2023, mentioned that there was a change in economic behavior among high-income households who were starting to spend more in comparison to the previous months. Instead of inflation, people with high incomes then supposedly feared the collapse of democracy, the influence of misinformation, and the strengthening of extremist sentiments in society, which should be considered the most significant threat by more than 50% of high-income Czechs. Nonetheless, the rest of the society was still most concerned about price increases. Two-thirds of respondents in the survey perceived that as the biggest threat. The co-author of the research, sociologist Daniel Prokop, pointed out that the varying level of concerns about inflation was also reflected in how much households save. Most of the bottom 70 percent of society, in terms of income, reduced their consumption of energy, food, and consumer goods, while the upper part did not reduce their consumption as much. Roughly half of them declared they did not save on any of those things.

3 Theoretical Background

This section presents theoretical fundamentals that we use for our empirical research. The first part discusses the household utility maximization problem, a key concept we use in demand modeling. Further, we summarize the events that caused the 2022 energy crisis and briefly monitor how the situation developed. We point out critical aggregate indicators for shaping demand for gas and other energy sources. At the end of the section, we explain what patterns we expected to find in the data during our analysis and how the expectations relate to our research questions.

3.1 Households' Economic Behavior

Our empirical analysis is based on one of the fundamental concepts from demand theory, where households are assumed to make rational decisions based on their preferences and constraints to maximize their utility derived from consuming goods and services. From now on, we refer to goods and services using the aggregate term goods. Households face a budget constraint, representing the limitation on their spending based on their income and the prices of goods. The household utility maximization problem can be mathematically described as follows, according to Mas-Colell et al. (1995):

Consider a household's utility function U that depends on its consumption of k goods $x_1, x_2, \ldots, x_k$:

$$U(x_1, x_2, \ldots, x_k)$$

subject to a budget constraint:

$$p_1 x_1 + p_2 x_2 + \ldots + p_k x_k = m$$

where $p_1, p_2, \ldots, p_k$ are the prices of goods $x_1, x_2, \ldots, x_k$, respectively, and m is the household's income. In this theoretical example, households are assumed to spend their whole income and not save anything. That is only for the simplicity of the theoretical example. However, we do consider savings in the empirical part.

The household's objective is to maximize its utility subject to the budget constraint, and this can be formulated as the following optimization problem:

$$\max_{x_1, x_2, \ldots, x_k} U(x_1, x_2, \ldots, x_k) \quad \text{subject to} \quad p_1 x_1 + p_2 x_2 + \ldots + p_k x_k = m$$

To solve this problem, we can use the method of Lagrange multipliers. We define the Lagrangian function as:

$$\mathcal{L}(x_1, x_2, \ldots, x_k, \lambda) = U(x_1, x_2, \ldots, x_k) + \lambda(m - p_1 x_1 - p_2 x_2 - \ldots - p_k x_k)$$

where λ is the Lagrange multiplier associated with the budget constraint.

To find the optimal consumption bundle $(x_1^*, x_2^*, \ldots, x_k^*)$, we solve the following first-order conditions:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial x_1} &= \frac{\partial U}{\partial x_1} - \lambda p_1 = 0 \\
\frac{\partial \mathcal{L}}{\partial x_2} &= \frac{\partial U}{\partial x_2} - \lambda p_2 = 0 \\
&\vdots \\
\frac{\partial \mathcal{L}}{\partial x_k} &= \frac{\partial U}{\partial x_k} - \lambda p_k = 0 \\
p_1 x_1 + p_2 x_2 + \ldots &+ p_k x_k = m
\end{aligned}$$

Solving this system of equations for $x_1, x_2, \ldots, x_k$ will yield the optimal levels of consumption of goods $(x_1^*, x_2^*, \ldots, x_k^*)$ that maximize the household's utility subject to the budget constraint. The optimal levels of consumption can be expressed as functions depending on the prices of the goods. Hence, any change in the prices of goods can cause a change in the optimal consumption levels. The main goal of this thesis is to explore the changes in economic behavior among Czech households associated with the energy crisis and, especially, to measure households' sensitivity to price shocks related to the energy crisis.

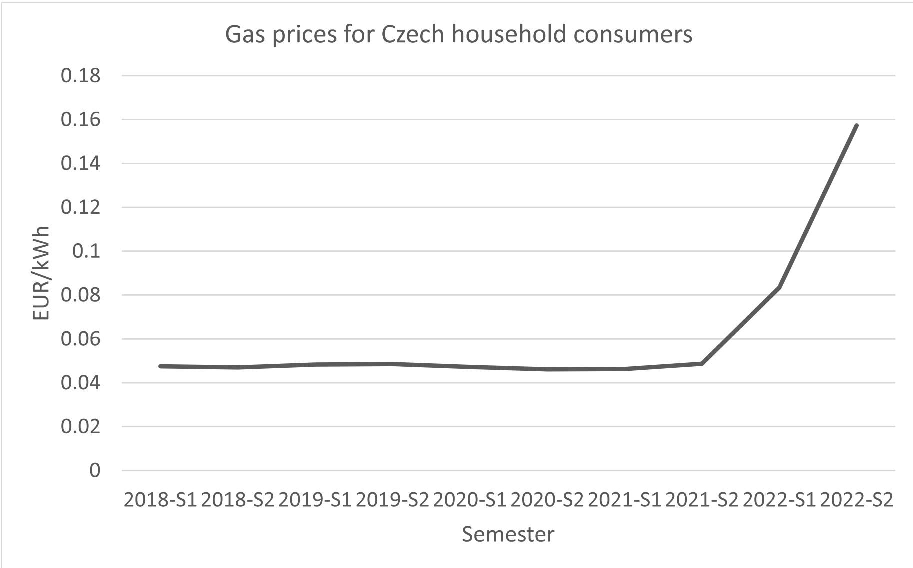
3.2 Description of the Energy Crisis

The energy crisis in Europe started approximately at the time when Russia invaded Ukraine on February 24, 2022. The date is not entirely accurate because the conflict was gradually developing, and the energy market reflected the uncertainty even before the invasion began. Since many European countries were heavily reliant on Russian gas imports before the war, any disruption in gas supply would lead to a severe energy crisis with widespread implications. Natural gas is a critical energy source for many European countries because it is frequently used to generate electricity, heat homes, and in industrial processes. More than 30% of households in the EU use gas for heating (European Council, 2023). Therefore, the beginning of the conflict in Ukraine caused massive uncertainty in the energy market and a subsequent price increase.

As the conflict continued, natural gas supplies from Russia to European countries were dramatically reduced or even completely stopped. The total amount of natural gas imports by the EU and the UK from Russia decreased from 11.2 billion m^3 (33% of total gas imports) to only 2.3 billion m^3 (8% of total gas imports)) between October 2021 and October 2022 (Goldthau and Tagliapietra, 2022). The situation was particularly challenging during the winter when energy demand is at its peak. Many European countries struggled with reduced gas reserves, strained energy infrastructure, and concerns about meeting the energy needs of their businesses, industries, and households. The war in Ukraine exposed the need for energy diversification strategies in most European countries and highlighted their dependency on gas imports from Russia. Countries suddenly had to adapt to the situation by finding alternative energy sources and supply routes. A common suggestion for policymakers was to accelerate the development of renewable energy sources and improve interconnections between countries, allowing for easier energy sharing. Eventually, the EU countries managed to find sufficient alternatives to Russian gas. For example, no gas from Russia was imported to Czechia in the first quarter of 2023 (Ministry of Industry and Trade of the Czech Republic, 2023). The supplies from Russia were reportedly substituted by imports from Belgium, the Netherlands, and Norway.

However, these sudden changes in energy sources resulted in unprecedented increases in energy prices. According to data from the Eurostat, the gas prices for household consumers in Czechia grew from 0.0463 EUR/kWh in the first semester of 2021 to 0.1573 EUR/kWh in the second semester of 2022 (Figure 1), which is a 240% increase.

Figure 1: Development of Gas Prices for Czech Households

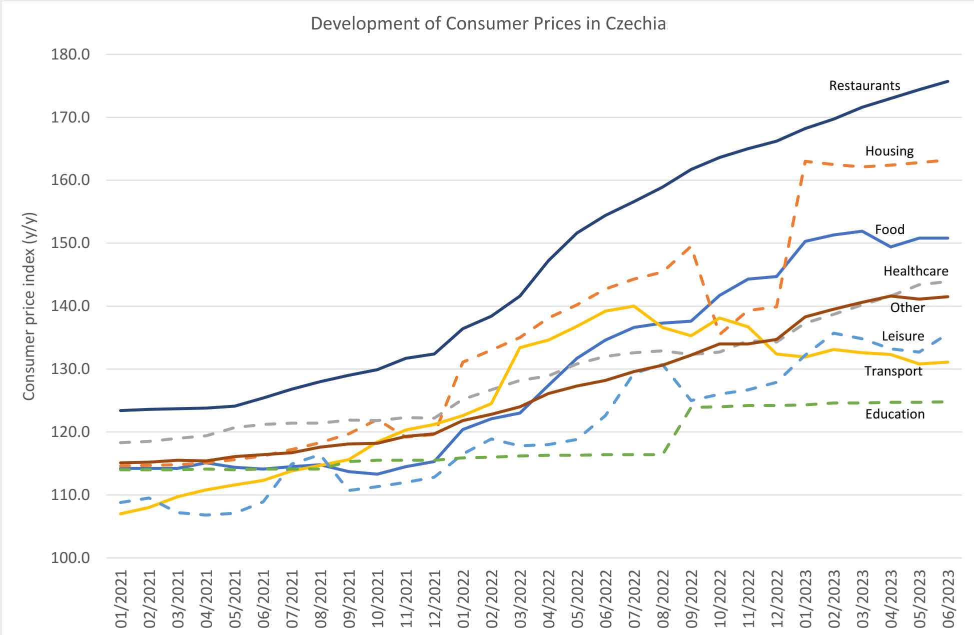


Source: Eurostat

Naturally, energy prices are reflected in almost all other goods and services. Hence, the inflation rate climbed quickly to levels we had not experienced for a long time. The average annual inflation rate in the Czech Republic was 15.1% in 2022, as per data provided by the Czech Statistical Office. We show the development of prices using year-on-year consumer price indices of various categories of goods in Figure 2. The fastest growing categories of goods in terms of prices were dining in restaurants and housing, which are strongly influenced by energy prices. They were followed by food and healthcare, which are necessities for households, so fast growth of their prices can lead households to extensive economic problems.

As we know from the Literature Review section, such a fast growth of goods' prices indeed was a severe problem for the whole economy. Our analysis con-

Figure 2: Development of Prices by Good Category



Source: Czech Statistical Office

centrates on households' demand for various categories of goods. The goal is to uncover household economic behavior patterns during this energy crisis, focusing on their demand for gas and other energy sources.

3.3 Expected Changes During the Energy Crisis

One of the consequences of the energy crisis could be increased energy savings by households. With higher energy prices and concerns about potential supply disruptions, households will likely become more conscious of their energy consumption. They can take various energy-saving measures, such as installing energy-efficient appliances, improving insulation, or adjusting their heating and cooling habits to reduce energy usage. This could lead to a decline in overall energy demand.

Further, we expect a shift towards renewable energy. The energy crisis highlighted the vulnerabilities of traditional energy sources and led to an increased interest in renewable energy options. Czech households may consider installing solar panels or other renewable energy systems to generate their own electricity and reduce their reliance on the power grid. This could eventually help the growth of the renewable energy sector.

The energy crisis is also likely to change the spending patterns of households in terms of goods and services other than energy, and this is what we analyze in this thesis. Higher energy prices can seriously affect households' budgets and force them to reassess their spending habits. They might reduce their spending on non-essential items or luxury goods to compensate for the increased energy costs. This could impact various sectors, such as retail, entertainment, and tourism. The latest findings that PAQ Research has published clearly show significant changes in spending patterns among Czech households. Lowering spending on unnecessities, such as tourism and entertainment, is expected and does not represent a massive societal problem. On the contrary, an especially worrying finding was that a considerable share of households cut their expenditures on education, which can have wide-ranging negative consequences in the long run. We explore these changes in more detail by estimating expenditure and cross-price elasticities of demand for various categories of goods, which provide an accurate overview of the shifts in household spending patterns.

Finally, households could become more interested in energy markets and policies. The energy crisis may motivate households to understand better energy markets, related policies, and their impact on prices. Consumers might engage more in debates concerning energy transition, climate change, and diversifying energy sources. This could increase demand for information, education, and transparency related to energy-related issues.

Our thoughts go in line with the claims of Goldthau and Tagliapietra (2022), who wrote that Europe would experience enduring reductions in its consumption of natural gas as a result of greater energy efficiency, a switch to more eco-friendly alternatives and a transfer of energy-intensive industries to other nations.

The above-mentioned expectations led us to form the following hypotheses that we test in the empirical part of our thesis. Firstly, we test whether households' demand for gas and other energy sources was income- and price-elastic during the energy crisis. Under normal circumstances, demand for gas and other energy sources is rather inelastic (Schulte and Heindl, 2017) because energy has a wide range of uses, and households use it regardless of income or energy prices. Nevertheless, this energy crisis was exceptional, so we decided to test if there was a significant change in the two types of elasticity of demand for gas and other energy sources among Czech households. Secondly, we find out if consumers reacted to the steep increase in the prices of gas and other energy sources by reducing their consumption of other goods (for example, food, healthcare, and education). We do that by estimating cross-price elasticities of demand between energy sources and other goods, i.e., we explore whether changes in households' demand for goods other than energy are associated with the increase in energy prices. Thirdly, we test if the extent of consumption adjustments differed among various socio-economic groups. Even though energy, including gas, is considered to be a necessity, we expect households with different demographic characteristics to react differently. For example, households whose members have a higher educational attainment could make different changes to their consumption than households with less educated members. We measure this by estimating the effect of demographic variables on elasticities of demand.

4 Data

In this section, we introduce the data we used to empirically analyze the energy crisis and its effects. First, since our data comes from multiple sources, we state the sources and describe which part of the data was obtained from which source. Then, we explain how we built the data frame, which we use for further steps in our analysis, including an overview of the basic properties of the data frame. Finally, we present a summary of essential variables to show the characteristics of our sample.

4.1 Data Sources

We collected data on the expenditures of Czech households (how much each household spent on each good every month), prices of those goods, and demographic characteristics of individual households.

Data on household expenditures and demographic characteristics was obtained from the ”Czechia 2022: Priceless Life” project (Prokop and Röschová, 2023). The project follows a previous project called ”Life During the Pandemic,” which aimed to collect data on the development of behavior of Czech adults during the COVID-19 pandemic from 2021 to 2022. The data was collected using a questionnaire survey. The survey content was mainly created by PAQ Research and the IDEA AntiCovid Initiative. Since autumn 2021, the investigation has been gradually supplemented with modules responding to current severe social crises and challenges (energy crisis, conflict in Ukraine). In spring 2022, on the other hand, the epidemiological module was weakened. Since April 2022, the research has been continued in cooperation with Czech Radio as a project called ”Czechia 2022: Priceless Life,” emphasizing the effects of inflation on household economic behavior. Since October 2022, research teams from the National Institute for Research of the Socio-economic Impacts of Diseases and System Risks (SYRI) have prepared a part of the survey. Their investigation has expanded the thematic modules related to health and other societal threats.

The development of prices of goods was approximated using consumer price indices. Gas and electricity prices were obtained from the Eurostat, and we calculated the consumer price index values. The consumer price indices for all other goods were taken directly from the database of the Czech Statistical Office.

4.2 Dataset Description

We used the above-stated sources to build a data frame in panel data format. Panel data is obtained by observing a cross-sectional sample for several periods. In this case, the data frame includes observations of 2,666 unique households during 30 waves of the survey that approximately correspond to months from January 2021 until June 2023. The observed variables include households' demographic characteristics, expenditures on various goods, and values of consumer price indices for each good in the relevant periods. The total number of observations in the data frame is 55,688. Unfortunately, not all observations contain responses to all survey questions, i.e., some variables carry missing values. Before doing any calculations, we tested for missing values and cleaned the data where it was needed. The summary statistics in the following sections were calculated using clean data where missing values had been removed. The obtained data was processed in the R Programming Language, and model estimation was done in the Stata Statistical Software. A detailed list of variables with explanations of each variable's meaning can be found in the Appendix of the thesis.

4.2.1 Demographic Variables

Since we believe that demographic characteristics play an important role in households' economic behavior, we decided to include the following variables in our analysis. Using these variables in our model estimation helps us isolate households' responses to price changes from other changes related to demographic characteristics, and we can also find out if there was heterogeneity in households' sensitivity to the energy crisis among various socio-economic groups. For example, households could behave differently depending on their educational attainment, the number of children, and whether they live in a big city or the countryside. A summary of numerical demographic variables that we used can be found in Table 1. We also used categorical demographic variables which are described below.

The variable educational attainment reaches values from 1 to 4. It provides

Table 1: Summary of Numerical Demographic Variables

Statistic	Mean	St. Dev.	Min	Max
Household size	2.235	1.074	1	7
Adults in the household	1.910	0.712	1	4
Children aged 0 to 17 in the household	0.316	0.635	0	2
Children aged 0 to 12 in the household	0.233	0.558	0	2
Size of place of residence	5.547	1.871	1	7
Age of head of the household	54.358	15.779	18	93

information on whether the person who filled in the survey on their household's behalf is less educated (1 = finished elementary school) or highly educated (4 = finished university). Wave of survey refers to the period when the data was collected. Our sample begins in wave 20, which was in January 2021. We excluded the previous waves because the survey was primarily aimed at the COVID-19 pandemic back then and did not include all questions on households' expenditures that are important for our analysis. The variable helps us account for any time trends. War in Ukraine is a dummy variable attaining the value 1 if the observation was collected during the war in Ukraine and 0 otherwise. Household size is the number of people living in a given household, and adults in the household is the number of adults living in a household. We also control for the number of children in households using variables children aged 0 to 17 in the household and children aged 0 to 12 in the household. The variable size of place of residence can reach values from 1 to 7. These values represent bins that contain intervals of the number of people living in the place of a given household's residence. The higher the value, the higher the population of the place. For example, bin 1 contains households living in a place with a population of less than 1,000, and bin 7 contains households living in a place with a population of 100,000 or more. Region is a factor that indicates one of the 14 regions in Czechia where a given household lives. Economic status is also a factor providing information about the person who filled in the survey on behalf of a household, and it can reach values from 1 to 7, where 1 = employee, 2 = self-employed, 3 = student, 4 = parental leave, 5 = pensioner, 6 = unemployed, 7 = other. The age of the head of the household is the age of the person who filled in the survey. The minimum age in our data is 18 years, and the maximum is 93 years, so the results we obtain should represent multiple generations.

4.2.2 Households' Expenditures

The original dataset contained the amounts that households spent on various types of goods. We used this data to calculate expenditure shares for these goods, which we need as inputs for our model. Expenditure share w_i for good i, where $i = 1, \ldots, k$, was calculated as a fraction of total expenditures for each household, i.e.

$$w_i = \frac{expenditure_i}{\sum_{j=1}^{k} expenditure_j}. \tag{1}$$

A summary of households' expenditure shares of various types of goods is provided in Table 2. According to this summary, most households spend most of their budget on food. The mean share of expenditures on food is almost 30%. Households spend a relatively large share of their budget on rent or mortgage repayments. The mean share of expenditures on gas is 5.26%. Such a value is way lower than shares of expenditures on food and rent or mortgage repayments, but if we consider that not all households use gas, then the share of more than five percent is relatively substantial. We also introduced an aggregate statistic Energy, which represents all goods in the data that are related to energy (gas, electricity, distant heat, solid fuels). The expenditure share of energy was obtained by taking the sum of expenditures on all energy-related goods for each household and dividing this number by the sum of all expenditures. As expected, energy is essential in household budgets, with an average share of more than 16%. Despite the energy crisis, there is still some share of households that can save a part of their income. However, this variable has a large standard deviation compared to its mean, so there seems to be much variation in the data, and we know from recent articles, such as Dvořáková (2023), that a large share of Czech households saves less after the energy crisis than before.

Figure 3 depicts the distribution of total monthly expenditures of households included in our data. Most households spend around 20,500 CZK per month, which is the median value. The mean of total expenditures is slightly influenced

Table 2: Summary of Expenditure Shares (in %)

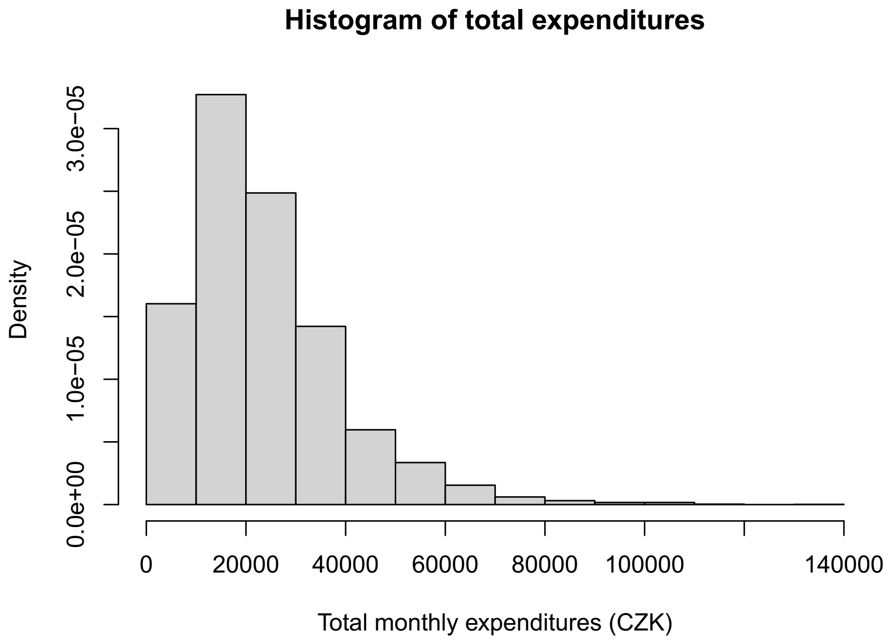
Statistic	Mean	St. Dev.	Median	Max
Food	29.901	13.907	24.570	88.889
Education	1.666	4.238	0.000	46.196
Gas	5.260	8.761	1.042	74.627
Electricity	8.920	7.828	5.618	86.364
Healthcare	3.276	4.173	1.796	79.710
Transport	6.780	6.529	4.938	50.378
Restaurants	3.685	4.786	1.974	45.045
Rent/mortgage	18.272	24.307	6.803	99.338
Distant heat	3.631	5.711	0.000	45.259
Solid fuels	1.370	5.884	0.000	78.125
Energy	16.572	12.541	13.231	95.748
Other	12.870	10.233	8.696	70.093
Savings	22.641	19.992	15.385	94.787

by the higher values and reaches 23,634 CZK per month. The wide dispersion of values is reflected by a relatively large standard deviation of 15,157. The shape of the histogram looks similar to the density function of a log-normal distribution. While a considerable number of households spend less than 10,000 CZK per month, a small fraction of households spend more than 100,000 CZK, with the maximum value reaching almost 140,000 CZK.

Since the main focus of our empirical analysis is on gas, we explore expenditures on gas in more detail. The distribution of households' expenditure shares of gas is presented in Figure 4. We can notice that most values are concentrated between 0 and 20%, which is something that we expect because not all households use gas, and those using gas could have decided to lower their consumption of gas as a consequence of the sudden increase in gas prices during the energy crisis. However, a fraction of households spent more than 20% of their budget on gas, which is a significant portion if we consider that gas does not have much use compared to other goods in the data.

To gain a deeper insight into households' expenditures on energy in general, we also show a histogram of electricity expenditure shares and a histogram of the aggregate statistic Energy (Figure 5), representing all energy-related goods from the data. The expenditure shares of energy are mainly distributed between 0 and 40%, with a median value of 13%. However, a considerable number of households

Figure 3: Histogram of Households' Total Expenditures



spend up to 80% of their budget on energy-related goods, which is problematic because those households are forced to save somewhere else. Then, the energy crisis can quickly turn into a more complex problem. For example, children's education quality can be lower if many households spend less money on things like textbooks, or even the population's health can decrease when households start massively limiting their budgets on food and decide to buy cheaper and unhealthy foodstuffs. The purpose of these graphical representations of selected variables is to indicate hints of patterns that could be extracted from the data. To properly expose the patterns, we employ an econometric model to estimate the energy crisis's effects empirically.

Figure 4: Histograms of Expenditure Shares of Gas

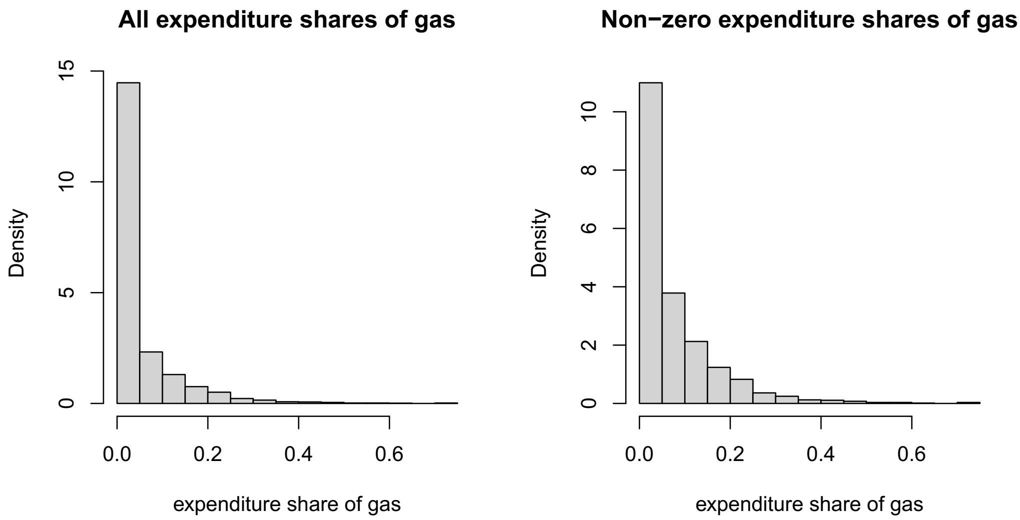
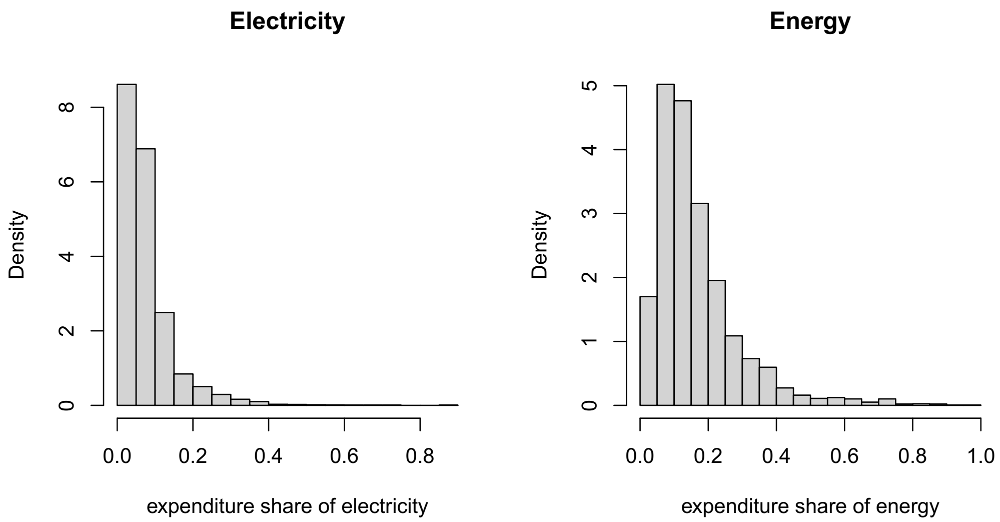


Figure 5: Histograms of Expenditure Shares of Electricity and Energy



4.2.3 Prices of Goods

Prices of goods are critical variables for our analysis because we use them as inputs in a model to estimate households' cross-price elasticities of demand. Prices of goods that we consider are approximated by consumer price indices summarized in Table 3. The consumer price index (CPI) values for gas and electricity were calculated from the original prices, and the prices of all other goods were obtained directly as consumer price indices. We present the mean, standard deviation, minimum, and maximum values of indices for all goods. Based on the values of standard deviation, we can see that gas and electricity prices have by far the highest volatility among the compared types of goods. The difference between the minimum and maximum value of the gas and electricity price index is well more than 1000% of the minimum value, which clearly shows a shock in gas prices during the energy crisis. Nonetheless, prices of other goods changed quickly as well when we consider that our sample includes only 30 months, and the differences between minimum and maximum values are more than 20% in all cases except education. The quick price changes are a natural consequence of the energy crisis, which starts by pushing energy prices up and then follows with an increase in prices of other goods once producers reflect the higher energy prices.

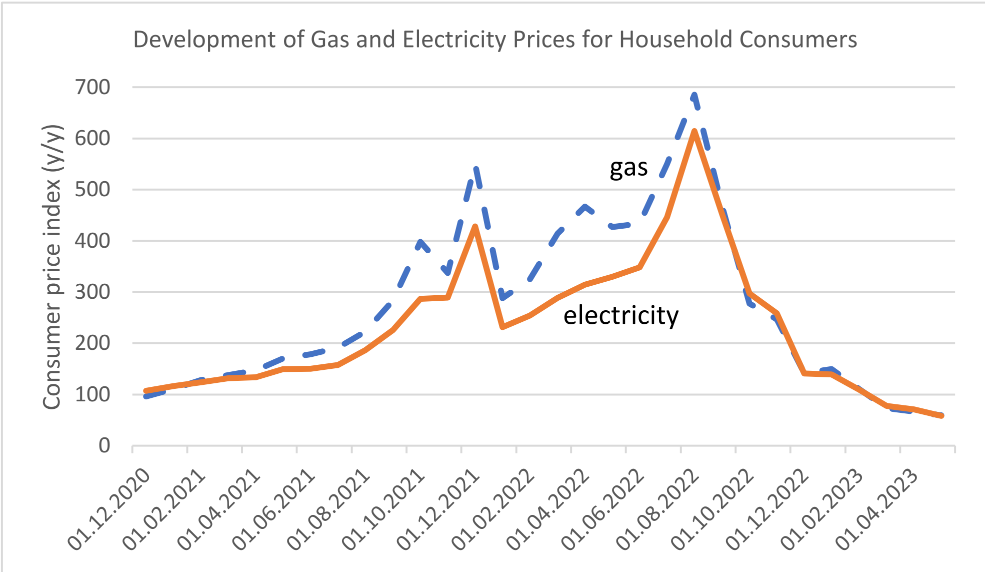
Table 3: Summary of Goods' Prices

Statistic	Mean	St. Dev.	Min	Max
Food	126.896	14.336	110.800	151.900
Education	117.614	4.235	113.900	124.700
Gas	266.119	163.029	59.301	685.278
Electricity	226.326	128.947	58.214	614.395
Healthcare	127.320	7.657	116.900	143.400
Transport	123.778	11.343	106.200	140.000
Restaurants	143.352	18.338	123.100	174.400
Rent/mortgage	156.745	8.343	136.900	161.000
Distant heat	158.833	8.399	139.900	163.000
Solid fuels	154.232	8.212	135.700	158.000
Other	124.755	9.061	113.800	141.600

The development of gas and electricity prices, which is approximated by the consumer price index, is presented in Figure 6. There were two main peaks in the prices of both gas and electricity. The first peak occurred at the end of 2021.

The second peak, which was the largest one, appeared in August 2022. The development of other goods' prices was shown in Figure 2.

Figure 6: Development of Gas and Electricity Prices for Households



5 Methodology

This section of the thesis introduces the theoretical framework we use for the empirical estimation on data summarized in the previous section. We start by explaining the theory which allows us to build and estimate a model describing a demand system, including assumptions that need to be made for the model to work correctly, and we continue by incorporating demographic variables. Further, we present how we calculate various types of elasticities of demand, which are essential for answering our research questions. Lastly, we discuss the method of estimation that we consider the most suitable under given circumstances to empirically estimate the model on our data.

5.1 Quadratic Almost Ideal Demand System

We decided to estimate the Quadratic Almost Ideal Demand System (QUAIDS) model of Banks, Blundell, and Lewbel (1997). The QUAIDS is an econometric model commonly used in microeconomics to analyze consumer demand patterns. It was developed as an extension of Deaton and Muellbauer's (1980) Almost Ideal Demand System (AIDS). This model is beneficial for estimating and understanding how changes in prices and incomes affect the demanded quantity of various goods and services.

A fundamental assumption of the QUAIDS model is that consumers maximize their utility subject to budget constraints when making consumption decisions. We briefly explained the utility maximization problem in the theoretical part of the thesis (section 3.1 Theoretical Background - Households' Economic Behavior). The model also assumes prices to be exogenous, which seems to be a reasonable assumption for the energy crisis, as the price shocks were primarily driven by the turbulent geopolitical situation. The QUAIDS model can be mathematically written as a system of equations representing the relationships among prices of goods, income, and demanded quantities of goods. An essential part of the system is a set of expenditure share equations specified with quadratic terms to allow for a polynomial relationship between supernumerary income and some goods. Allowing for such a relationship is essential because the model then provides a more complex and realistic representation of consumer demand compared to simpler demand systems that do not contain such terms.

The QUAIDS model is suitable for our empirical estimation because it can be used to analyze the demand for individual goods and commodity bundles using individual-level (in our case household-level) data, and it can also account for heterogeneous (demographic) characteristics of households. Estimated parameters from this model can be used to calculate various types of elasticities of demand, which we need for answering our research questions.

A further advantage of the QUAIDS model is its ability to handle corner solutions, where consumers may choose not to consume a particular good at all. This is especially relevant in cases where certain goods have inherent constraints or are luxury items that are only consumed when households' incomes reach a certain level. The quadratic terms enable the model to capture these corner solutions more accurately than linear models.

5.1.1 Technical Description of the Model

The QUAIDS model can be mathematically described as written below. We follow the estimation procedure suggested by Poi (2012). We consider a household's demand for a set of k goods for which the household has budgeted m units of currency. The k goods represent categories such as food, education, healthcare, transport, leisure, utilities, and savings. The QUAIDS model is based on an indirect utility function, which has a specific form to capture substitution effects, income effects, and curvature in preferences, i. e. the structure allows for a flexible and realistic representation of how consumers make choices in response to changes in prices and income. The indirect utility function can be written as

$$\ln V(\mathbf{p}, m) = \left[\left(\frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})} \right)^{-1} + \lambda(\mathbf{p}) \right]^{-1}, \tag{2}$$

where $\ln a(\mathbf{p})$ is the transcendental logarithm function

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k. \tag{3}$$

In this function, p_i is the price of good i for $i = 1, \ldots, k$. $b(\mathbf{p})$ is the Cobb-

Douglas price aggregator that can be written as

$$b(\mathbf{p}) = \prod_{i=1}^{k} p_i^{\beta_i}, \tag{4}$$

and

$$\lambda(\mathbf{p}) = \sum_{i=1}^{k} \lambda_i \ln p_i. \tag{5}$$

Lowercase Greek letters other than α_0 represent model parameters that we want to estimate. Theoretically, α_0 could be estimated jointly with the other parameters. However, in practice, estimating α_0 is claimed to be rather tricky. Deaton and Muellbauer (1980), Banks, Blundell, and Lewbel (1997), and most others suggest that α_0 should be set to a value that is slightly less than the lowest value of the logarithm of household income which can be observed in the data.

Adding up, homogeneity, and Slutsky symmetry impose the conditions that

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{j=1}^{k} \gamma_{ij} = 0, \quad \sum_{i=1}^{k} \lambda_i = 0, \quad \gamma_{ij} = \gamma_{ji}. \tag{6}$$

Let q_i denote the quantity of good i consumed by a household, and define the expenditure share for good i as $w_i = \frac{p_i q_i}{m}$. Then, by applying Roy's identity to Equation (2), we obtain the following expenditure share equation for good i:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{m}{a(\mathbf{p})}\right) + \frac{\lambda_i}{b(\mathbf{p})}\left[\ln\left(\frac{m}{a(\mathbf{p})}\right)\right]^2, \quad i = 1, \ldots, k. \tag{7}$$

When $\lambda_i = 0$ for all i, the quadratic term in each expenditure share equation drops out, and we receive the Deaton and Muellbauer's (1980) original almost ideal demand system (AIDS) model.

5.1.2 Inclusion of Demographic Variables

We believe that demographic variables, such as the number of people in a household and their age or educational attainment, play an important role in households' decisions about their expenditures. The above-described demand system, however, does not reflect demographic variables by default. Therefore, we include them in our model using the scaling technique that was first introduced by Ray (1983) and later extended to the QUAIDS model by Poi (2002a). We use $\mathbf{z}$ to represent a vector of s household demographic characteristics. Let $e^R(\mathbf{p}, u)$ denote the expenditure function of a reference household. Ray's method uses, for each household, an expenditure function in the form

$$e(\mathbf{p}, \mathbf{z}, u) = m_0(\mathbf{p}, \mathbf{z}, u) \times e^R(\mathbf{p}, u). \tag{8}$$

The function $m_0(\mathbf{p}, \mathbf{z}, u)$ scales the expenditure function to control for household characteristics. Ray further decomposes the scaling function as

$$m_0(\mathbf{p}, \mathbf{z}, u) = \bar{m}_0(\mathbf{z}) \times \phi(\mathbf{p}, \mathbf{z}, u). \tag{9}$$

The first term measures the increase in a household's expenditures as a function of $\mathbf{z}$, not controlling for any changes in consumption patterns. The intuition behind this is that, for example, a household with four members will probably have higher expenditures than a different household with a single member, even ignoring that the composition of goods consumed may change. The second term accounts for changes in relative prices and the actual goods consumed. A household with two adults and two children will likely consume different goods than a household consisting of four adults. Following Ray (1983), QUAIDS parameterizes $\bar{m}_0(\mathbf{z})$ as

$$\bar{m}_0(\mathbf{z}) = 1 + \rho' \mathbf{z}, \tag{10}$$

where ρ is a vector of parameters to be estimated. As in Poi (2002a), QUAIDS parameterizes $\phi(\mathbf{p}, \mathbf{z}, u)$ as

$$\ln \phi(\mathbf{p}, \mathbf{z}, u) = \frac{\prod_{j=1}^k p_j^{\beta_j} \left(\prod_{j=1}^k p^{\eta_j' \mathbf{z}} - 1 \right)}{\frac{1}{u} - \sum_{j=1}^k \lambda_j \ln p_j}. \tag{11}$$

This functional form has the advantage of resulting in expenditure share equations that are very similar to their counterparts without demographic variables. η_j represents the j-th column of an $s \times k$ parameter matrix η. The expenditure share equations can be written as

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \left(\beta_i + \eta_i' \mathbf{z}\right) \ln\left(\frac{m}{\bar{m}_0(\mathbf{z}) a(\mathbf{p})}\right) + \frac{\lambda_i}{b(\mathbf{p}) c(\mathbf{p}, \mathbf{z})} \left[\ln\left(\frac{m}{\bar{m}_0(\mathbf{z}) a(\mathbf{p})}\right)\right]^2, \tag{12}$$

where

$$c(\mathbf{p}, \mathbf{z}) = \prod_{j=1}^{k} p_j^{\eta_j' \mathbf{z}}. \tag{13}$$

The adding-up condition requires that $\sum_{j=1}^{k} \eta_{rj} = 0$ for $r = 1, \ldots, s$. If we set $\lambda_i = 0$ for all i, we get to the AIDS model with demographic variables used by Ray (1983).

5.2 Elasticities of Demand

Parameter estimates from the QUAIDS model allow us to calculate expenditure elasticities of demand, sometimes also referred to as income elasticities, for all goods. Expenditure elasticity of demand indicates how the demanded quantity of a good changes in response to changes in a household's income while keeping the prices of all goods constant. This is already valuable information, but the main reason why we use the QUAIDS model is that we can also use the estimated parameters to calculate cross-price elasticities of demand for various pairs of goods. Cross-price elasticities of demand tell us how the demanded quantity of one good changes in response to a change in the price of another good while keeping other factors constant. This information is crucial for answering our second research question because it reflects the sensitivity of households to price shocks. For example, we are interested in how households reacted to the extreme increase in gas prices during the energy crisis. Hence, we find cross-price elasticities of demand for various goods with respect to gas price, and we can see if households increased or decreased their demand for those goods when the price of gas increased. We can obtain uncompensated and compensated cross-price elasticities. The uncompensated cross-price elasticity is derived from the Marshallian demand equation, obtained by maximizing utility subject to a budget constraint. In contrast, the compensated cross-price elasticity is derived from the Hicksian demand equation, which can be obtained by solving the dual problem of expenditure minimization at a certain utility level. If cross-price elasticity is positive, the two compared goods are considered gross substitutes. If it is negative, the goods are gross complements. A zero value indicates that the goods are independent (Dybczak, 2014).

Below, we present formulas for calculating the elasticities using estimates from the QUAIDS model with demographic variables, as suggested by Poi (2012).

The expenditure elasticity for good i is determined by

$$\mu_i = 1 + \frac{1}{w_i}\left[\beta_i + \eta_j' \mathbf{z} + \frac{2\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})} \ln\left(\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right)\right]. \tag{14}$$

The uncompensated cross-price elasticity of good i with respect to changes in the price of good j is calculated as

$$\begin{aligned} \epsilon_{ij}^U = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - \left[\beta_i + \eta_j'\mathbf{z} + \frac{2\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})}\ln\left(\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right)\right] \times \right. \\ \left. \left(\alpha_j + \sum_l \gamma_{jl} \ln p_l\right) - \frac{(\beta_j + \eta_j'\mathbf{z})\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})}\left[\ln\left(\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right)\right]^2\right). \end{aligned} \tag{15}$$

Compensated cross-price elasticities are obtained from the Slutsky equation, and they can be expressed as

$$\epsilon_{ij}^C = \epsilon_{ij}^U + \mu_i w_j. \tag{16}$$

5.3 Method of Estimation

Because the QUAIDS model is not linear in parameters, we cannot rely on elementary estimation methods, such as OLS, as they require linearity in parameters. We considered the recommendations from relevant academic literature (for more details see section 2.1.2 Literature Review - Methods for Empirical Estimation) and the feasibility of possible methods regarding software availability and performance. We decided to apply the estimation procedure that was proposed by Poi (2012). We assume an additive zero-mean error term is associated with each of the k expenditure share equations. The model parameters are estimated using iterated feasible generalized nonlinear least-squares (FGNLS) method. The

FGNLS estimation is a nonlinear variant of the seemingly unrelated regression (SUR) model that was presented by Zellner (1962), Zellner and Huang (1962), and Zellner (1963). Therefore, the FGNLS estimation procedure is also commonly called nonlinear SUR. This method of estimation was also discussed in more recent literature, such as Davidson and MacKinnon (1993), and Greene (2012). The errors for each observation might be correlated. Hence, if we fit the k equations jointly, we should obtain more efficient estimates. Furthermore, we can impose cross-equation restrictions on the parameters when we fit the equations jointly. All parameter and data matrix elements do not have to appear in all equations. However, each element of the parameter matrix has to appear in at least one equation so that the parameters can be identified. The iterative FGNLS estimation is equivalent to maximum likelihood estimation with multivariate normal disturbances for this model.

The FGNLS method can be described in more detail as follows. Our description is based on the Stata Base Reference Manual (2023). We can write our system of equations in general terms for the i-th observation as

$$y_i = f(x_i, \beta) + u_i, \tag{17}$$

where y_i and u_i represent $1 \times M$ vectors, for $i = 1, \ldots, N$. x_i represents all the independent variables in the demand system, and β denotes a $1 \times k$ vector of parameters, which we want to estimate. f is a function that takes x_i and β as inputs and returns a $1 \times M$ vector. The generalized nonlinear least-squares system estimator is defined as

$$\hat{\beta} \equiv \text{argmin}_\beta \sum_{i=1}^{N} \{y_i - f(x_i, \beta)\} \Sigma^{-1} \{y_i - f(x_i, \beta)\}', \tag{18}$$

where $\Sigma = E(u_i' u_i)$ is an $M \times M$ positive-definite weight matrix. Let T be the Cholesky decomposition of Σ^{-1}. That is $TT' = \Sigma^{-1}$. By postmultiplying Equation (17) by T we obtain

$$y_i T = f(x_i, \beta) T + u_i T. \tag{19}$$

Since we know that $E(T'u_i'u_iT) = I$, we can rewrite Equation (19) as

$$
\begin{aligned}
y_1T_1 &= f(x_1,\beta)T_1 + \tilde{u}_{11} \\
y_1T_2 &= f(x_1,\beta)T_2 + \tilde{u}_{12} \\
&\vdots \\
y_1T_M &= f(x_1,\beta)T_M + \tilde{u}_{1M} \\
&\vdots \\
y_NT_1 &= f(x_N,\beta)T_1 + \tilde{u}_{N1} \\
y_NT_2 &= f(x_N,\beta)T_2 + \tilde{u}_{N2} \\
&\vdots \\
y_NT_M &= f(x_N,\beta)T_M + \tilde{u}_{NM},
\end{aligned}
\tag{20}
$$

where T_j represents the j-th column of T. By construction, all $\tilde{u}_{ij}$ are independently distributed with unit variance. As a result, by transforming the model in Equation (17) to that presented in Equation (20), the multivariate generalized nonlinear least-squares system estimator has been reduced to a univariate nonlinear least-squares problem. Furthermore, the residuals $\tilde{u}_{ij}$ all have variance equal to 1, so the final scaled residual sum of squares (RSS) is equal to NM.

We need an estimate $\hat{\Sigma}$ of Σ to make the estimator feasible. The estimate is first set to $\hat{\Sigma} = I$. Even though such an estimator is inefficient, the resulting estimate, $\hat{\beta}_{NLS}$, is at least consistent. Then, we calculate the residuals

$$\hat{u}_i = y_i - f(x_i, \hat{\beta}_{NLS}), \tag{21}$$

and we use them to compute

$$\hat{\Sigma} = \frac{1}{N}\sum_{i=1}^{N} \hat{u}_i'\hat{u}_i. \tag{22}$$

Further, having $\hat{\Sigma}$, we obtain a new estimate $\hat{\beta}$. We follow with an iterative procedure, where we use the new $\hat{\beta}$ to recompute the residuals and to get a new estimate of $\hat{\Sigma}$, from which we can then reestimate $\hat{\beta}$. Iterations stop when one of the following conditions is satisfied.

- The relative change in $\hat{\beta}$ is smaller than the convergence criterion for successive parameter estimates and for the RSS. The criterion value is by default set to 10^{-5}.
- The relative change in $\hat{\Sigma}$ is smaller than the convergence criterion for successive estimates of the error covariance matrix. The default value of this criterion is set to 10^{-10}.
- 300 iterations have been performed.

Because our sample consists of individual households observed over multiple periods, we expect an intragroup correlation in our data that would cause incorrect standard errors of our model parameter estimates. We employ a cluster-robust variance-covariance matrix estimator to compute the standard errors correctly. Each household in our data has its identification number, which allows us to adjust standard errors for household clusters. If we omitted clustering, the simple variance-covariance matrix could be computed as

$$V(\hat{\beta}) = \left(\sum_{i=1}^{N} X_i' \hat{\Sigma}^{-1} X_i \right)^{-1}, \tag{23}$$

where the $M \times k$ matrix X_i has a typical element X_{ist}, the derivative of the s-th element of f with respect to the t-th element of β, evaluated at x_i and $\hat{\beta}$.

The cluster–robust variance-covariance matrix can be expressed as

$$V_c(\hat{\beta}) = \left(\sum_{i=1}^{N} X_i' \hat{\Sigma}^{-1} X_i \right)^{-1} \sum_{c=1}^{N_C} w_c w_c' \left(\sum_{i=1}^{N} X_i' \hat{\Sigma}^{-1} X_i \right)^{-1}, \tag{24}$$

where N_C is the number of clusters and

$$w_c = \sum_{j \in C_k} X_j' \hat{\Sigma}^{-1} \hat{u}_j' \tag{25}$$

with C_k referring to the set of observations in the k-th cluster. When evaluating these formulas, we use the value of $\hat{\Sigma}$ that was used in calculating the final estimate of $\hat{\beta}$. Hence, we do not recalculate $\hat{\Sigma}$ after obtaining the final value of $\hat{\beta}$.

5.4 Goodness-of-Fit Evaluation

To measure the goodness of fit of our model, we use R^2 and log-likelihood. Below, we briefly explain how we obtain these values. R^2 is calculated using residual sum of squares (RSS), total sum of squares (TSS), and model sum of squares (MSS). We calculate these sums of squares for each (j-th) equation. The RSS is obtained as

$$\mathrm{RSS}_j = \sum_{i=1}^{N} (\hat{y}_{ij} - y_{ij})^2, \tag{26}$$

where $\hat{y}_{ij}$ denotes the predicted value of the i-th observation on the j-th dependent variable. The TSS can be expressed as

$$\mathrm{TSS}_j = \sum_{i=1}^{N} (y_{ij} - \bar{y}_j)^2, \tag{27}$$

provided the j-th equation contains a constant term. $\bar{y}_j$ is the sample mean of the j-th dependent variable. When there is not a constant term in the j-th equation, the TSS is calculated as

$$\mathrm{TSS}_j = \sum_{i=1}^{N} y_{ij}^2. \tag{28}$$

We calculate the MSS as

$$\mathrm{MSS}_j = \mathrm{TSS}_j - \mathrm{RSS}_j. \tag{29}$$

Then, using these sums of squares we can calculate R^2 for the j-th equation as

$$R_j^2 = \frac{\mathrm{MSS}_j}{\mathrm{TSS}_j}. \tag{30}$$

Given the assumption that the residuals u_i are independent and identically distributed, $u_i \sim \mathcal{N}(0, \hat{\Sigma})$, we can calculate the log-likelihood for the model as

$$\ln L = -\frac{MN}{2} \{1 + \ln(2\pi)\} - \frac{N}{2} \ln \left| \hat{\Sigma} \right|. \tag{31}$$

We use the log-likelihood for the likelihood ratio test to check the robustness of our model by comparing its goodness of fit to a restricted model. The test statistic θ_{LR} is calculated as

$$\theta_{LR} = -2 \cdot (\ln L_{\text{restricted}} - \ln L_{\text{unrestricted}}), \tag{32}$$

where $\ln L_{\text{restricted}}$ is the log-likelihood of a restricted model, and $\ln L_{\text{unrestricted}}$ is the log-likelihood of an unrestricted model. The test statistic θ_{LR} converges asymptotically to the χ^2 distribution with the number of degrees of freedom equal to the difference between the degrees of freedom of the full model and the restricted model.

6 Empirical Results

In this section we present an overview of empirical results of our analysis. Because the full results consist of multiple long tables with estimates of model parameters, indicators of the estimates' quality, and estimates of elasticities of demand, we provide only a selection of the most important parts, so that the results are easy to read and understand. Tables with the full results can be found in the Appendix (see section A.2 Full Results).

Table 4: Basic Model Characteristics

QUAIDS Model	
Method of estimation	Iterated FGNLS
Number of observations	4,766
Number of goods	12
Number of demographics	4
Demographic method	Scaling
Centered R^2 of model for goods	
Food	0.1101
Education	0.1898
Gas	0.0289
Electricity	0.2536
Healthcare	0.0507
Transport	0.0913
Restaurants	0.0351
Rent/mortgage	0.0203
Distant heat	0.1467
Solid fuels	0.1063
Other	0.0537
Savings	0.1743

The first part of the empirical analysis was obtaining parameter estimates of the QUAIDS model. Table 4 shows a summary of basic characteristics of this model. It was estimated using the iterated feasible generalized nonlinear least squares (FGNLS) method on the clean data set consisting of 4,766 observations. We included 12 categories of goods and 4 demographic variables (educational attainment of household head, wave of survey, household size, size of place of residence) that were incorporated into the model using the scaling method as described in section 5.1.2 Methodology - Inclusion of Demographic Variables. The centered R^2 is a model diagnostic that tells us what proportion of variation in the data was explained by estimating the model. It might appear that the values of centered R^2 are low, but if we consider that each value corresponds only to an individual good, we can say we explained a solid proportion of the variation in the data, especially using expenditure shares of electricity, education, and savings, where the R^2 was higher than 17% in each case.

6.1 Estimated Model Parameters

In this part, we discuss the obtained estimates of the model parameters, including their statistical significance and interpretation. The estimated model coefficients can be interpreted as follows. Alpha estimates are constant terms in expenditure-share equations and also appear in the price index. In practice, they represent the average expenditure share. Beta estimates measure sensitivity of expenditure shares to changes in deflated expenditure and also appear in price aggregator function. Gamma estimates measure the effect of price on expenditure shares across goods. Lambda estimates measure the sensitivity of expenditure shares to changes in deflated expenditure. Rho estimates modify the price index to account for demographic variables. Eta estimates measure the effect of demographic variables on expenditure elasticities. The parameters of central interest in our thesis are beta, gamma, lambda, and eta because they carry information that is crucial for answering our research questions. The standard errors of the estimates were adjusted for clusters in households (based on household identification numbers) to control for intragroup correlation. The estimates of alpha parameters for all goods were not significantly different from zero, so it appears that the alpha parameter, which represents the constant in the expenditure share equation, does not play an important role in the demand system. Among the estimates of the slope coefficients, which are covered by the parameters beta, lambda, and eta (the exact positions of the parameters in the model equations are described in Equation (12) in section 5.1.2 Methodology - Inclusion of Demographic Variables), we found more than 40% of estimates that are statistically significant. The biggest share of significant estimates was obtained for the parameter gamma with more than 70%, so we can say that we found significant effects of prices on expenditure shares across goods, which is essential information for answering our research questions.

We concentrate mainly on analyzing demand for gas, so we present a selection of parameter estimates for gas in Table 5. We also included electricity in this selection for comparison. The table shows estimates of all parameters for gas in the top panel and the same for electricity in the bottom panel. We can notice that we have more significant estimates of parameters for electricity. That is probably because not all households use gas, while almost every household uses electricity. Thus, the share of observations in the data, where expenditure shares on gas are zero, is higher than the share of observations where expenditure shares on electricity are zero. This is shown by the histograms in section 4.2.2 Data - Households' Expenditures (see Figure 4 and Figure 5).

Table 5: Parameter Estimates for Gas and Electricity

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Gas						
Alpha	1.414708	3.743836	0.38	0.706	-5.923077	8.752492
Beta	0.0485899	0.0416139	1.17	0.243	-0.0329718	0.1301517
Gamma						
Gas	0.0658571	0.1097928	0.60	0.549	-0.1493328	0.2810469
Electricity	-0.0370186	0.1292595	-0.29	0.775	-0.2903625	0.2163253
Healthcare	0.5348756	0.2692587	1.99	0.047	0.0071383	1.062613
Transport	0.1475216	0.176518	0.84	0.403	-0.1984473	0.4934904
Restaurants	-0.4051117	0.0623849	-6.49	0.000	-0.527384	-0.2828395
Rent/mortgage	0.0511632	0.1369352	0.37	0.709	-0.2172249	0.3195513
Distant heat	-0.154153	0.0949875	-1.62	0.105	-0.3403251	0.0320192
Solid fuels	0.2442628	0.1025597	2.38	0.017	0.0432494	0.4452762
Other	-0.4886755	0.1159809	-4.21	0.000	-0.7159938	-0.2613571
Lambda	-0.0107403	0.0100379	-1.07	0.285	-0.0304143	0.0089337
Eta						
Educational attainment	0.0006947	0.000465	1.49	0.135	-0.0002168	0.0016061
Wave of survey	0.0004576	0.0004482	1.02	0.307	-0.0004209	0.0013361
Household size	0.0000293	0.0006969	0.04	0.966	-0.0013365	0.0013952
Size of place of residence	8.17e-06	0.0001978	0.04	0.967	-0.0003796	0.0003959
Electricity						
Alpha	0.3083853	2.479124	0.12	0.901	-4.550609	5.16738
Beta	-0.2002759	0.053338	-3.75	0.000	-0.3048164	-0.0957354
Gamma						
Electricity	-0.2521321	0.2476392	-1.02	0.309	-0.7374961	0.2332319
Healthcare	-0.4057478	0.1858444	-2.18	0.029	-0.7699962	-0.0414995
Transport	0.036634	0.1966693	0.19	0.852	-0.3488307	0.4220987
Restaurants	0.3587629	0.0651249	5.51	0.000	0.2311204	0.4864053
Rent/mortgage	-0.2018557	0.259288	-0.78	0.436	-0.7100508	0.3063393
Distant heat	-0.0910902	0.1541769	-0.59	0.555	-0.3932714	0.2110911
Solid fuels	-0.339106	0.1376663	-2.46	0.014	-0.608927	-0.069285
Other	0.5912101	0.1327607	4.45	0.000	0.3310039	0.8514163
Lambda	0.0268364	0.017798	1.51	0.132	-0.008047	0.0617198
Eta						
Educational attainment	-0.0025816	0.0012649	-2.04	0.041	-0.0050608	-0.0001024
Wave of survey	-0.0021123	0.0009009	-2.34	0.019	-0.0038781	-0.0003465
Household size	0.0050007	0.0015136	3.30	0.001	0.0020341	0.0079673
Size of place of residence	-0.0016952	0.0005727	-2.96	0.003	-0.0028176	-0.0005728

Table 6: Rho Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Educational attainment	3.426521	280.5438	0.01	0.990	-546.4293	553.2823
Wave of survey	2.496577	204.3987	0.01	0.990	-398.1176	403.1107
Household size	-18.03442	1464.068	-0.01	0.990	-2887.556	2851.487
Size of place of residence	2.785249	225.815	0.01	0.990	-439.804	445.3745

Based on the estimates of parameters rho (Table 6) and eta (Table 7) we can evaluate the importance of demographic variables in terms of explaining households' demand because rho estimates modify the price index to account for demographic variables, and eta estimates measure the effect of demographic variables directly on expenditure elasticities of demand. The estimated rho coefficients are not statistically significant, so it appears that the price index in our demand system does not need to be modified. However, almost 50% of the estimates of eta are significant. Hence, demographic variables do have an effect on expenditure elasticities of demand according to the estimates of model parameters. Educational attainment has a positive effect on expenditure elasticitity of demand for food, education, transport, and dining in restaurants. This means that households whose members are more educated usually increase their demand for these goods more strongly when their income increases than households with less educated members. On the other hand, educational attainment has a negative effect on expenditure elasticities of demand for electricity, rent and mortgage payments, and solid fuels. The variable wave of survey was included in the model to account for any time trends, and it appears to be important because it yields multiple significant estimates. Expenditure elasticities of demand for food, electricity, and distant heat seem to be impacted by time trends. Household size has a positive effect on expenditure elasticity of demand for education, electricity, and distant heat. The expenditure elasticity of demand for transport, dining in restaurants, and the category of other goods is negatively affected by household size. Size of place of residence, which is determined by the number of inhabitants, has a positive effect on expenditure elasticity of demand for food, dining in restaurants, and the category of other goods. It has a negative effect on expenditure elasticity of demand for electricity, and solid fuels. None of the analyzed demographic variables have a significant effect on expenditure elasticity of demand for gas, so there are probably not large differences among socio-economic groups in terms of expenditure elasticity of demand for gas. If we consider expenditure elasticity of demand for electricity, our results show that there is significant heterogeneity among socio-economic groups.

Table 7: Effects of Demographics on Expenditure Elasticities of Demand Measured by Eta Parameter Estimates

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Educational attainment						
Food	0.0033376	0.0013735	2.43	0.015	0.0006457	0.0060295
Education	0.000626	0.0003073	2.04	0.042	0.0000238	0.0012282
Gas	0.0006947	0.000465	1.49	0.135	-0.0002168	0.0016061
Electricity	-0.0025816	0.0012649	-2.04	0.041	-0.0050608	-0.0001024
Healthcare	-0.0003364	0.0003251	-1.03	0.301	-0.0009735	0.0003007
Transport	0.0023519	0.0007753	3.03	0.002	0.0008322	0.0038715
Restaurants	0.0006077	0.0002962	2.05	0.040	0.000027	0.0011883
Rent/mortgage	-0.0054154	0.0019135	-2.83	0.005	-0.0091657	-0.001665
Distant heat	-0.0012382	0.0007272	-1.70	0.089	-0.0026636	0.0001871
Solid fuels	-0.0017537	0.000796	-2.20	0.028	-0.0033138	-0.0001937
Other	0.0012606	0.0007593	1.66	0.097	-0.0002276	0.0027488
Wave of survey						
Food	0.0028594	0.0012513	2.29	0.022	0.0004069	0.0053118
Education	0.0002416	0.0004102	0.59	0.556	-0.0005624	0.0010455
Gas	0.0004576	0.0004482	1.02	0.307	-0.0004209	0.0013361
Electricity	-0.0021123	0.0009009	-2.34	0.019	-0.0038781	-0.0003465
Healthcare	-0.000533	0.0004879	-1.09	0.275	-0.0014894	0.0004234
Transport	0.0012255	0.0008265	1.48	0.138	-0.0003943	0.0028453
Restaurants	0.0004542	0.000436	1.04	0.298	-0.0004004	0.0013089
Rent/mortgage	-0.0028326	0.0015028	-1.88	0.059	-0.005778	0.0001129
Distant heat	-0.0022042	0.0008821	-2.50	0.012	-0.0039331	-0.0004753
Solid fuels	0.0009648	0.000729	1.32	0.186	-0.000464	0.0023936
Other	-0.0012577	0.0009042	-1.39	0.164	-0.0030298	0.0005145
Household size						
Food	-0.0022871	0.0016647	-1.37	0.169	-0.0055499	0.0009758
Education	0.0013449	0.0004204	3.20	0.001	0.000521	0.0021688
Gas	0.0000293	0.0006969	0.04	0.966	-0.0013365	0.0013952
Electricity	0.0050007	0.0015136	3.30	0.001	0.0020341	0.0079673
Healthcare	0.0004108	0.0003496	1.17	0.240	-0.0002745	0.001096
Transport	-0.0017246	0.0007538	-2.29	0.022	-0.0032021	0.0002472
Restaurants	-0.0007335	0.0003469	-2.11	0.034	-0.0014135	0.0000535
Rent/mortgage	0.0017319	0.0020233	0.86	0.392	-0.0022338	0.0056976
Distant heat	0.0022191	0.0009986	2.22	0.026	0.0002619	0.0041763
Solid fuels	0.0012125	0.0009467	1.28	0.200	-0.0006431	0.003068
Other	-0.0029399	0.0009118	-3.22	0.001	-0.004727	0.0011529
Size of place of residence						
Food	0.0011087	0.0004897	2.26	0.024	0.000149	0.0020684
Education	0.0001212	0.0001014	1.20	0.232	-0.0000775	0.0003199
Gas	8.17e-06	0.0001978	0.04	0.967	-0.0003796	0.0003959
Electricity	-0.0016952	0.0005727	-2.96	0.003	-0.0028176	-0.0005728
Healthcare	-0.0000263	0.0000924	-0.28	0.776	-0.0002073	0.0001548
Transport	-0.000314	0.000241	-1.30	0.193	-0.0007863	0.0001583
Restaurants	0.0002943	0.0001059	2.78	0.005	0.0000868	0.0005019
Rent/mortgage	0.0002601	0.000527	0.49	0.622	-0.0007729	0.001293
Distant heat	0.0003258	0.0002419	1.35	0.178	-0.0001483	0.0007998
Solid fuels	-0.0012843	0.0003544	-3.62	0.000	-0.0019788	-0.0005897
Other	0.0006166	0.0002629	2.35	0.019	0.0001014	0.0011318

6.2 Estimated Elasticities of Demand

After estimating the QUAIDS model we used the obtained coefficients to calculate expenditure elasticities of demand, and uncompensated (Marshallian) as well as compensated (Hicksian) cross-price elasticities of demand to uncover how households change their consumption behavior in response to changes in their income and prices of various goods. We present the calculated expenditure elasticities in Table 8, and a selection of cross-price elasticities can be found in Tables 9, 10, and 11. Tables with full results can be found in the Appendix.

Table 8: Estimated Expenditure Elasticities of Demand

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food	0.6415766	0.0288163	22.26	0.000	0.5850977	0.6980555
Education	0.4503105	0.2602669	1.73	0.084	-0.0598032	0.9604242
Gas	-5.327598	1.104963	-4.82	0.000	-7.493286	-3.16191
Electricity	0.268321	0.0576493	4.65	0.000	0.1553305	0.3813114
Healthcare	0.5145454	0.0634928	8.10	0.000	0.3901018	0.6389889
Transport	0.778891	0.0541375	14.39	0.000	0.6727835	0.8849985
Restaurants	1.324828	0.0709776	18.67	0.000	1.185714	1.463941
Rent/mortgage	1.19293	0.0768346	15.53	0.000	1.042337	1.343523
Distant heat	0.3438724	0.1804465	1.91	0.057	-0.0097962	0.6975411
Solid fuels	0.139068	0.5489273	0.25	0.800	-0.9368097	1.214946
Other	1.328012	0.0557308	23.83	0.000	1.218782	1.437242
Savings	1.826004	0.0746604	24.46	0.000	1.679673	1.972336

Even though we did not find significant differences among socio-economic groups in relation to expenditure elasticity of demand for gas, the most interesting result among estimates of overall expenditure elasticities of demand was obtained for gas. The estimated value of expenditure elasticity of demand for gas is -5.33, which is the largest magnitude among the compared goods, and the result is statistically significant. Such a value tells us that when a household's income increases by one percent, the household will decrease its expenditure share of gas by 5.33 percent. The value of expenditure elasticity of demand for gas is far from zero, so we can confidently say that demand for gas is income-elastic during the energy crisis. The sign of the calculated elasticity is negative, which is what we expected. Such a result is interesting because energy sources are usually considered to be inelastic goods with an exception of energy crises when households react more strongly to changes in both income and prices. All the other expenditure elasticities of demand are way closer to zero. Savings, the category of other goods, and dining in restaurants are the next three categories of goods with the highest expenditure elasticities of demand. The values of the elasticities are higher than 1 in all the mentioned cases, so we can still consider demand for these goods to be income-elastic. Demand for energy sources other than gas seems to be income-inelastic.

Next, we present cross-price elasticities of demand for pairs of goods. Cross-price elasticitiy of demand tells us how the demanded quantity of one good changes in response to a change in the price of another good, while keeping other factors constant. The uncompensated cross-price elasticities, which are derived from the Marshallian demand function, are presented in Table 9, Table 10, and Table 11.

We obtained statistically significant estimates of cross-price elasticity of expenditure shares of healthcare, dining in restaurants, distant heat, solid fuels, and the category of other goods with respect to gas price. The cross-price elasticity of expenditure share of healthcare with respect to gas price is positive, which means that an increase in the price of gas is related to an increase in households' expenditure shares of healthcare. The elasticities of expenditure shares of all the other above mentioned goods are negative and smaller than 1, so we have evidence that an increase in prices of gas causes households to decrease their expenditure share of these goods. Such results are intuitive because households cannot afford to buy as much of the goods as before the energy crisis. Households apparently strongly decrease their expenditure shares of dining in restaurants, which is quite understandable since it is a luxury good, and households are forced to spend a higher proportion of their income on necessities. The own-price elasticity of expenditure share of gas is not significantly different from zero.

The estimated cross-price elasticities of expenditure shares with respect to electricity price show that when the price of electricity increases, households decrease their expenditure shares of goods related to healthcare and transport. The decrease in expenditure shares of healthcare is not only statistically significant, but also very strong in terms of magnitude. The cross-price elasticity of expenditure share of healthcare with respect to electricity price is -14.41. This means that when the price of electricity increases by one percent, the expenditure share of goods related to healthcare decreases by 14.41 percent. Such a reaction from households is intuitive, and it shows how dangerous an energy crisis can be. If a large number of households decide to lower their expenditures on healthcare, the overall level of health in the population could significantly fall. On the contrary, we received positive cross-price elasticities of expenditure shares of solid fuels and the category of other goods with respect to electricity price. The relationship between electricity and solid fuels seems logical because households probably react to high electricity prices by using cheaper energy sources. The relationship between energy and the category of other goods is difficult to interpret because it represents a bundle of various goods that do not correspond to any of the other categories from our analysis. Nevertheless, we have further evidence that households change their demand due to the higher energy prices. The own-price elasticity of expenditure share of electricity is not significantly different from zero.

Regarding cross-price elasticities between other pairs of goods, we obtained intuitive estimates in terms of both significance and magnitude. The cross-price elasticities of expenditure shares of luxury goods with respect to prices of necessities are usually negative. This means that households decrease their expenditure shares of luxury goods, such as dining in restaurants, in response to increasing prices of necessities. Solid fuels are the only energy-related category of goods that has the own-price elasticity of its expenditure share significantly different from zero. The elasticity is strongly positive. A result going against our expectations is that savings are mostly an inelastic good. The estimated cross-price elasticities of savings as a share of income with respect to goods' prices are often statistically insignificant or very close to zero. We expected households to decrease the proportion of their income which they save as a consequence of higher prices of goods, but this does not seem to be true, according to the estimates. A possible explanation for such a result is that many households saved only a very low proportion of their income even before the energy crisis, so the change during the energy crisis is too small for our model to recognize. Furthermore, the few households that saved a lot before the energy crisis might be so financially responsible or rich that they are able to save also during the energy crisis, so the change in the proportion of savings is insignificant.

We received very similar results when we calculated the compensated cross-price elasticities of demand, which are derived from the Hicksian demand function. Tables with the estimated compensated cross-price elasticities of demand can be found in the Appendix. The estimates of compensated cross-price elasticities of demand show mostly the same intuition as the uncompensated cross-price elasticities.

Table 9: Uncompensated (Marshallian) Cross-price Elasticities - Part 1

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Food						
Food	-6.59877	6.418695	-1.03	0.304	-19.17918	5.981642
Education	-40.34013	29.67789	-1.36	0.174	-98.50773	17.82746
Gas	-13.13723	55.21083	-0.24	0.812	-121.3485	95.07401
Electricity	0.2809745	4.182519	0.07	0.946	-7.916613	8.478562
Healthcare	70.88958	44.64759	1.59	0.112	-16.61809	158.3973
Transport	2.996722	11.32177	0.26	0.791	-19.19353	25.18697
Restaurants	-42.49201	7.428519	-5.72	0.000	-57.05163	-27.93238
Rent/mortgage	5.889919	3.187433	1.85	0.065	-0.3573344	12.13717
Distant heat	-42.96837	15.18531	-2.83	0.005	-72.73103	-13.20571
Solid fuels	-3.837637	21.14985	-0.18	0.856	-45.29058	37.61531
Other	-6.476959	3.883592	-1.67	0.095	-14.08866	1.134742
Savings	10.50166	19.89193	0.53	0.598	-28.4858	49.48912
Education						
Food	-1.011225	0.808725	-1.25	0.211	-2.596296	0.5738473
Education	-33.46221	1.233903	-27.12	0.000	-35.88062	-31.04381
Gas	8.94077	8.576129	1.04	0.297	-7.868134	25.74967
Electricity	-1.19938	0.8326348	-1.44	0.150	-2.831314	0.4325544
Healthcare	-4.373479	0.2786834	-15.69	0.000	-4.919689	-3.82727
Transport	13.62345	1.406921	9.68	0.000	10.86594	16.38097
Restaurants	38.97504	7.887135	4.94	0.000	23.51654	54.43354
Rent/mortgage	-6.04562	0.292856	-20.64	0.000	-6.619607	-5.471633
Distant heat	60.65702	2.994885	20.25	0.000	54.78715	66.52689
Solid fuels	16.32063	1.552247	10.51	0.000	13.27828	19.36298
Other	-12.38116	0.1525212	-81.18	0.000	-12.6801	-12.08223
Savings	-1.595312	0.177876	-8.97	0.000	-1.943942	-1.246681
Gas						
Food	-0.5634169	1.578451	-0.36	0.721	-3.657124	2.530291
Education	8.085899	8.947845	0.90	0.366	-9.451554	25.62335
Gas	13.303	14.31553	0.93	0.353	-14.75492	41.36092
Electricity	-1.934079	1.173774	-1.65	0.099	-4.234634	0.3664752
Healthcare	20.71512	10.34828	2.00	0.045	0.4328715	40.99737
Transport	3.595425	2.834002	1.27	0.205	-1.959117	9.149968
Restaurants	-13.79087	2.112371	-6.53	0.000	-17.93105	-9.650703
Rent/mortgage	-0.1115033	0.7737646	-0.14	0.885	-1.628054	1.405047
Distant heat	-8.980449	3.573002	-2.51	0.012	-15.9834	-1.977495
Solid fuels	-10.1261	4.057003	-2.50	0.013	-18.07768	-2.174516
Other	-4.576838	1.061936	-4.31	0.000	-6.658194	-2.495483
Savings	1.571938	4.878785	0.32	0.747	-7.990304	11.13418
Electricity						
Food	0.0922642	1.055845	0.09	0.930	-1.977154	2.161682
Education	-9.116385	7.739808	-1.18	0.239	-24.28613	6.053361
Gas	-19.42811	10.15041	-1.91	0.056	-39.32255	0.4663299
Electricity	1.163516	0.8962163	1.30	0.194	-0.5930357	2.920068
Healthcare	-14.41921	6.538799	-2.21	0.027	-27.23502	-1.603403
Transport	-3.84171	1.884962	-2.04	0.042	-7.536167	-0.1472526
Restaurants	11.22284	1.845047	6.08	0.000	7.606615	14.83907
Rent/mortgage	0.3831436	0.622933	0.62	0.539	-0.8377826	1.60407
Distant heat	4.824406	3.230734	1.49	0.135	-1.507715	11.15653
Solid fuels	8.705797	3.53885	2.46	0.014	1.769778	15.64182
Other	4.793211	0.9242005	5.19	0.000	2.981811	6.604611
Savings	-0.9558016	3.115295	-0.31	0.759	-7.061667	5.150064

Table 10: Uncompensated (Marshallian) Cross-price Elasticities - Part 2

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Healthcare						
Food	7.456259	4.699534	1.59	0.113	-1.754658	16.66718
Education	-16.59572	0.874104	-18.99	0.000	-18.30893	-14.88251
Gas	76.74937	38.27096	2.01	0.045	1.739677	151.7591
Electricity	-6.024846	2.736057	-2.20	0.028	-11.38742	-0.6622728
Healthcare	124.4343	26.24192	4.74	0.000	73.00104	175.8675
Transport	17.62048	8.074769	2.18	0.029	1.794227	33.44674
Restaurants	-83.35241	8.941897	-9.32	0.000	-100.8782	-65.82662
Rent/mortgage	5.523671	3.979239	1.39	0.165	-2.275494	13.32284
Distant heat	50.10819	20.57983	2.43	0.015	9.772459	90.44392
Solid fuels	107.0273	36.8362	2.91	0.004	34.82971	179.225
Other	1.513338	4.633243	0.33	0.744	-7.567651	10.59433
Savings	-23.72046	14.71293	-1.61	0.107	-52.55726	5.116347
Transport						
Food	0.7700543	2.766697	0.28	0.781	-4.652573	6.192681
Education	120.0381	12.5886	9.54	0.000	95.36489	144.7113
Gas	33.54212	24.56969	1.37	0.172	-14.61358	81.69783
Electricity	-3.884892	1.830033	-2.12	0.034	-7.471692	-0.2980923
Healthcare	40.94192	18.76636	2.18	0.029	4.160539	77.72331
Transport	1.42967	5.803393	0.25	0.805	-9.944771	12.80411
Restaurants	-32.82044	4.376471	-7.50	0.000	-41.39817	-24.24272
Rent/mortgage	-10.30928	1.568315	-6.57	0.000	-13.38312	-7.235437
Distant heat	-12.51039	10.68715	-1.17	0.242	-33.45683	8.436047
Solid fuels	-82.40856	5.961598	-13.82	0.000	-94.09308	-70.72404
Other	-6.337787	1.867036	-3.39	0.001	-9.99711	-2.678465
Savings	-3.148202	9.016905	-0.35	0.727	-20.82101	14.52461
Restaurants						
Food	-5.043186	0.8856317	-5.69	0.000	-6.778992	-3.307379
Education	169.2935	34.26605	4.94	0.000	102.1332	236.4537
Gas	-57.48993	8.877026	-6.48	0.000	-74.88858	-40.09128
Electricity	5.340742	0.8751179	6.10	0.000	3.625542	7.055941
Healthcare	-94.50716	10.14114	-9.32	0.000	-114.3834	-74.63089
Transport	-15.9924	2.133173	-7.50	0.000	-20.17334	-11.81145
Restaurants	59.57265	0.1821122	327.12	0.000	59.21571	59.92958
Rent/mortgage	-11.3253	0.2118184	-53.47	0.000	-11.74045	-10.91014
Distant heat	-42.26042	2.990461	-14.13	0.000	-48.12161	-36.39922
Solid fuels	-138.8984	0.998244	-139.14	0.000	-140.8549	-136.9419
Other	4.544192	0.1083549	41.94	0.000	4.331821	4.756564
Savings	7.15905	0.1281915	55.85	0.000	6.907799	7.4103
Rent/mortgage						
Food	3.471568	1.854451	1.87	0.061	-0.1630883	7.106225
Education	-126.7219	5.166823	-24.53	0.000	-136.8487	-116.5951
Gas	-3.790563	15.60455	-0.24	0.808	-34.37492	26.79379
Electricity	1.168032	1.413444	0.83	0.409	-1.602267	3.938331
Healthcare	30.68096	22.0331	1.39	0.164	-12.50313	73.86504
Transport	-24.44752	3.747175	-6.52	0.000	-31.79185	-17.10319
Restaurants	-55.2743	1.018295	-54.28	0.000	-57.27012	-53.27848
Rent/mortgage	29.44814	1.788759	16.46	0.000	25.94224	32.95404
Distant heat	-171.8951	8.050893	-21.35	0.000	-187.6745	-156.1156
Solid fuels	48.97993	7.13738	6.86	0.000	34.99092	62.96894
Other	26.79881	0.7611797	35.21	0.000	25.30693	28.2907
Savings	-0.3872512	0.8988252	-0.43	0.667	-2.148916	1.374414

Table 11: Uncompensated (Marshallian) Cross-price Elasticities - Part 3

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Distant heat						
Food	-3.841209	1.378169	-2.79	0.005	-6.542372	-1.140047
Education	202.7141	10.40138	19.49	0.000	182.3277	223.1004
Gas	-29.55985	11.586	-2.55	0.011	-52.26798	-6.851708
Electricity	1.704644	1.173384	1.45	0.146	-0.5951475	4.004435
Healthcare	43.38206	17.80881	2.44	0.015	8.477433	78.28669
Transport	-4.473669	3.960733	-1.13	0.259	-12.23656	3.289225
Restaurants	-32.27729	2.306924	-13.99	0.000	-36.79878	-27.75581
Rent/mortgage	-26.97408	1.300864	-20.74	0.000	-29.52372	-24.42443
Distant heat	2.574947	4.344171	0.59	0.553	-5.939471	11.08937
Solid fuels	-183.4325	7.740179	-23.70	0.000	-198.6029	-168.262
Other	-1.680131	4.040751	-0.42	0.678	-9.599856	6.239595
Savings	0.4832314	1.705105	0.28	0.777	-2.858712	3.825175
Solid fuels						
Food	0.5705352	1.862269	0.31	0.759	-3.079445	4.220516
Education	-46.56503	3.206405	-14.52	0.000	-52.84947	-40.2806
Gas	29.3698	11.69965	2.51	0.012	6.438902	52.3007
Electricity	-3.190695	1.116192	-2.86	0.004	-5.378391	-1.002999
Healthcare	-82.85018	28.57931	-2.90	0.004	-138.8646	-26.83577
Transport	27.81655	1.691655	16.44	0.000	24.50096	31.13213
Restaurants	94.84262	0.5613152	168.97	0.000	93.74247	95.94278
Rent/mortgage	-7.02748	1.102323	-6.38	0.000	-9.187994	-4.866967
Distant heat	163.45	6.990411	23.38	0.000	149.749	177.151
Solid fuels	108.696	4.978625	21.83	0.000	98.93804	118.4539
Other	-25.40099	3.877494	-6.55	0.000	-33.00074	-17.80125
Savings	0.4405337	0.3869591	1.14	0.255	-0.3178922	1.19896
Other						
Food	-2.673158	1.656466	-1.61	0.107	-5.919771	0.5734555
Education	-192.4327	2.055705	-93.61	0.000	-196.4618	-188.4036
Gas	-67.41067	15.93117	-4.23	0.000	-98.6352	-36.18615
Electricity	8.212089	1.567476	5.24	0.000	5.139892	11.28428
Healthcare	6.224063	18.78835	0.33	0.740	-30.60043	43.04856
Transport	-10.98439	3.253429	-3.38	0.001	-17.36099	-4.607786
Restaurants	16.24923	0.3862662	42.07	0.000	15.49217	17.0063
Rent/mortgage	19.64154	0.5676197	34.60	0.000	18.52903	20.75406
Distant heat	-7.761027	18.90534	-0.41	0.681	-44.81482	29.29276
Solid fuels	133.5117	20.1719	6.62	0.000	93.97546	173.0478
Other	19.3361	0.332376	58.18	0.000	18.68465	19.98754
Savings	-1.035983	0.2966487	-3.49	0.000	-1.617404	-0.4545622
Savings						
Food	6.728707	12.52208	0.54	0.591	-17.81412	31.27153
Education	-35.34773	3.491461	-10.12	0.000	-42.19087	-28.50459
Gas	34.23888	108.2999	0.32	0.752	-178.0249	246.5027
Electricity	-1.904426	7.793862	-0.24	0.807	-17.18011	13.37126
Healthcare	-141.6325	87.9831	-1.61	0.107	-314.0762	30.81122
Transport	-8.121507	23.21169	-0.35	0.726	-53.61558	37.37256
Restaurants	37.82012	0.6712327	56.34	0.000	36.50453	39.13571
Rent/mortgage	-0.2860893	0.989292	-0.29	0.772	-2.225066	1.652887
Distant heat	4.417277	11.61203	0.38	0.704	-18.34188	27.17643
Solid fuels	-4.677232	3.938944	-1.19	0.235	-12.39742	3.042956
Other	-1.459795	0.4348695	-3.36	0.001	-2.312124	-0.6074667
Savings	8.860588	42.29617	0.21	0.834	-74.03837	91.75955

6.3 Robustness Check

To check the robustness of our model we estimated restricted versions of the model where we firstly omitted the energy-related goods (gas, electricity, distant heat, solid fuels), and secondly, we excluded demographic variables. Then, we obtained log-likelihood and degrees of freedom for all models (for details see Table 12), and we used these statistics for the likelihood-ratio test to compare the goodness of fit of the full model to the two restricted models. More specifically, we wanted to determine if adding the energy-related goods or demographic variables makes our model fit the data significantly better than a restricted model without the additional variables. Under the null hypothesis, there is not a significant difference in the goodness of fit between the restricted and the full model. Hence, if we cannot reject the null hypothesis, the additional variables do not significantly improve the model, and we would not need them. If we reject the null hypothesis, the additional variables bring us some additional information, and we should keep them in the model. Even under the 1% significance level, we can reject the null hypothesis in both cases, and we can conclude that we should use the full model which includes energy-related goods and demographic variables because they carry important information.

Table 12: Testing Goodness of Fit Using Log-likelihood

	Log-likelihood	Degrees of freedom
Full model	73,394.76	127
Model without energy	44,762.02	79
Model without demographics	72,069.87	79

7 Conclusion

This thesis aimed to analyze the effects of the 2022 energy crisis on changes in consumption patterns among Czech households. We focused mainly on the demand for gas and other energy sources. We built a quadratic almost ideal demand system model, which we estimated on household-level data collected by PAQ Research using the method of iterated feasible generalized nonlinear least squares. We used the estimated model parameters for calculating income and cross-price elasticities of demand, which measure the sensitivity of households to changes in their income and goods' prices. Such information can be helpful for policy decisions to mitigate the adverse effects of potential future energy crises.

We found statistically significant evidence that households' demand for gas is strongly negatively income-elastic during the energy crisis. In contrast, demand for other energy sources is income-inelastic, according to our estimates. The only energy-related category of goods having the own-price elasticity of demand significantly different from zero are solid fuels. We found significant heterogeneity among socio-economic groups when it comes to income elasticity of demand. Socio-economic groups, which we distinguished by educational attainment, number of members in a household, and size of place of residence, have a significant effect on income elasticity of demand for electricity, solid fuels, and distant heat, but not for gas. Socio-economic groups also have significant effects on income elasticity of demand for goods other than energy, including both necessities and luxury goods. We found negative cross-price elasticity of expenditure shares of luxury goods, distant heat, and solid fuels with respect to gas price. Hence, households are forced to decrease their expenditure shares of these goods in response to an increase in gas price. The cross-price elasticity of expenditure shares of goods related to healthcare and transport with respect to electricity price is also negative. Especially the expenditure shares of healthcare have significantly decreased due to the high electricity prices. Expenditure shares of solid fuels have a positive cross-price elasticity with respect to electricity price. Thus, households increase their shares of expenditures on solid fuels in response to higher electricity prices. The cross-price elasticities of luxury goods' expenditure shares with respect to prices of necessities are negative, so households usually decrease their expenditure shares of luxury goods in response to increasing prices of necessities.

The results are robust per the robustness check, which was performed using likelihood-ratio tests. Energy-related goods and demographic variables were proven to play an essential role in the demand system. What we consider a deficiency of the analysis are goods' prices that are only available as aggregate values for all households. But in reality, the prices of some goods differ across households. For example, energy prices are often dependent on the contract between the consumer and the supplier. If we had such information, the results could be more accurate. The analysis could be further developed using more recent data because households still have to deal with the consequences of the energy crisis at the moment of publishing this thesis. If the analysis covered a more extended period, all the relevant variables could be more informative. One could also add more variables, representing goods and demographics, into the demand system to better control for different aspects of the energy crisis.

By all counts and with proven results, the 2022 energy crisis severely affected Czech households. The high prices of energy were reflected by prices of many other goods, which caused households to significantly change their consumption, including cutting back on important categories of goods, such as healthcare, and it will take time until they fully recover.

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Acronyms

AIDADS An implicitly directly additive demand system

AIDS Almost ideal demand system

CPI Consumer price index

CZSO Czech Statistical Office

DRM Dynamic regression model

EU European Union

FGNLS Feasible generalized non-linear least squares

GMM Generalized method of moments

MLE Maximum likelihood estimation

MSS Model sum of squares

OLS Ordinary least squares

QUAIDS Quadratic almost ideal demand system

RSS Residual sum of squares

SUR Seemingly unrelated regressions

SYRI National Institute for Research of the Socio-economic Impacts of Diseases and System Risks

TSS Total sum of squares

A Appendix

A.1 List of Variables

- Educational attainment - reaches value from 1 to 4, and provides information how the person who filled in the survey on behalf of their household is educated (1 = finished elementary school, 2 = finished high school without leaving exam, 3 = finished high school with leaving exam, 4 = finished university).

- Wave of survey - refers to the period when the data was collected. Our sample begins in wave 20, which was in January 2021. We excluded the previous waves because back then the survey was mostly aimed at the COVID-19 pandemic and did not include all questions on households' expenditures that are important for our analysis. The variable helps us account for any time trends.

- War in Ukraine - a dummy variable attaining the value 1 if the observation was collected in a period during the war in Ukraine and 0 otherwise.

- Household size - the number of people living in a given household.

- Adults in the household - the number of adult people living in a given household.

- Children aged 0 to 17 in the household - the number of children aged 0 to 17 living in a given household.

- Children aged 0 to 12 in the household - the number of children aged 0 to 12 living in a given household.

- Size of place of residence - can reach values from 1 to 7. These values represent bins that contain intervals of the number of people living in the place of a given household's residence. The higher the value, the higher the population of the place. For example, bin 1 contains households living in a place with a population less than 1,000, and bin 7 contains households living in a place with a population of 100,000 and more.

- Region - a factor indicating in which of the 14 Czech regions a given household lives.
- Economic status - a factor providing information about the person who filled in the survey on behalf of a household, and it can reach values from 1 to 7, where 1 = employee, 2 = self-employed, 3 = student, 4 = parental leave, 5 = pensioner, 6 = unemployed, 7 = other.
- Age of head of the household - the age of the person who filled in the survey on behalf of their household.
- wFood - expenditure share of food
- wEducation - expenditure share of education
- wGas - expenditure share of gas
- wHealthcare - expenditure share of healthcare
- wTransport - expenditure share of transport
- wRestaurants - expenditure share of restaurants
- wOther - expenditure share of other goods
- wSavings - expenditure share of savings
- pFood - consumer price index of food
- pEducation - consumer price index of education
- pGas - consumer price index of gas
- pHealthcare - consumer price index of healthcare
- pTransport - consumer price index of transport
- pRestaurants - consumer price index of restaurants
- pOther - consumer price index of other goods

A.2 Full Results

Table A.1: Basic Model Characteristics

QUAIDS Model	
Number of observations	4,766
Number of goods	12
Number of demographics	4
Demographic method	Scaling
Centered R^2 of model for goods	
Food	0.1101
Education	0.1898
Gas	0.0289
Electricity	0.2536
Healthcare	0.0507
Transport	0.0913
Restaurants	0.0351
Rent/mortgage	0.0203
Distant heat	0.1467
Solid fuels	0.1063
Other	0.0537
Savings	0.1743

A.2.1 Estimated Model Parameters

Standard errors were adjusted for clusters in households (based on household ID number).

Table A.2: Alpha Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food	8.284978	15.30445	0.54	0.588	-21.7112	38.28116
Education	-1.468815					
Gas	1.414708	3.743836	0.38	0.706	-5.923077	8.752492
Electricity	0.3083853	2.479124	0.12	0.901	-4.550609	5.16738
Healthcare	-17.54558	11.28102	-1.56	0.120	-39.65598	4.564826
Transport	-2.456745	6.92713	-0.35	0.723	-16.03367	11.12018
Restaurants	5.287116					
Rent/mortgage	0.334636					
Distant heat	1.445181	1.633891	0.88	0.376	-1.757188	4.647549
Solid fuels	-0.0713489					
Other	-1.08375					

Table A.3: Beta Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food	0.3741075	0.1287688	2.91	0.004	0.1217254	0.6264897
Education	0.0376063	0.0207201	1.81	0.070	-0.0030042	0.0782169
Gas	0.0485899	0.0416139	1.17	0.243	-0.0329718	0.1301517
Electricity	-0.2002759	0.053338	-3.75	0.000	-0.3048164	-0.0957354
Healthcare	-0.0036931	0.0342038	-0.11	0.914	-0.0707314	0.0633452
Transport	0.1686699	0.0480863	3.51	0.000	0.0744224	0.2629173
Restaurants	0.0039515	0.0256517	0.15	0.878	-0.0463249	0.0542279
Rent/mortgage	-0.0790173	0.104029	-0.76	0.448	-0.2829104	0.1248759
Distant heat	-0.0557441	0.0535665	-1.04	0.298	-0.1607326	0.0492443
Solid fuels	-0.1534423	0.0932191	-1.65	0.100	-0.3361483	0.0292637
Other	0.1316072	0.0498221	2.64	0.008	0.0339577	0.2292567

Table A.4: Gamma Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food#Food	-2.473214	1.812987	-1.36	0.173	-6.026604	1.080176
Food#Education	-0.3609231	0.2205851	-1.64	0.102	-0.7932619	0.0714156
Food#Gas	-0.2990402	0.431581	-0.69	0.488	-1.144924	0.5468431
Food#Electricity	0.6241179	0.4909671	1.27	0.204	-0.3381599	1.586396
Food#Healthcare	1.860808	1.17808	1.58	0.114	-0.4481854	4.169802
Food#Transport	-0.2874986	0.7083211	-0.41	0.685	-1.675782	1.100785
Food#Restaurants	-1.278031	0.2293974	-5.57	0.000	-1.727641	-0.82842
Food#Rent/mortgage	1.296516	0.6080581	2.13	0.033	0.1047436	2.488288
Food#Distant heat	-0.623844	0.3499356	-1.78	0.075	-1.309705	0.0620171
Food#Solid fuels	0.3816079	0.6573717	0.58	0.562	-0.906817	1.670033
Food#Other	-0.7974758	0.4487523	-1.78	0.076	-1.677014	0.0820625
Education#Education	-0.225692					
Education#Gas	0.0408201	0.0635591	0.64	0.521	-0.0837534	0.1653936
Education#Electricity	-0.0080392	0.0695869	-0.12	0.908	-0.1444271	0.1283486
Education#Healthcare	-0.1058893					
Education#Transport	0.7595496	0.0928172	8.18	0.000	0.5776312	0.941468
Education#Restaurants	1.122864	0.2275861	4.93	0.000	0.6768031	1.568924
Education#Rent/mortgage	-0.8056598					
Education#Distant heat	1.376367	0.0838664	16.41	0.000	1.211992	1.540742
Education#Solid fuels	-0.2885077					
Education#Other	-1.295712					
Gas#Gas	0.0658571	0.1097928	0.60	0.549	-0.1493328	0.2810469
Gas#Electricity	-0.0370186	0.1292595	-0.29	0.775	-0.2903625	0.2163253
Gas#Healthcare	0.5348756	0.2692587	1.99	0.047	0.0071383	1.062613
Gas#Transport	0.1475216	0.176518	0.84	0.403	-0.1984473	0.4934904
Gas#Restaurants	-0.4051117	0.0623849	-6.49	0.000	-0.527384	-0.2828395
Gas#Rent/mortgage	0.0511632	0.1369352	0.37	0.709	-0.2172249	0.3195513
Gas#Distant heat	-0.154153	0.0949875	-1.62	0.105	-0.3403251	0.0320192
Gas#Solid fuels	0.2442628	0.1025597	2.38	0.017	0.0432494	0.4452762
Gas#Other	-0.4886755	0.1159809	-4.21	0.000	-0.7159938	-0.2613571
Electricity#Electricity	-0.2521321	0.2476392	-1.02	0.309	-0.7374961	0.2332319
Electricity#Healthcare	-0.4057478	0.1858444	-2.18	0.029	-0.7699962	-0.0414995
Electricity#Transport	0.036634	0.1966693	0.19	0.852	-0.3488307	0.4220987
Electricity#Restaurants	0.3587629	0.0651249	5.51	0.000	0.2311204	0.4864053
Electricity#Rent/mortgage	-0.2018557	0.259288	-0.78	0.436	-0.7100508	0.3063393
Electricity#Distant heat	-0.0910902	0.1541769	-0.59	0.555	-0.3932714	0.2110911
Electricity#Solid fuels	-0.339106	0.1376663	-2.46	0.014	-0.608927	-0.069285
Electricity#Other	0.5912101	0.1327607	4.45	0.000	0.3310039	0.8514163
Healthcare#Healthcare	3.197204	0.6684849	4.78	0.000	1.886998	4.50741
Healthcare#Transport	1.069632	0.4902541	2.18	0.029	0.1087516	2.030512
Healthcare#Restaurants	-2.408968	0.2583133	-9.33	0.000	-2.915253	-1.902683
Healthcare#Rent/mortgage	0.757501	0.5531461	1.37	0.171	-0.3266455	1.841648
Healthcare#Distant heat	1.088069	0.4446595	2.45	0.014	0.2165526	1.959586
Healthcare#Solid fuels	-2.127864	0.7458475	-2.85	0.004	-3.589698	-0.6660296
Healthcare#Other	0.1673658	0.4818493	0.35	0.728	-0.7770415	1.111773
Transport#Transport	-0.05646	0.3326042	-0.17	0.865	-0.7083522	0.5954323
Transport#Restaurants	-0.9726739	0.1313536	-7.41	0.000	-1.230122	-0.7152257
Transport#Rent/mortgage	-1.257189	0.3467978	-3.63	0.000	-1.936901	-0.5774782
Transport#Distant heat	-0.1321492	0.2472318	-0.53	0.593	-0.6167146	0.3524161
Transport#Solid fuels	1.757131					
Transport#Other	-0.7174402	0.221787	-3.23	0.001	-1.152135	-0.2827456
Restaurants#Restaurants	1.750476					
Restaurants#Rent/mortgage	-1.576735					
Restaurants#Distant heat	-0.9170275	0.0808242	-11.35	0.000	-1.07544	-0.758615
Restaurants#Solid fuels	2.757368					
Restaurants#Other	0.4626058					
Rent/mortgage#Rent/mortgage	4.109307					
Rent/mortgage#Distant heat	-3.941537	0.296434	-13.30	0.000	-4.522537	-3.360537
Rent/mortgage#Solid fuels	-1.095069	0.2385218	-4.59	0.000	-1.562563	-0.6275743
Rent/mortgage#Other	2.837661					
Distant heat#Distant heat	-0.021589					
Distant heat#Solid fuels	3.536738	0.1853214	19.08	0.000	3.173515	3.899962
Distant heat#Other	-0.1256928	0.4226821	-0.30	0.766	-0.9541344	0.7027488
Solid fuels#Solid fuels	-2.234206					
Solid fuels#Other	-2.595899	0.4260761	-6.09	0.000	-3.430992	-1.760805
Other#Other	2.083525					

Table A.5: Lambda Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food	-0.0634441	0.0468905	-1.35	0.176	-0.1553479	0.0284596
Education	-0.0064162	0.004974	-1.29	0.197	-0.0161651	0.0033327
Gas	-0.0107403	0.0100379	-1.07	0.285	-0.0304143	0.0089337
Electricity	0.0268364	0.017798	1.51	0.132	-0.008047	0.0617198
Healthcare	0.0016903	0.003158	0.54	0.592	-0.0044991	0.0078798
Transport	-0.0246731	0.0178135	-1.39	0.166	-0.059587	0.0102408
Restaurants	-0.0018543	0.0030069	-0.62	0.537	-0.0077477	0.0040391
Rent/mortgage	0.0265252	0.0157833	1.68	0.093	-0.0044096	0.05746
Distant heat	0.0137066	0.0105738	1.30	0.195	-0.0070177	0.034431
Solid fuels	0.0128824	0.0135638	0.95	0.342	-0.0137021	0.0394669
Other	-0.0042291	0.007365	-0.57	0.566	-0.0186643	0.010206

Table A.6: Rho Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Educational attainment	3.426521	280.5438	0.01	0.990	-546.4293	553.2823
Wave of survey	2.496577	204.3987	0.01	0.990	-398.1176	403.1107
Household size	-18.03442	1464.068	-0.01	0.990	-2887.556	2851.487
Size of place of residence	2.785249	225.815	0.01	0.990	-439.804	445.3745

Table A.7: Eta Parameter Estimates and Standard Errors

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Educational attainment						
Food	0.0033376	0.0013735	2.43	0.015	0.0006457	0.0060295
Education	0.000626	0.0003073	2.04	0.042	0.0000238	0.0012282
Gas	0.0006947	0.000465	1.49	0.135	-0.0002168	0.0016061
Electricity	-0.0025816	0.0012649	-2.04	0.041	-0.0050608	-0.0001024
Healthcare	-0.0003364	0.0003251	-1.03	0.301	-0.0009735	0.0003007
Transport	0.0023519	0.0007753	3.03	0.002	0.0008322	0.0038715
Restaurants	0.0006077	0.0002962	2.05	0.040	0.000027	0.0011883
Rent/mortgage	-0.0054154	0.0019135	-2.83	0.005	-0.0091657	-0.001665
Distant heat	-0.0012382	0.0007272	-1.70	0.089	-0.0026636	0.0001871
Solid fuels	-0.0017537	0.000796	-2.20	0.028	-0.0033138	-0.0001937
Other	0.0012606	0.0007593	1.66	0.097	-0.0002276	0.0027488
Wave of survey						
Food	0.0028594	0.0012513	2.29	0.022	0.0004069	0.0053118
Education	0.0002416	0.0004102	0.59	0.556	-0.0005624	0.0010455
Gas	0.0004576	0.0004482	1.02	0.307	-0.0004209	0.0013361
Electricity	-0.0021123	0.0009009	-2.34	0.019	-0.0038781	-0.0003465
Healthcare	-0.000533	0.0004879	-1.09	0.275	-0.0014894	0.0004234
Transport	0.0012255	0.0008265	1.48	0.138	-0.0003943	0.0028453
Restaurants	0.0004542	0.000436	1.04	0.298	-0.0004004	0.0013089
Rent/mortgage	-0.0028326	0.0015028	-1.88	0.059	-0.005778	0.0001129
Distant heat	-0.0022042	0.0008821	-2.50	0.012	-0.0039331	-0.0004753
Solid fuels	0.0009648	0.000729	1.32	0.186	-0.000464	0.0023936
Other	-0.0012577	0.0009042	-1.39	0.164	-0.0030298	0.0005145
Household size						
Food	-0.0022871	0.0016647	-1.37	0.169	-0.0055499	0.0009758
Education	0.0013449	0.0004204	3.20	0.001	0.000521	0.0021688
Gas	0.0000293	0.0006969	0.04	0.966	-0.0013365	0.0013952
Electricity	0.0050007	0.0015136	3.30	0.001	0.0020341	0.0079673
Healthcare	0.0004108	0.0003496	1.17	0.240	-0.0002745	0.001096
Transport	-0.0017246	0.0007538	-2.29	0.022	-0.0032021	0.0002472
Restaurants	-0.0007335	0.0003469	-2.11	0.034	-0.0014135	0.0000535
Rent/mortgage	0.0017319	0.0020233	0.86	0.392	-0.0022338	0.0056976
Distant heat	0.0022191	0.0009986	2.22	0.026	0.0002619	0.0041763
Solid fuels	0.0012125	0.0009467	1.28	0.200	-0.0006431	0.003068
Other	-0.0029399	0.0009118	-3.22	0.001	-0.004727	0.0011529
Size of place of residence						
Food	0.0011087	0.0004897	2.26	0.024	0.000149	0.0020684
Education	0.0001212	0.0001014	1.20	0.232	-0.0000775	0.0003199
Gas	8.17e-06	0.0001978	0.04	0.967	-0.0003796	0.0003959
Electricity	-0.0016952	0.0005727	-2.96	0.003	-0.0028176	-0.0005728
Healthcare	-0.0000263	0.0000924	-0.28	0.776	-0.0002073	0.0001548
Transport	-0.000314	0.000241	-1.30	0.193	-0.0007863	0.0001583
Restaurants	0.0002943	0.0001059	2.78	0.005	0.0000868	0.0005019
Rent/mortgage	0.0002601	0.000527	0.49	0.622	-0.0007729	0.001293
Distant heat	0.0003258	0.0002419	1.35	0.178	-0.0001483	0.0007998
Solid fuels	-0.0012843	0.0003544	-3.62	0.000	-0.0019788	-0.0005897
Other	0.0006166	0.0002629	2.35	0.019	0.0001014	0.0011318

Table A.8: Normalized Parameters

	Estimate	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Alpha						
Savings	6.551232	32.39502	0.20	0.840	-56.94183	70.0443
Beta						
Savings	-0.2723596	0.1229428	-2.22	0.027	-0.5133231	-0.0313961
Gamma						
Good#Savings						
Food	1.956976	3.037204	0.64	0.519	-3.995834	7.909787
Education	-0.209177	0.0244952	-8.54	0.000	-0.2571868	-0.1611672
Gas	0.2994987	0.7451774	0.40	0.688	-1.161022	1.76002
Electricity	-0.2757353	0.5079008	-0.54	0.587	-1.271203	0.7197321
Healthcare	-3.626988	2.256706	-1.61	0.108	-8.05005	0.7960746
Transport	-0.3470573	1.367779	-0.25	0.800	-3.027856	2.333741
Restaurants	1.10647	0.0273205	40.50	0.000	1.052923	1.160017
Rent/mortgage	-0.1741021	0.1538625	-1.13	0.258	-0.4756671	0.1274629
Distant heat	0.0059079	0.3170094	0.02	0.985	-0.6154191	0.6272349
Solid fuels	0.0035425	0.0781312	0.05	0.964	-0.1495919	0.1566769
Other	-0.1214725	0.0632802	-1.92	0.055	-0.2454995	0.0025545
Eta						
Savings# Educational attainment	0.0297162	0.0339156	0.88	0.381	-0.0367571	0.0961896
Savings# Wave of survey	0.0024469	0.001254	1.95	0.051	-0.000011	0.0049048
Savings# Household size	0.0027367	0.0008358	3.27	0.001	0.0010986	0.0043747
Savings# Size of place of residence	-0.004264	0.0015829	-2.69	0.007	-0.0073664	-0.0011617
Lambda						
Savings	0.0005849	0.0004107	1.42	0.154	-0.0002201	0.0013899

A.2.2 Estimated Elasticities of Demand

Table A.9: Expenditure Elasticities

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food	0.6415766	0.0288163	22.26	0.000	0.5850977	0.6980555
Education	0.4503105	0.2602669	1.73	0.084	-0.0598032	0.9604242
Gas	-5.327598	1.104963	-4.82	0.000	-7.493286	-3.16191
Electricity	0.268321	0.0576493	4.65	0.000	0.1553305	0.3813114
Healthcare	0.5145454	0.0634928	8.10	0.000	0.3901018	0.6389889
Transport	0.778891	0.0541375	14.39	0.000	0.6727835	0.8849985
Restaurants	1.324828	0.0709776	18.67	0.000	1.185714	1.463941
Rent/mortgage	1.19293	0.0768346	15.53	0.000	1.042337	1.343523
Distant heat	0.3438724	0.1804465	1.91	0.057	-0.0097962	0.6975411
Solid fuels	0.139068	0.5489273	0.25	0.800	-0.9368097	1.214946
Other	1.328012	0.0557308	23.83	0.000	1.218782	1.437242
Savings	1.826004	0.0746604	24.46	0.000	1.679673	1.972336

Table A.10: Uncompensated (Marshallian) Cross-price Elasticities - Part 1

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Food						
Food	-6.59877	6.418695	-1.03	0.304	-19.17918	5.981642
Education	-40.34013	29.67789	-1.36	0.174	-98.50773	17.82746
Gas	-13.13723	55.21083	-0.24	0.812	-121.3485	95.07401
Electricity	0.2809745	4.182519	0.07	0.946	-7.916613	8.478562
Healthcare	70.88958	44.64759	1.59	0.112	-16.61809	158.3973
Transport	2.996722	11.32177	0.26	0.791	-19.19353	25.18697
Restaurants	-42.49201	7.428519	-5.72	0.000	-57.05163	-27.93238
Rent/mortgage	5.889919	3.187433	1.85	0.065	-0.3573344	12.13717
Distant heat	-42.96837	15.18531	-2.83	0.005	-72.73103	-13.20571
Solid fuels	-3.837637	21.14985	-0.18	0.856	-45.29058	37.61531
Other	-6.476959	3.883592	-1.67	0.095	-14.08866	1.134742
Savings	10.50166	19.89193	0.53	0.598	-28.4858	49.48912
Education						
Food	-1.011225	0.808725	-1.25	0.211	-2.596296	0.5738473
Education	-33.46221	1.233903	-27.12	0.000	-35.88062	-31.04381
Gas	8.94077	8.576129	1.04	0.297	-7.868134	25.74967
Electricity	-1.19938	0.8326348	-1.44	0.150	-2.831314	0.4325544
Healthcare	-4.373479	0.2786834	-15.69	0.000	-4.919689	-3.82727
Transport	13.62345	1.406921	9.68	0.000	10.86594	16.38097
Restaurants	38.97504	7.887135	4.94	0.000	23.51654	54.43354
Rent/mortgage	-6.04562	0.292856	-20.64	0.000	-6.619607	-5.471633
Distant heat	60.65702	2.994885	20.25	0.000	54.78715	66.52689
Solid fuels	16.32063	1.552247	10.51	0.000	13.27828	19.36298
Other	-12.38116	0.1525212	-81.18	0.000	-12.6801	-12.08223
Savings	-1.595312	0.177876	-8.97	0.000	-1.943942	-1.246681
Gas						
Food	-0.5634169	1.578451	-0.36	0.721	-3.657124	2.530291
Education	8.085899	8.947845	0.90	0.366	-9.451554	25.62335
Gas	13.303	14.31553	0.93	0.353	-14.75492	41.36092
Electricity	-1.934079	1.173774	-1.65	0.099	-4.234634	0.3664752
Healthcare	20.71512	10.34828	2.00	0.045	0.4328715	40.99737
Transport	3.595425	2.834002	1.27	0.205	-1.959117	9.149968
Restaurants	-13.79087	2.112371	-6.53	0.000	-17.93105	-9.650703
Rent/mortgage	-0.1115033	0.7737646	-0.14	0.885	-1.628054	1.405047
Distant heat	-8.980449	3.573002	-2.51	0.012	-15.9834	-1.977495
Solid fuels	-10.1261	4.057003	-2.50	0.013	-18.07768	-2.174516
Other	-4.576838	1.061936	-4.31	0.000	-6.658194	-2.495483
Savings	1.571938	4.878785	0.32	0.747	-7.990304	11.13418
Electricity						
Food	0.0922642	1.055845	0.09	0.930	-1.977154	2.161682
Education	-9.116385	7.739808	-1.18	0.239	-24.28613	6.053361
Gas	-19.42811	10.15041	-1.91	0.056	-39.32255	0.4663299
Electricity	1.163516	0.8962163	1.30	0.194	-0.5930357	2.920068
Healthcare	-14.41921	6.538799	-2.21	0.027	-27.23502	-1.603403
Transport	-3.84171	1.884962	-2.04	0.042	-7.536167	-0.1472526
Restaurants	11.22284	1.845047	6.08	0.000	7.606615	14.83907
Rent/mortgage	0.3831436	0.622933	0.62	0.539	-0.8377826	1.60407
Distant heat	4.824406	3.230734	1.49	0.135	-1.507715	11.15653
Solid fuels	8.705797	3.53885	2.46	0.014	1.769778	15.64182
Other	4.793211	0.9242005	5.19	0.000	2.981811	6.604611
Savings	-0.9558016	3.115295	-0.31	0.759	-7.061667	5.150064

Table A.11: Uncompensated (Marshallian) Cross-price Elasticities - Part 2

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Healthcare						
Food	7.456259	4.699534	1.59	0.113	-1.754658	16.66718
Education	-16.59572	0.874104	-18.99	0.000	-18.30893	-14.88251
Gas	76.74937	38.27096	2.01	0.045	1.739677	151.7591
Electricity	-6.024846	2.736057	-2.20	0.028	-11.38742	-0.6622728
Healthcare	124.4343	26.24192	4.74	0.000	73.00104	175.8675
Transport	17.62048	8.074769	2.18	0.029	1.794227	33.44674
Restaurants	-83.35241	8.941897	-9.32	0.000	-100.8782	-65.82662
Rent/mortgage	5.523671	3.979239	1.39	0.165	-2.275494	13.32284
Distant heat	50.10819	20.57983	2.43	0.015	9.772459	90.44392
Solid fuels	107.0273	36.8362	2.91	0.004	34.82971	179.225
Other	1.513338	4.633243	0.33	0.744	-7.567651	10.59433
Savings	-23.72046	14.71293	-1.61	0.107	-52.55726	5.116347
Transport						
Food	0.7700543	2.766697	0.28	0.781	-4.652573	6.192681
Education	120.0381	12.5886	9.54	0.000	95.36489	144.7113
Gas	33.54212	24.56969	1.37	0.172	-14.61358	81.69783
Electricity	-3.884892	1.830033	-2.12	0.034	-7.471692	-0.2980923
Healthcare	40.94192	18.76636	2.18	0.029	4.160539	77.72331
Transport	1.42967	5.803393	0.25	0.805	-9.944771	12.80411
Restaurants	-32.82044	4.376471	-7.50	0.000	-41.39817	-24.24272
Rent/mortgage	-10.30928	1.568315	-6.57	0.000	-13.38312	-7.235437
Distant heat	-12.51039	10.68715	-1.17	0.242	-33.45683	8.436047
Solid fuels	-82.40856	5.961598	-13.82	0.000	-94.09308	-70.72404
Other	-6.337787	1.867036	-3.39	0.001	-9.99711	-2.678465
Savings	-3.148202	9.016905	-0.35	0.727	-20.82101	14.52461
Restaurants						
Food	-5.043186	0.8856317	-5.69	0.000	-6.778992	-3.307379
Education	169.2935	34.26605	4.94	0.000	102.1332	236.4537
Gas	-57.48993	8.877026	-6.48	0.000	-74.88858	-40.09128
Electricity	5.340742	0.8751179	6.10	0.000	3.625542	7.055941
Healthcare	-94.50716	10.14114	-9.32	0.000	-114.3834	-74.63089
Transport	-15.9924	2.133173	-7.50	0.000	-20.17334	-11.81145
Restaurants	59.57265	0.1821122	327.12	0.000	59.21571	59.92958
Rent/mortgage	-11.3253	0.2118184	-53.47	0.000	-11.74045	-10.91014
Distant heat	-42.26042	2.990461	-14.13	0.000	-48.12161	-36.39922
Solid fuels	-138.8984	0.998244	-139.14	0.000	-140.8549	-136.9419
Other	4.544192	0.1083549	41.94	0.000	4.331821	4.756564
Savings	7.15905	0.1281915	55.85	0.000	6.907799	7.4103
Rent/mortgage						
Food	3.471568	1.854451	1.87	0.061	-0.1630883	7.106225
Education	-126.7219	5.166823	-24.53	0.000	-136.8487	-116.5951
Gas	-3.790563	15.60455	-0.24	0.808	-34.37492	26.79379
Electricity	1.168032	1.413444	0.83	0.409	-1.602267	3.938331
Healthcare	30.68096	22.0331	1.39	0.164	-12.50313	73.86504
Transport	-24.44752	3.747175	-6.52	0.000	-31.79185	-17.10319
Restaurants	-55.2743	1.018295	-54.28	0.000	-57.27012	-53.27848
Rent/mortgage	29.44814	1.788759	16.46	0.000	25.94224	32.95404
Distant heat	-171.8951	8.050893	-21.35	0.000	-187.6745	-156.1156
Solid fuels	48.97993	7.13738	6.86	0.000	34.99092	62.96894
Other	26.79881	0.7611797	35.21	0.000	25.30693	28.2907
Savings	-0.3872512	0.8988252	-0.43	0.667	-2.148916	1.374414

Table A.12: Uncompensated (Marshallian) Cross-price Elasticities - Part 3

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf. interval]	
Distant heat						
Food	-3.841209	1.378169	-2.79	0.005	-6.542372	-1.140047
Education	202.7141	10.40138	19.49	0.000	182.3277	223.1004
Gas	-29.55985	11.586	-2.55	0.011	-52.26798	-6.851708
Electricity	1.704644	1.173384	1.45	0.146	-0.5951475	4.004435
Healthcare	43.38206	17.80881	2.44	0.015	8.477433	78.28669
Transport	-4.473669	3.960733	-1.13	0.259	-12.23656	3.289225
Restaurants	-32.27729	2.306924	-13.99	0.000	-36.79878	-27.75581
Rent/mortgage	-26.97408	1.300864	-20.74	0.000	-29.52372	-24.42443
Distant heat	2.574947	4.344171	0.59	0.553	-5.939471	11.08937
Solid fuels	-183.4325	7.740179	-23.70	0.000	-198.6029	-168.262
Other	-1.680131	4.040751	-0.42	0.678	-9.599856	6.239595
Savings	0.4832314	1.705105	0.28	0.777	-2.858712	3.825175
Solid fuels						
Food	0.5705352	1.862269	0.31	0.759	-3.079445	4.220516
Education	-46.56503	3.206405	-14.52	0.000	-52.84947	-40.2806
Gas	29.3698	11.69965	2.51	0.012	6.438902	52.3007
Electricity	-3.190695	1.116192	-2.86	0.004	-5.378391	-1.002999
Healthcare	-82.85018	28.57931	-2.90	0.004	-138.8646	-26.83577
Transport	27.81655	1.691655	16.44	0.000	24.50096	31.13213
Restaurants	94.84262	0.5613152	168.97	0.000	93.74247	95.94278
Rent/mortgage	-7.02748	1.102323	-6.38	0.000	-9.187994	-4.866967
Distant heat	163.45	6.990411	23.38	0.000	149.749	177.151
Solid fuels	108.696	4.978625	21.83	0.000	98.93804	118.4539
Other	-25.40099	3.877494	-6.55	0.000	-33.00074	-17.80125
Savings	0.4405337	0.3869591	1.14	0.255	-0.3178922	1.19896
Other						
Food	-2.673158	1.656466	-1.61	0.107	-5.919771	0.5734555
Education	-192.4327	2.055705	-93.61	0.000	-196.4618	-188.4036
Gas	-67.41067	15.93117	-4.23	0.000	-98.6352	-36.18615
Electricity	8.212089	1.567476	5.24	0.000	5.139892	11.28428
Healthcare	6.224063	18.78835	0.33	0.740	-30.60043	43.04856
Transport	-10.98439	3.253429	-3.38	0.001	-17.36099	-4.607786
Restaurants	16.24923	0.3862662	42.07	0.000	15.49217	17.0063
Rent/mortgage	19.64154	0.5676197	34.60	0.000	18.52903	20.75406
Distant heat	-7.761027	18.90534	-0.41	0.681	-44.81482	29.29276
Solid fuels	133.5117	20.1719	6.62	0.000	93.97546	173.0478
Other	19.3361	0.332376	58.18	0.000	18.68465	19.98754
Savings	-1.035983	0.2966487	-3.49	0.000	-1.617404	-0.4545622
Savings						
Food	6.728707	12.52208	0.54	0.591	-17.81412	31.27153
Education	-35.34773	3.491461	-10.12	0.000	-42.19087	-28.50459
Gas	34.23888	108.2999	0.32	0.752	-178.0249	246.5027
Electricity	-1.904426	7.793862	-0.24	0.807	-17.18011	13.37126
Healthcare	-141.6325	87.9831	-1.61	0.107	-314.0762	30.81122
Transport	-8.121507	23.21169	-0.35	0.726	-53.61558	37.37256
Restaurants	37.82012	0.6712327	56.34	0.000	36.50453	39.13571
Rent/mortgage	-0.2860893	0.989292	-0.29	0.772	-2.225066	1.652887
Distant heat	4.417277	11.61203	0.38	0.704	-18.34188	27.17643
Solid fuels	-4.677232	3.938944	-1.19	0.235	-12.39742	3.042956
Other	-1.459795	0.4348695	-3.36	0.001	-2.312124	-0.6074667
Savings	8.860588	42.29617	0.21	0.834	-74.03837	91.75955

Table A.13: Compensated (Hicksian) Cross-price Elasticities - Part 1

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Food						
Food	-6.424779	6.419121	-1.00	0.317	-19.00602	6.156466
Education	-40.22892	29.66367	-1.36	0.175	-98.36866	17.91081
Gas	-13.65552	55.22347	-0.25	0.805	-121.8915	94.5805
Electricity	0.3518352	4.181835	0.08	0.933	-7.844411	8.548081
Healthcare	71.02354	44.6478	1.59	0.112	-16.48453	158.5316
Transport	3.22089	11.32038	0.28	0.776	-18.96665	25.40842
Restaurants	-42.15264	7.427884	-5.67	0.000	-56.71103	-27.59426
Rent/mortgage	6.189624	3.188777	1.94	0.052	-0.0602639	12.43951
Distant heat	-42.89768	15.19094	-2.82	0.005	-72.67137	-13.124
Solid fuels	-3.807096	21.22898	-0.18	0.858	-45.41513	37.80094
Other	-6.137983	3.884318	-1.58	0.114	-13.75111	1.47514
Savings	10.9743	19.89365	0.55	0.581	-28.01653	49.96513
Education						
Food	-1.003329	0.8087157	-1.24	0.215	-2.588383	0.5817242
Education	-33.45461	1.233013	-27.13	0.000	-35.87127	-31.03795
Gas	8.965934	8.576095	1.05	0.296	-7.842904	25.77477
Electricity	-1.193424	0.8326112	-1.43	0.152	-2.825311	0.4384643
Healthcare	-4.367024	0.2779098	-15.71	0.000	-4.911717	-3.82233
Transport	13.63941	1.406949	9.69	0.000	10.88184	16.39698
Restaurants	38.99254	7.88713	4.94	0.000	23.53405	54.45103
Rent/mortgage	-6.02846	0.292388	-20.62	0.000	-6.60153	-5.45539
Distant heat	60.64939	2.994131	20.26	0.000	54.781	66.51778
Solid fuels	16.30706	1.542129	10.57	0.000	13.28454	19.32958
Other	-12.36347	0.1520728	-81.30	0.000	-12.66153	-12.06541
Savings	-1.569562	0.1769961	-8.87	0.000	-1.916468	-1.222656
Gas						
Food	-0.529454	1.578559	-0.34	0.737	-3.623373	2.564465
Education	8.106239	8.94499	0.91	0.365	-9.425619	25.6381
Gas	13.32037	14.31604	0.93	0.352	-14.73856	41.3793
Electricity	-1.920797	1.173555	-1.64	0.102	-4.220922	0.3793283
Healthcare	20.74034	10.34813	2.00	0.045	0.4583739	41.02231
Transport	3.633252	2.833483	1.28	0.200	-1.920273	9.186778
Restaurants	-13.72816	2.112378	-6.50	0.000	-17.86835	-9.587979
Rent/mortgage	-0.0574246	0.7740316	-0.07	0.941	-1.574499	1.459649
Distant heat	-8.964412	3.573398	-2.51	0.012	-15.96814	-1.96068
Solid fuels	-10.11574	4.062792	-2.49	0.013	-18.07866	-2.152812
Other	-4.513861	1.061968	-4.25	0.000	-6.595281	-2.432442
Savings	1.660063	4.87908	0.34	0.734	-7.902758	11.22288
Electricity						
Food	.1487773	1.055668	0.14	0.888	-1.920294	2.217849
Education	-9.072773	7.74335	-1.17	0.241	-24.24946	6.103913
Gas	-19.48359	10.14975	-1.92	0.055	-39.37672	.4095508
Electricity	1.188923	.8964233	1.33	0.185	-.5680342	2.94588
Healthcare	-14.37725	6.538943	-2.20	0.028	-27.19334	-1.561153
Transport	-3.805886	1.886473	-2.02	0.044	-7.503304	-.1084671
Restaurants	11.32684	1.845006	6.14	0.000	7.710699	14.94299
Rent/mortgage	.4719477	.622604	0.76	0.448	-.7483338	1.692229
Distant heat	4.858878	3.230986	1.50	0.133	-1.473739	11.19149
Solid fuels	8.738744	3.544331	2.47	0.014	1.791982	15.68551
Other	4.899467	.9243598	5.30	0.000	3.087755	6.711179
Savings	-.8053295	3.114817	-0.26	0.796	-6.910259	5.2996

Table A.14: Compensated (Hicksian) Cross-price Elasticities - Part 2

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Healthcare						
Food	7.476318	4.699552	1.59	0.112	-1.734634	16.68727
Education	-16.58222	.8740524	-18.97	0.000	-18.29533	-14.86911
Gas	76.67984	38.2704	2.00	0.045	1.671237	151.6884
Electricity	-6.017421	2.735942	-2.20	0.028	-11.37977	-.6550726
Healthcare	124.4495	26.24181	4.74	0.000	73.01645	175.8824
Transport	17.63918	8.074552	2.18	0.029	1.813353	33.46502
Restaurants	-83.31468	8.941806	-9.32	0.000	-100.8403	-65.78906
Rent/mortgage	5.556134	3.979182	1.40	0.163	-2.242919	13.35519
Distant heat	50.11893	20.57945	2.44	0.015	9.783955	90.45391
Solid fuels	107.0371	36.82813	2.91	0.004	34.85533	179.2189
Other	1.551333	4.633026	0.33	0.738	-7.529232	10.6319
Savings	-23.66773	14.71278	-1.61	0.108	-52.50424	5.16878
Transport						
Food	.8067289	2.766786	0.29	0.771	-4.616073	6.22953
Education	120.0614	12.58365	9.54	0.000	95.39795	144.7249
Gas	33.46355	24.57115	1.36	0.173	-14.69501	81.62212
Electricity	-3.866979	1.829995	-2.11	0.035	-7.453703	-.2802543
Healthcare	40.97095	18.7666	2.18	0.029	4.189089	77.7528
Transport	1.481422	5.803507	0.26	0.799	-9.893243	12.85609
Restaurants	-32.74505	4.376399	-7.48	0.000	-41.32264	-24.16747
Rent/mortgage	-10.24043	1.568942	-6.53	0.000	-13.3155	-7.165357
Distant heat	-12.48534	10.68423	-1.17	0.243	-33.42606	8.455369
Solid fuels	-82.40275	5.941021	-13.87	0.000	-94.04694	-70.75856
Other	-6.262591	1.867325	-3.35	0.001	-9.922482	-2.602701
Savings	-3.043475	9.017155	-0.34	0.736	-20.71677	14.62982
Restaurants						
Food	-5.024977	.8856197	-5.67	0.000	-6.76076	-3.289195
Education	169.3059	34.26926	4.94	0.000	102.1393	236.4724
Gas	-57.74094	8.87627	-6.51	0.000	-75.13811	-40.34377
Electricity	5.34763	.8751244	6.11	0.000	3.632418	7.062843
Healthcare	-94.49187	10.14111	-9.32	0.000	-114.3681	-74.61565
Transport	-15.96622	2.13317	-7.48	0.000	-20.14715	-11.78528
Restaurants	59.61274	.1820999	327.36	0.000	59.25583	59.96965
Rent/mortgage	-11.28821	.2114787	-53.38	0.000	-11.7027	-10.87372
Distant heat	-42.24882	2.989909	-14.13	0.000	-48.10893	-36.38871
Solid fuels	-138.8965	.9898993	-140.31	0.000	-140.8366	-136.9563
Other	4.584183	.1078376	42.51	0.000	4.372825	4.795541
Savings	7.212444	.127818	56.43	0.000	6.961926	7.462963
Rent/mortgage						
Food	3.563238	1.854947	1.92	0.055	-0.0723905	7.198867
Education	-126.6421	5.17113	-24.49	0.000	-136.7774	-116.5069
Gas	-4.918739	15.59383	-0.32	0.752	-35.48208	25.6446
Electricity	1.206782	1.413851	0.85	0.393	-1.564315	3.977878
Healthcare	30.7559	22.03399	1.40	0.163	-12.42992	73.94172
Transport	-24.3405	3.747507	-6.50	0.000	-31.68548	-16.99552
Restaurants	-55.0809	1.017762	-54.12	0.000	-57.07568	-53.08613
Rent/mortgage	29.62177	1.790469	16.54	0.000	26.11251	33.13102
Distant heat	-171.8722	8.045986	-21.36	0.000	-187.642	-156.1023
Solid fuels	48.99222	7.13581	6.87	0.000	35.00629	62.97815
Other	26.99227	0.7626673	35.39	0.000	25.49747	28.48707
Savings	-0.1179271	0.9003561	-0.13	0.896	-1.882593	1.646738

Table A.15: Compensated (Hicksian) Cross-price Elasticities - Part 3

	Elasticity	Std. err.	z	$P > \|z\|$	[95% conf.	interval]
Distant heat						
Food	-3.817847	1.378167	-2.77	0.006	-6.519006	-1.116689
Education	202.7257	10.40092	19.49	0.000	182.3403	223.1111
Gas	-29.62593	11.58554	-2.56	0.011	-52.33316	-6.91869
Electricity	1.711498	1.173231	1.46	0.145	-0.5879915	4.010988
Healthcare	43.39929	17.80845	2.44	0.015	8.495378	78.3032
Transport	-4.455892	3.960364	-1.13	0.261	-12.21806	3.306278
Restaurants	-32.23565	2.307539	-13.97	0.000	-36.75834	-27.71296
Rent/mortgage	-26.93942	1.301261	-20.70	0.000	-29.48984	-24.38899
Distant heat	2.579447	4.342654	0.59	0.553	-5.931999	11.09089
Solid fuels	-183.4269	7.734404	-23.72	0.000	-198.5861	-168.2678
Other	-1.637719	4.040958	-0.41	0.685	-9.557852	6.282414
Savings	0.5414107	1.705501	0.32	0.751	-2.801309	3.884131
Solid fuels						
Food	0.5785133	1.862252	0.31	0.756	-3.071434	4.22846
Education	-46.55381	3.206271	-14.52	0.000	-52.83798	-40.26963
Gas	29.29975	11.70132	2.50	0.012	6.365575	52.23392
Electricity	-3.184001	1.116215	-2.85	0.004	-5.371743	-0.9962598
Healthcare	-82.84387	28.57922	-2.90	0.004	-138.8581	-26.82963
Transport	27.8174	1.691924	16.44	0.000	24.50129	31.13351
Restaurants	94.859	0.5613653	168.98	0.000	93.75874	95.95925
Rent/mortgage	-7.013017	1.102299	-6.36	0.000	-9.173484	-4.85255
Distant heat	163.4635	6.988801	23.39	0.000	149.7657	177.1613
Solid fuels	108.7114	4.979484	21.83	0.000	98.95176	118.471
Other	-25.38395	3.877501	-6.55	0.000	-32.98371	-17.78419
Savings	0.4665088	0.3870901	1.21	0.228	-0.2921739	1.225192
Other						
Food	-2.607178	1.656352	-1.57	0.115	-5.853568	0.6392123
Education	-192.3876	2.055127	-93.61	0.000	-196.4155	-188.3596
Gas	-68.24014	15.92182	-4.29	0.000	-99.44633	-37.03395
Electricity	8.23752	1.566926	5.26	0.000	5.166401	11.30864
Healthcare	6.279127	18.78824	0.33	0.738	-30.54515	43.1034
Transport	-10.89874	3.253511	-3.35	0.001	-17.2755	-4.521976
Restaurants	16.39297	0.3856446	42.51	0.000	15.63712	17.14882
Rent/mortgage	19.77346	0.5657034	34.95	0.000	18.66471	20.88222
Distant heat	-7.712084	18.9134	-0.41	0.683	-44.78167	29.3575
Solid fuels	133.5257	20.20902	6.61	0.000	93.91678	173.1347
Other	19.47938	0.3305232	58.93	0.000	18.83157	20.1272
Savings	-0.8430657	0.2952495	-2.86	0.004	-1.421744	-0.2643872
Savings						
Food	6.833989	12.52195	0.55	0.585	-17.70857	31.37655
Education	-35.27721	3.494297	-10.10	0.000	-42.12591	-28.42851
Gas	31.93541	108.2771	0.29	0.768	-180.2838	244.1546
Electricity	-1.861566	7.792671	-0.24	0.811	-17.13492	13.41179
Healthcare	-141.5386	87.98116	-1.61	0.108	-313.9785	30.90131
Transport	-7.964328	23.21075	-0.34	0.731	-53.45657	37.52791
Restaurants	38.07299	0.6735015	56.53	0.000	36.75295	39.39303
Rent/mortgage	-0.0459831	0.9836385	-0.05	0.963	-1.973879	1.881913
Distant heat	4.51035	11.6091	0.39	0.698	-18.24306	27.26376
Solid fuels	-4.663284	3.96897	-1.17	0.240	-12.44232	3.115754
Other	-1.207067	0.4352685	-2.77	0.006	-2.060178	-0.3539568
Savings	9.192365	42.2957	0.22	0.828	-73.70569	92.09042

A.2.3 Robustness Check

Table A.16: Testing Goodness of Fit Using Log-likelihood

	Log-likelihood	Degrees of freedom
Full model	73,394.76	127
Model without energy	44,762.02	79
Model without demographics	72,069.87	79