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Causal Effects of Natural Gas Price Hikes on the Adjustment of Household
Gas Consumption in Germany from 2018 to 2023

A földgáz áremelkedésének ok-okozati hatásai a háztartási gázfogyasztás
kiigazítására németországban 2018 és 2023 között

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1. Introduction

Natural gas being a crucial energy resource has always played an essential role in economic activities. Since 1980 when the term “Energiewende” was introduced Oeko-Institute in Germany, it is a concept which translates to “Energy Transition”, the German Federal Government has firmly decided to shift away from the consumption of non-renewable energy resources such as coal and petroleum to the renewable energy resources like solar and wind energy. Subsequently, the government has committed to decommission all power plants fired by nuclear energy by early 2020. The execution of these energy transition policies and implementation of requisite rules have comparatively limited the alternate energy sources in Germany. Simultaneously the rising demand for energy due to economic development has warned the concerned policy makers of potential energy crunch early 2010’s in Germany (Sacco et al., 2024). According to the International Energy Agency 2022 report, Germany consumed natural gas around a quarter of its total primary energy usage in 2021. It is worth noting that gas and natural gas terms are interchangeably used in this paper.

The world started to face an energy crisis as soon as global economies started to revive after the engraved COVID-19 pandemic socio-economic catastrophe. The natural gas imports from Russia to the European Union (EU-27) drastically declined to one third of the 2020 imports by June-2021. These events have pushed the natural gas prices on an upward trajectory. The price hikes as well as the plummeted Russian gas supplies have gravely affected German natural gas sector. Germany is the largest Russian gas importer, she has received around half of the total Russian supplies to EU-27 in 2020 (Fulwood, 2022). In February 2022, following the Russia Ukraine conflict, the situation has worsened that led to further natural gas shortages in Germany. The plot got thicker when the gas supply was halted due to the servicing of Nord Stream-I gas pipeline in summer 2022, the lack of alternative energy source for the upcoming winter and shortage of Liquefied Natural Gas (LNG) has exacerbated the existing crisis. As a result, natural gas wholesale prices have begun to notably rise from 25.0 Euros per megawatt hour (MWh) in the beginning of 2021 and reaching their peak around 300.0 Euros/MWh in September 2022 (Jamissen et al., 2023).

It has severely affected residential and small business natural gas consumers in Germany. Verivox data in 2023 shows that the end-use consumer gas prices surged from 5.75 Eurocents per kilowatt hour (kWh) in early 2018 to 21.75 Eurocents/kWh in September 2022 for the average household consuming around 20,000 kWh natural gas per year. This price raise makes around fourfold increase which is beyond the limit of average household to maintain its consumption levels. This study aims to investigate the impact of gas price hikes on the natural gas consumption of household in Germany between 2018 and 2023. Standard literature published in this regard shows that such analysis can be performed by computing price elasticity of household demand for the natural gas (Jamissen et al, 2023). Similarly, the causal effects can be figured out using the income elasticity of natural gas demand at household-level approach opted by Meier et al. (2013).

This study attempts to determine the causal relationship between the rise in household natural gas prices and the household gas consumption in Germany for the period extending from 2018 till 2023. No observable impact or correlation is considered as null hypothesis (H0). Conversely the alternative hypothesis (H1) can means that there is significant reduction in household natural gas consumption because of the gas price hikes. The study analyzes aggregate household natural gas consumption data on monthly basis, coupled with the monthly retail natural gas prices for household and small consumers data. It controls for various endogenous factors like the weather data, household mean income, data of the government support provided to the household and the crisis awareness of the internet users in Germany. The study sheds light on the description and the preparation of the data. It explains the methods used for analysis in considerable length. The analysis is duly supported by the standard literature published in a prestigious journal. The paper concludes with a comprehensive conclusion and recommendations for further research.

2. Background: Natural Gas as Vital Energy Source in Europe

Europe has witnessed an upward trajectory of natural gas consumption since 1960's (Honore, 2010). There was a unanimous consensus regarding the anticipated rising demand for natural gas in EU-27 until early 2000's., however the emergence of policies encouraging reduced carbon emissions has initiated transformation in the EU energy market. The surge in natural gas demand was primarily driven by gas consumption in the power sector throughout 1990s and early 2000s in EU-27 (IEA, 2013). Meanwhile, in evolving liberalized market, the natural gas sector witnessed widespread favoritism from investment perspective, governments as well as big firms flushed huge investments in the power plants fueled by natural gas. It was motivated by the objective to mitigate increasing carbon emissions due to coal power plants. Furthermore, natural gas demand forecast predicted an upward trajectory throughout 2010's and early 2020's as depicted in Figure 1. The steady changes in the energy mix remained unnoticed due to the productivity driven higher demand for energy in Europe throughout 2010's. This has streamlined the sustained consumption of natural gas even within the competitive energy market of EU-27. However, the 2008/9 financial and economic crunch has gravely dented this demand, Europe (EU-27) couldn't be recovered from it until 2023 (Honore, 2014) as visible in Figure 1 .

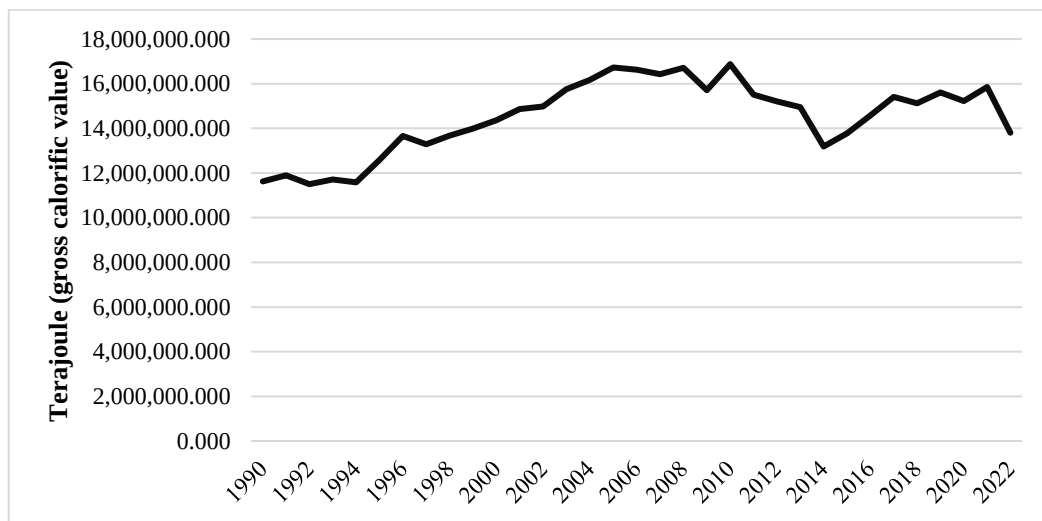


Figure 1: EU-27 Natural Gas Consumption 1990-2022

Source: Eurostat, data code: nrg_cb_gas

Europe has witnessed a significant and rapid growth in the market share of natural gas in Europe's total primary energy supply (TPES). It doubled during the period from 1970s till 2012, exactly from 12% in 1970s soared up to 24% in 2012. Natural gas has popped up as a significant alternative energy source, replacing oil to a greater extent and coal to a lesser degree, because coal was already displaced by oil in power generation. However, these natural gas consumptions have concealed the intra-Europe consumption disparities, for instance Germany, Hungary, the Netherlands, UK and Italy used to consume around 50% of the total European natural gas consumption in 2006 (Honore, 2014). According to EIA 2020 report, in 2014 Germany has emerged as the trailblazer in gas consumption while by 2019 she had emerged as the biggest consumer of the natural gas in EU-27.

EU-27 not only import natural gas for its needs but also produces, there are several in-land natural gas producers like the Netherlands, Romania, Poland, Germany, and Belgium, however the inland production is not sufficient to meet the consumption need of the whole Union. Therefore, the Union (EU-27) import natural gas from the countries like Norway, Russia, United States of America (USA), Algeria, and Qatar etc. EU-27 has opted for the strategy to curtail its reliance on imported gas and shifting away from gas and oil towards renewable energy sources (EC, 2023). Household natural gas consumption in the European Union constitutes around 40% of the total final natural gas consumption, which is predominantly used for space heating. The basic heating needs of households are impacted by the unforeseen changes in weather conditions (Jamissen et al., 2023).

Since the oil price shocks in 1973, the EU-27 has never found itself in such an engraved crisis as it suffered during 2021 to 2023 (Ruhnau et al, 2023). The conjunction of heightened liquified natural gas (LNG) demand in Asia, lowered natural gas production in Europe and Russia's refrain to replenish gas reserves in Germany and Austria led to depleted gas reserves in Europe and provided reason for substantial surge in the prices (Fulwood, 2022). The crisis intensified since September 2021 as Russian natural gas shipments to the EU-27 were slashed by 67% as compared to the natural gas exports of the last year (Fulwood, 2022). Consequently, the spot prices of natural gas witnessed a notable rising trend reaching 200 Euros/MWh in 2022 (Ruhnau et al, 2023).

3. Literature Review

Article	Location	Period	Topic	Results
Alberini et al, 2011	USA	1997-2007	Natural Gas	OPE: -0.693 to -0.566
Burke & Yang, 2016	44 countries	1978-2011	Natural Gas	LR Elasticity: -1.25 SR Elasticity: 0.5 to -0.68
Schulte & Heindl, 2017	Germany	1993-2008	Electricity & Gas Space Heating	Electricity Elasticity: -0.431 Gas Elasticity: -0.5008
Auffhammer & Rubin, 2018	USA	300 million gas billings	Natural Gas	OPE: -0.23 to -0.17
Malzi et al, 2020	OECD countries	1980-2016	Natural Gas	OPE SR: -0.0002 OPE LR: -0.0015
Schmidt & Madlener, 2020	Germany	1996-2014	Heating Expenditure	OPE: 0.573 to 0.690
Ersias & Iglesias, 2022	15 European countries	2016-2020	Natural Gas	SR Elasticity: -2.2 to 0 LR Elasticity: -0.94 to -4.3
Ruhnau et al, 2023	Germany	2021-2022	Natural Gas	Elasticity: -0.1
Jamissen et al, 2023	Germany	2018-2023	Natural Gas	Wholesale price Elasticity: -0.01 Household Price Elasticity: -0.04
OPE: Own Price Elasticity, LR: Long Run SR: Short Run				

Table 1: Summary of Literature Review

Table 1 presents a summary of the standard literature reviewed during this study. The standard literature provides initial guidelines regarding the direction or sign of the gas price elasticity that is aimed to achieve in this paper. It suggests that the gas price elasticity for households shall be negative meaning that with increase in the gas prices the natural gas consumption shall decrease holding all other influencing factors as constant.

Alberini et al, in 2011 extensively analyzed the micro-level household electricity and natural gas consumption data from 1997 till 2007 in the 50 major metropolitan areas of United States, taking into account variables like weather, cooling and heating equipment, size of the house and socio-demographic variables like age, size of the household, and locality etc., employing

multiple regression and fixed effects regression methods. They found own-price elasticity (OPE) of natural gas demand ranging from -0.693 to -0.566.

Burke & Yang in 2016 has estimated the price and income elasticities of natural gas demand analyzing aggregate national data over a period of 33 years from 1978 till 2011 for 44 countries across the globe, using instrumental variable (IV) approach, national natural reserves and distance-weighted gas reserves in other countries are used as IV. They found that aggregate long run gas price elasticity is around -1.25 while long run income elasticity estimates are around +1, there are more possibilities of substitution in the long run. While the short-run gas price elasticity across 44 countries ranges from -0.5 to -0.68.

Schulte and Heindl in 2017 computed price and expenditure elasticities of household energy demand in Germany particularly focusing on the electricity and space heating using microlevel data acquired from German Income and Expenditure Survey (IES) from 1993 to 2008. They have employed the Quadratic Expenditure System to estimate the elasticities. They found price elasticity of -0.4310 for electricity and -0.5008 for the space heating.

Auffhammer & Rubin in 2018 worked on the natural gas elasticities analyzing micro-level data, by going through around 300 million natural gas bills in United States of America (USA). They have computed the own-price elasticity ranges from -0.23 to -0.17 taking into account various factors such as weather, five different measures of gas prices, customer types those on low-income program (using subsidized gas), and regions. They estimated summer & winter household price elasticities and found that consumers are more alert to gas prices or gas expenditure in the high-consumption season (the winter). The average winter household price elasticity determined by Auffhammer & Rubin (2018) is -0.38 while the elasticity of subsidized household is quite that is -0.52. This also shows that targeted subsidies don't incentivize extra consumption.

Natural gas price elasticity is well versed topic, Malzi et al in 2020 have worked on the residential natural gas consumption data of the OECD countries from 1980 to 2016 employing cross-sectional autoregressive distributed lag (CS-ARDL) method. They found that energy prices negatively influence households' natural gas consumption in the long run. They concluded the matter that income elasticity is positive while price elasticity is negative towards natural gas consumption in the longer run. Schmitz & Madlener, 2020 has computed own-price demand elasticity of heating expenditures ranging from 0.573 to 0.690, analyzing the panel dataset derived

from residential household survey from 1996-2014. They have taken into account various factors including technical variables like building age, dwelling size, and socio-demographic variables like age, gender, composition of the household and household income; and found a significant effect of these variables on the own-price elasticity of household heating expenditure. They found that households living in rented houses & single-person households exhibit the strongest response to the rise in gas prices.

Erias and Iglesias in 2022 analyzed the natural gas consumption data of 15 European countries using wholesale gas prices and a daily frequency from 2016 to 2022. They used ARDL method for analysis computing long-run and short-run gas price elasticities and reported that the short run gas price elasticity in Europe is ranging from -2.2 to 0 while in the long-run the range widens from -0.94 to -4.3. They provided comprehensive literature review on the energy demand responses focusing on different products including natural gas. They mentioned that natural gas elasticities need to be carefully examined as the access to distribution networks or overall energy infrastructure plays a pivotal role in defining the elasticities across countries. Europe and North America have comparatively highly integrated markets and there is easy access to the high-level infrastructure which provides credibility to the results.

Jamissen et al, 2023, and Ruhnau et al, 2023, have computed gas price elasticities in Germany for both the industrial sector and small consumers including households and small businesses using the aggregated natural gas consumption data and other variables like wholesale natural gas prices and retail household gas prices, data on the weather variability using multiple regression model. Ruhnau et al, 2023, found that the natural gas consumers in Germany have seriously responded to the 2021-onward global energy crisis and the gas price hikes by substantially reducing their natural gas consumption. Industrial consumers have promptly acknowledged the natural gas shortages and rise in prices and have therefore reduced the consumption by 4% as early as the prices started to surge in September 2021, and this reduction reached up to 27% in 2022 (Ruhnau et al, 2023). Similarly, the households and other small consumer have reduced their consumption by 10% in March 2022, the lagged effect is the result of the existence of long-term fixed price natural gas contracts for the German households (Ruhnau et al, 2023).

Jamissen et al, 2023, have used aggregate natural gas consumption data for households on daily frequency and monthly basis from 2018 till 2023, using complex Autoregressive Distributed

Lag (ARDL) model. They found that for wholesale prices small consumers in Germany are significantly inelastic having a price elasticity of -0.012 both on the daily basis and monthly frequency. Additionally, they found that for retail natural gas prices the elasticity of gas demand is -0.04 which is almost 4 times stronger than the wholesale price elasticity -0.01 for daily frequency gas usage by households.

Analyzing natural gas consumption data, major volatility is observed in the short run (Dagher, 2012). Given the essential nature of gas it is difficult to drastically adjust its consumption in peak seasons, where households majorly rely on it for home central heating and water boilers across the globe. This high short-run volatility motivates changes in the usage of natural gas equipment, insulation of the building, conversion to other alternative sources and other efficient measures. However, in the long term since these changes could have taken place wherever it is feasible or possible then high fluctuations can't be observed in the natural gas consumption. Bigger price changes on month-to-month basis like during 2021-2023 stimulates the consumers to replace the efficient equipment and shift to the alternative gas infrastructure (Erias & Iglesias, 2022). High frequency elasticities permit the analysts to learn more about the instant reaction of households to the price adjustment (Dagher, 2012). However, the data availability is the major constraint in revealing this relationship.

3.1. Household gas utility, pricing procedures & controls in Germany

German household and small enterprises natural gas customers have consumed around 41% of the total final natural gas consumption in 2023 (Bundesnetzagentur, 2024). German households primarily use natural gas for house heating, hot water and cooking. According to Schmitz & Madlener, 2019, the cost of home heating, and hot water preparations accounts for over 80% of the total energy expenditures for the households in Germany. It reflects the magnitude of the effect of natural gas consumption expenditure on the private household's budget. Germany presents an interesting picture of household behavior, despite the government objective to shift the consumers from non-renewable energy resources to renewable energy, almost 70% of the newly installed heating equipment in 2021 is fueled by natural gas (BMWK, 2022).

The size of the natural gas expense share in the total household expenditure features the impact of natural gas prices shocks on the household. Therefore, when the wholesale gas price shock translates into retail household gas prices then the magnitude of its impact is enlarged and compels to either reallocate additional its resources to maintain the same consumption or simply

slash gas consumption (Kroger et al., 2021). However, it is noteworthy that the impact of natural gas price shocks is not uniform across all households in Germany. Households living in multiple-person houses, smaller in size and equipped with efficient heating systems are less likely to be reactionary to the gas price increase, on the contrary households of the single-person apartments, tenants, low-income households are more vulnerable to the gas price shocks (Schmitz and Madlener, 2019).

The wholesale natural gas market in EU-27 like TTF works effectively taking into consideration both the supply and demand. The market wholesale price accurately reflects real time information regarding the gas supply, level of gas inventories, weather data and other geopolitical events like Russia Ukraine crisis (Jamissen et al, 2023). Households and small businesses have fixed price gas contracts in Germany and therefore, it shields them from drastic yet short term wholesale gas price shocks. The term fixed price contract refers to the fact that customers have to pay “Arbeitspreis” meaning that a unit price of the gas as well as predetermined fixed amount per month “Grundpreis” as a network charge irrespective of the consumption set forth in the gas contract signed with the gas retailers. The unit price does not vary across the months for either the entire year or a fixed term of the contract (Verivox.de & FORBEG, 2020). German retail gas prices for small consumers including households are comprised of various components including the gas production (extraction) or import price, distribution network or pipeline charges (cost of transportation from the storage to the consumer’s site), energy tax, national carbon pricing, 19% of the value added tax on gas consumption. The natural gas metering is based on an annual and manual basis and there is a two-part tariff pricing system for households in Germany. Average gas price is charged to the households who consume natural gas up to 20000 kWh or 20.0 to 200.0 Gigajoule per year (DESTATIS, 2022).

The retail gas prices started to rise in September 2021 however, the household gas consumption pattern exhibited decline in March 2022. This delayed response to the gas prices is primarily due to fixed contracts, in addition the essential nature of the gas commodity in winter cannot be overlooked. The savings in terms of natural gas by the households depicted the same temporal pattern as drawn by the heating demand in Germany, it reached its peak in September 2022 constituting 28% of reduction household natural gas consumption. Similarly, the industrial sector in Germany has recorded around 23% of reduction in its gas consumption during the second half of 2022 (Ruhnau et al., 2023).

German government has put in place several controls to assure economical use of natural gas in heating the buildings, it includes the applying insulation layer of thermoform to the exterior of buildings, installing the modern and energy efficient heating system in the building. Reduced heating expenditure was observed in the new building following the standard operating procedures (SOPs) building (Sperber et al, 2024). The projected average household size in Germany is expected to decline from 2.0 in 2015 to 1.9 by 2035 (Federal Statistical Office, 2017). Assuming other factors remain constant (*ceteris paribus*), this reduction suggests a rise in per capita energy consumption for heating by 3–3.6% (Schmitz & Madlener, 2019). Although policy interventions that push individuals into larger household formations are largely impractical, this trend should still be taken into account when forecasting future energy demands. Furthermore, Schmitz & Madlener (2019) found that single-person households respond most significantly to price changes, enhancing the potential effectiveness of price-driven policy measures for this demographic.

3.2. Government Support for Household Gas consumption in the time of crisis

Wealthy or well-off families typically receive the most benefits from subsidies aimed at promoting energy-efficient products and technologies, consequently it limits the reduction in energy-poverty (Kroger et al, 2022). In Germany, various subsidies and governmental financial aids were offered to small consumers to alleviate the adverse effects of rising gas prices on households. For instance, in February-2021, 135 Euros subsidy was offered for heating costs to those who receive “wohngeld” meaning the housing benefits. It was later on increased to 230 Euros and eventually rose to 350 Euros. Furthermore, the base of this subsidy was expanded to include households receiving social assistance (Kroger et al, 2022).

A series of notable policy measures were enacted in 2022 by the German federal government targeting various segments of the society. It includes a single-time disbursement of 300 Euros for employed and retired households along with the 200 Euros support for the recipients of social assistance. The government also waived or in other words paid the December 2022 gas bills for small consumers. Gasoline and diesel taxes were reduced and a monthly pass of 9 Euros was introduced for public transport for the period of three months in 2022 (Brugel, 2023). In 2023, primary energy regulations were introduced, including limits on natural gas, heat, and electricity prices to curtail energy expenses for households, small to medium-sized enterprises, and industrial firms. These price reductions are determined based on the previous year's consumption levels,

providing an 80% discount on the previous year's consumption for families and small enterprises, and 70% for the industries. Retail rates for energy for households were standardized at 12 cents/kWh for gas, 9.5 cents/kWh for district heating, and 40 cents/kWh for electricity. Furthermore, the government reduced the value-added tax (VAT) on gas and district heating from the standard 19% to 7% for the period spanning October 2022 to March 2024 (Brugel, 2023).

4. Material & Methods

4.1. Material

The data analyzed in this paper are fetched from several sources such as Trading Hub Europe (THE), Eurostat, German Federal Agency of Statistics (DESTATIS), Burel site, Federal Network Agency of Germany (Bundesnetzagentur or BNetzA) etc. Table 2 summarizes the variables and its sources.

Type	Variable	Description	Unit	Source
Time period	Date	time-period from January 2018 till December 2023		
Dependent Variable	AggrGasCons	Aggregate household natural gas consumption	kWh	THE & BNetzA
Independent Variable	TTF	Dutch Title Transfer Facility index that provides gas wholesale prices	Euros/MWh	THE & Investing.com
Independent Variable	GasPrice	Retail household gas price (for maximum consumption of 20,000 kWh/Year)	Eurocents/kWh	Verivox.de
Control	HDD	Heating degree days	Celsius Degree	Eurostat
Control	Crisis Awareness Indicator	Indicator based on the data from Google trends for particular search terms	linear scale 1-5	Google Trends
Control	Govt Support	Financial support provided by government to mitigate the prices hikes burden.	Euro	Bruegel
Control	Total_HH_Gas Consumers	Number of Households consuming natural gas	Number of households	DESTATIS
Control	AvgMonthlyGas ConsPerHH	Average Monthly Natural Gas consumption per household	kWh	Own Calculation based on the data
Control	AvgGasExpPer HH	Average Gas Consumption expenses per month per household	Euro	Own Calculation based on the data
Control	HHIncome	Mean Household Income on annual basis	Euro	Eurostat

Table 2: Data Variables Summary

4.1.1. Household Natural Gas Consumption Data

Germany has two major natural gas consumers that is industrial and small consumers. Small consumers include households and small businesses. I have collected the households and small enterprises' natural gas consumption data from two different sources THE and BNetzA.

There is standard load profile (SLP) supplied by THE for industrial entities and smaller consumers. The actual gas consumption of SLP consumers is estimated based on the residual load curve (RLC), which computes the total natural gas consumption by summing up all inputs measurement and subtracting all outputs measurement within a particular network. Daily frequency gas consumption data in Kilowatt hours (kWh) were acquired from THE and was converted into monthly gas consumption data.

Furthermore, a dataset of aggregate weekly household gas consumption data acquired from BNetzA in Gigawatt hours (GWh). It was later converted into monthly data in kWh. Figure 2 depicts both of the time series of household natural gas consumption in Germany from 2018 to 2023, acquired from different credible sources. It exhibits strong seasonality in both its mean and variance overtime. The data show changes in consumption over the seasons such as summer and winter as the peak season. German household uses 70% of the natural gas for space heating in winter that rises its demand in peak season (Jamissen et al, 2023) while in summer households consumes it only for cooking and water boiling, which is lower and more stable.

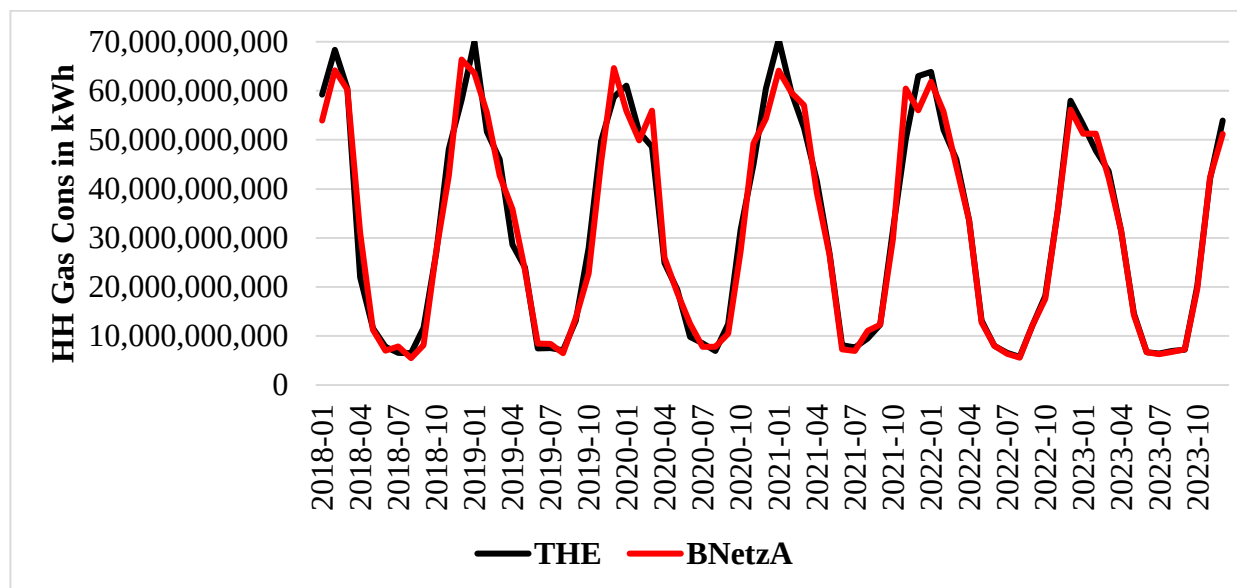


Figure 2: Household Natural Gas Consumption in Germany 2018-2023

Source: Trading Hub Economic and BNetzA

Furthermore, Monthly Average Natural Gas Consumption per Household in kWh variable is created based on the number of households consuming natural gas in Germany in different year, to be able to calculate gas expenses per household. The number of household projections data are

obtained from DESTATIS and 50% portion of the data are considered as the total number of households consuming natural gas (Kroger et al., 2022, Jamison et al, 2023, Schmitz and Madlener, 2019). This variable is created to help in computing average monthly gas expenses per household and to assist in quantifying the Government Support variable.

4.1.2. Retail Household Natural Gas Prices Data

Data of the monthly retail gas prices for households and small businesses are sourced from the Verivox.de site. This site offers a comprehensive gas price index encapsulating all the components of natural gas pricing in Germany. It also provides a platform to compare the gas contracts prices of various suppliers. Retail gas prices consist of network fee comprising transportation expenses from storage to the consumer's premises, procurement or import cost, energy tax, national carbon pricing and value added tax (VAT) of 19%. Gas metering is done manually, and consumers are billed on an annual basis, however, they are able to track their consumption. Household consumers using natural gas up to 20,000 kWh per year are subject to the standard rates as depicted in Figure 3. According to Verivox.de German natural gas providers typically offers a contract having two price elements: a fixed monthly charge ("Grundpreis"), ranging from 10 Euros to 20 Euros per month based on the gas supplier (private entities) and geographical location, and a variable fee per kWh of gas consumed ("Arbeitspreis") denoted in Eurocents/kWh (Verivox.de). A Verivox price index reflects the unit cost of natural gas for household usage, computed based on an assumed annual consumption of 20,000 kWh. This index integrates both the variable and fixed elements of the contract.

Figure 3 illustrates the trajectory of natural gas prices in Germany spanning from January 2018 to December 2023. It is evident that the surge in wholesale gas prices (TTF) commences in early 2021 due to the global energy crisis; however, this increase is reflected in retail household gas prices in early 2022, although there was a slight increase observed in the beginning of the 2021 in the household gas prices, however it was negligible to influence the gas consumption. Since household gas contracts typically feature fixed unit prices for specified durations, suppliers often transfer the impact of price increases to consumers at a later stage (Jamissen et al., 2023). Overall, the trend in household prices demonstrates a delayed pattern.

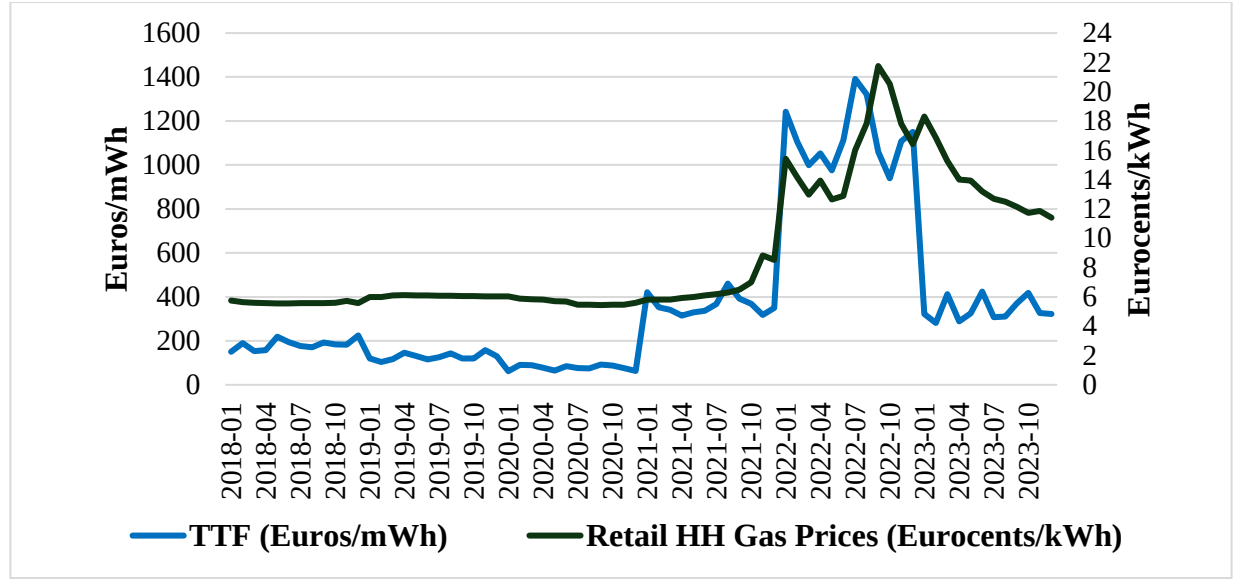


Figure 3: Monthly Natural Gas Prices in Germany 2018-2023

Sources: THE & Verivox.de

4.1.3. Weather Data

Variations in weather are captured by the data encapsulating changes in temperature. Consumption of energy is hugely influenced by temperature fluctuations over time across different geographic regions. Degree Days (DD) serves as an indicator of these variations. Heating Degree Days (HDD) is a metric that facilitates assessing the heating energy requirements of the buildings in specific locales at point of time such as day or week. Similarly, Cooling Degree Days (CDD) gauges the need for cooling or air-conditioning in those areas.

Analysts at the Eurostat database computes HDD based on threshold-temperature specified as the lowest daily mean air temperature (T_{im}) that do not need an inside house heating, here i refers to the day and m represents the mean. It differs across countries and regions within a country over time. 18° Celsius (C) is taken as baseline-temperature in Europe using general climatological approach for HDD calculations. If $T_{im} \leq 15^\circ \text{C}$ then

$$HDD = \sum_i (18^\circ \text{C} - T_{im})$$

Else $HDD = 0$, Where T_{im} is the mean air temperature of day i . For example, if $T_{im} = 10^\circ \text{C}$ then the HDD index will be 8 for that day. HDD calculations are carried out only for the day when $T_{im} \leq 15^\circ \text{C}$ otherwise it will fall into the scope of CDD. The method provides daily HDD index,

these daily HDD indices are simply summed up to get the monthly HDD value. Monthly HDD data for Germany are fetched from the Eurostat database.

4.1.4. Government Support Data

Federal Government of Germany has put in place various financial support instruments to mitigate the adverse effects of gas prices hikes. It is worth mentioning that I have taken into consideration only financial support provided to all households uniformly due to the inaccessibility to the micro-level household data. All households in Germany received a lump sum cash of 300 Euros in March 2022. Furthermore, in the same year, the national exchequer has waived (paid) December-2022 natural gas bills for small consumers. To quantify this relief, I already have computed average monthly natural gas expenditure per household, therefore, I had the amount of December-2022 gas bills (539.6 Euros), I added both reliefs and distributed the amount evenly over the entire year of 2022, since gas billing occurs annually in Germany.

Additionally, government has slashed the value added tax on gas consumption levied on households to 7% reduced from 19% effective from October 2022 till March 2024, resulting in VAT reduction of 11%, however since my monthly gas price data obtained from Verivox.de has already incorporated this into the household gas prices therefore, I didn't need to quantify the effect this into government support variable. Moreover, government enacted yet another impactful initiative that is capping the gas prices called "Gas Price Brake" policy in October 2022, which has capped household natural gas prices at 12 eurocents/kWh for the households consuming average gas up to 20,000 kWh/year from January 2022 to December 2023. 12 eurocents/kWh were deducted from the running market price of household gas to measure the relief of this policy. District gas heating prices were also capped at 9.5 eurocents/kWh, however, since it is not directly connected to individual household's gas billing therefore, this relief was not taken into account. A Government Support (GS) variable was created by aggregating the quantified relief amounts in corresponding months, to capture the collective impact of these relief instruments.

Figure 4 depicts the government support provided to the households by German Federal Government to cover their natural gas expenses. It shows the percentage of gas expenses covered by the government support, since I have equally distributed the government financial support throughout the year, in which it was provided. Therefore, it can be easily visualized. The peak of the graph actually shows the summer months where gas expenses reach their lowest point but since the government supported equally distributed therefore it shows higher than 100% of expenses.

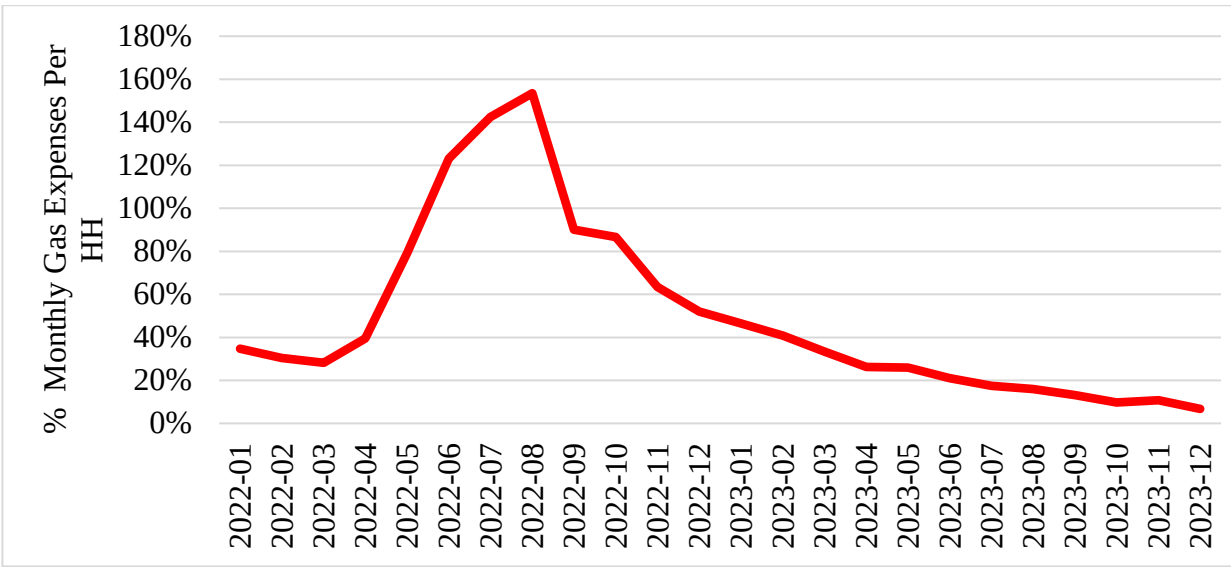


Figure 4: Govt Support Covering Percentage of Monthly Gas Expenses Per HH

Source: BRUGEL & DESTATIS

4.1.5. Crisis Awareness Indicator

In the modern-day world where internet have been essential good in developed world, Google Trends, the analytical website that provides critical insights regarding netizens awareness or their perception of various matters like global security, artificial intelligence, and energy crisis etc. I have opted for analyzing the Google Trends data related to the particular search terms associated with the current gas crisis. As per Jamissen et al. (2023) and Ruhnau et al. (2023), the decrease in gas consumption during the crisis may be attributed to multiple factors such as skyrocketed gas prices, further anticipation of escalating prices in future, repeated discussion on gas crisis in the electronic, print and social media, various energy saving campaigns by European Union and state governments such “save gas for safer winter”, and the ongoing Russia-Ukraine war. Separating the effects of awareness and price hikes, researchers can provide more accurate estimates of gas price elasticity and gas demand.

I have looked into various search terms related to global gas crisis, and German gas crisis and discussed it with my Germany colleagues, subsequent to enough deliberation, I have fetched google trends data for a period from January 2018 to December 2023 for these search terms *Gastarife*, *Gaspreis*, *Erdgas* and *Gaskrise* that refers to gas tariffs, gas prices, natural gas and gas

crisis respectively. Z-score was computed for each term (variable) to normalize the data and subsequently, it was aggregated into a single variable by adding up all the individual z-scores.

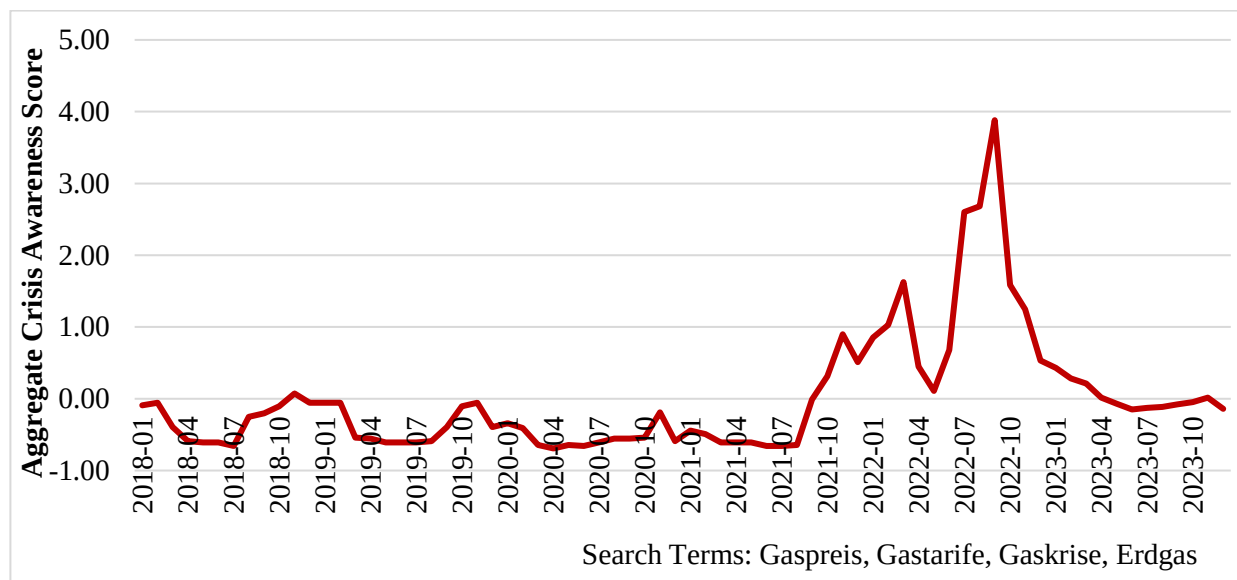


Figure 5: Crisis Awareness Indicator
Source: Google Trend Search Term Data

Figure 5 depicts the aggregated score of crisis awareness indicator of German netizens over the period of 2018 to 2023. The figure shows that the awareness or the search of these particular terms started to increase in September 2021 touching its peak in 2022. Internet users in Germany have exhibited responsible behaviour regarding the onset of global gas crisis, persistently looking for the information on expected rise in natural gas prices. This also illustrates the response and sensitivity of the German household towards the anticipated rise in gas prices. It is intriguing that trajectory of public awareness represented by Google Trends closely aligns with that of the household natural gas prices in Germany. This implies a potential connection between public sentiment and changes in natural gas prices. A more in-depth analysis could reveal the root causes of this correlation and its implications for public policies on energy. It will shed light on the consumer behavior as well.

4.1.6. Household Mean Income

Annual household mean income data are acquired from Eurostat and then interpolated into monthly income data. Since it's aggregated household income data, there were no big changes observed in the income.

4.2. Methods

This paper target to reveal the causal impact of natural gas price increase on the adjustment of household natural gas consumption in Germany. It focuses on determining the natural gas price elasticity of household. The inaccessibility to the micro-level household natural gas consumption data and other socio-demographic variables, therefore, I have relied upon the aggregate monthly household natural gas consumption data covering the period from January 2018 till December 2023. I have employed Ordinary Least Squares (OLS) regression method to examine the association between gas prices and household gas consumption. Furthermore, logarithmic transformations have been employed to aggregate household natural gas consumption, monthly household gas prices, government support variable and household mean income variable to avoid any non-linearity, skewness and to ease the interpretation of coefficients.

$$\ln AggrGasCons_t = \alpha_0 + \alpha_1 \ln HHGasP_t + \gamma_{it} Z_{it} + \epsilon_{it}$$

Where $\ln AggrGasCons$ & $\ln HHGasP$ are aggregate monthly household natural gas consumption and monthly household natural gas prices, Z_{it} are controls where i represents the controls including HDD, Crisis Awareness Indicator, Government Support and Household Mean Income, where t refers to the time. $\alpha_0, \alpha_1, \gamma_{it}$ are coefficients and ϵ is the error term. Coefficient α_1 will be considered causal if the control variables effectively capture all the endogenous sources of variation and changes in gas prices solely reflect exogenous variation (Bekes & Kezdi, 2021).

Various methods like Difference in Differences and First Differences Regression can be employed in such analysis however, it requires micro-level panel household data. The current bottlenecks of my data and the aggregate nature of my data do not allow me to carry out those analyses.

5. Results & Discussion

5.1. Data at a first glance

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Aggr HH Gas Cons in kWh (000,000,000)	5.74	9.76	28.30	31.70	51.60	70.50
TTF (Euro/MWh)	61.98	124.56	253.07	369.28	375.97	1391.35
HH Gas Price (Eurocents/kWh)	5.44	5.73	6.08	8.93	12.66	21.75
HDD	1.36	31.18	224.53	233.75	383.83	543.33
Crisis Awareness Indicator	-0.63	-0.55	-0.16	0.00	0.02	4.04
Govt Support (Euros)	0.00	0.00	0.00	35.47	30.51	280.23
Avg HH Gas Cons Per HH (kWh)	323.30	587.60	1679.60	1846.00	3041.80	3910.70
Avg Gas Expense Per HH (Euros)	18.01	49.26	131.82	160.96	214.43	557.64
Mean HH Income (Euros)	2156	2175	2403	2358	2491	2518

Table 3: Descriptive Statistics

Source: Own Calculations

Table 3 presents descriptive statistics of the data analyzed for this study. It offers a valuable insight into various factors influencing household gas consumption, gas prices, weather conditions, public awareness, government support, and socioeconomic factors in Germany. Overall, almost all of the variables are right-skewed because mean is higher than the median except household income. The variation in aggregated household gas consumption (kWh) are both due to changes in household gas consumption due to price increase, the dominant factor is the aggregate nature of the dataset and the major changes between winter and summer months.

Examining the Title Transfer Facility (TTF) prices in Euro per MWh reveals substantial variability, with prices ranging from 61.98 Euro/MWh to 1391.35 Euro/MWh. The distribution appears positively skewed, with potential outliers on the higher end influencing the mean to be higher than the median. Similarly, household gas prices in Eurocents per kWh exhibit significant variability, with a positively skewed distribution. The median price is lower than the mean, suggesting that while most prices are relatively low, there are instances of higher-priced gas.

Analysis of Heating Degree Days (HDD) indicates considerable variability in weather conditions affecting heating demand. It is ranging from 1.36 to 543.33, If the maximum monthly value of HDD is divided which is 543.33 by 30, I get 18.1 value for daily HDD which suggests that on average there around 0.1 ~ 0 HDD in a year in Germany. The distribution of crisis awareness scores is highly skewed, with a large proportion of values concentrated around zero. The reason is that the gas crisis began in 2021, while I have obtained throughout my analysis period 2018-2023. It is obvious that as the crisis began internet users (public) have started responding to the crisis by searching different ways to acquire information about intensity of the crisis and its potential impact on them. Similarly, Government Support begun in 2022 therefore it's highly skewed. These insights are crucial for further analysis and interpretation in understanding the dynamics of gas consumption patterns and their implications for energy policy and consumer behavior.

5.2. Regression Results

	<i>Dependent variable:</i>				
	Aggr gas consumption		Log Aggr gas consumption		
	(1)	(2)	(3)	(4)	(5)
HH Gas Prices	-316.371*** (115.885)	-374.560 (339.814)			
Log HH Gas Prices			-0.111** (0.055)	0.184 (0.213)	0.310 (0.259)
HDD	114.921*** (2.934)	115.300*** (3.319)	0.005*** (0.0001)	0.005*** (0.0001)	0.005*** (0.0001)
HH Income		-1.049 (4.431)			
Govt Support		-3.886 (16.486)			
Crisis Awareness Indicator		823.059 (1,110.596)			-0.042 (0.048)
Log HH Income					0.184 (0.464)
Log Govt Support				-0.026 (0.018)	-0.032* (0.019)
Constant	7,402.804*** (1,345.775)	10,444.890 (9,361.465)	9.203*** (0.122)	8.502*** (0.503)	6.787* (3.552)
Observations	72	72	72	72	72
R ²	0.957	0.958	0.943	0.944	0.945
Adjusted R ²	0.956	0.955	0.941	0.942	0.941
Residual Std. Error	4,432.375 (df = 69)	4,499.392 (df = 66)	0.208 (df = 69)	0.206 (df = 68)	0.207 (df = 66)
F Statistic	770.423*** (df = 2; 69)	299.249*** (df = 5; 66)	565.593*** (df = 2; 69)	383.531*** (df = 3; 68)	227.855*** (df = 5; 66)

Note:

* p < 0.1
** p < 0.05
*** p < 0.01

Table 4: OLS Regression Results

Table 4 represents the regression results of different model analyzed. Models 1 and 2 are linear while models 3, 4, and 5 are log-log models. The impact of each control variable is tested, included one by one. Overall, the results are encouraging and intuitive, the rise in household (HH) gas price results in reduction of the household natural gas consumption.

Model 1 regresses Aggregate Monthly Household Natural Gas Consumption on Household Gas Prices and Heating Degree Days. The coefficient -316.371 of the Household Gas Prices is statistically significant at 1% significance level. It suggests that if the gas price increases by 1 eurocent the household and other small enterprises gas consumption will *ceteris paribus* decrease by 316.371 kWh. Similarly, if the HDD is increased by one unit the natural consumption will *ceteris paribus* increased by 114.921 kWh in a month, meaning that if the temperature is lowered significantly that it increases the HDD index by one unit, that the gas heating requirement would be raised by 114.921. All the results are statistically significant and R-squared that is 0.957 and adjusted R-squared 0.956 shows the good fitness of the model. However, when the control variables such as HH Mean Income, Crisis Awareness Indicator and Government variables into the model, it distorts the model and provides statistically non-significant and counter intuitive results.

The estimates of Log-Log models 3,4, and 5 provide us with the gas price elasticity of German household during the timeframe from 2018 till 2023. The coefficient of Log-HH Gas Prices in model 3 that is -0.111 statistically significant at 5%, suggests that a 1% increase in the household gas prices will *ceteris paribus* reduce the natural gas consumption by 0.111% in German households and other small businesses. Correspondingly, the coefficient of the control variable HDD is 0.005 statistically significant at 1%, suggest that a 1 unit increase in HDD is linked with a half percent (0.05%) rise in natural gas consumption among households and other small businesses in Germany without altering any other factors. In common parlance one unit rise in HDD is associated with an average temperature of a day 1 degree Celsius colder than the base temperature of 18°C. Therefore, it is safe to say that a 1 unit increase in HDD directly corresponds to a day where the temperature was 1°C lower than base temperature, and in that case the household will consume additional 0.05% of natural gas holding all other factors as constant. 94.2% of good fitness of model 3 is evident from adjusted-R-squared.

The Logarithmic form Government Support variable was added to the model 4, the coefficient -0.026 is statistically insignificant and counter intuitive. It has distorted the whole

model and has made the estimates of principal independent variable anomalous. Analogously, other control variables such as Crisis Awareness Indicator and HH Mean Income were added in model 5, interestingly the coefficient of log-Government Support variable -0.032 became statistically significant at 10%, however the result is still incongruent to the economic intuition. Similarly, the coefficients of Crisis Awareness Indicator and HH Mean Income are also statistically insignificant.

Verily, the statistical results of the three control variables that are Government Support, Crisis Awareness Indicator and HH Mean income are insignificant in this analysis, however, there conceptual importance and real-life effect on the household gas consumption is unquestionable. The possible problems could arise from the data interpolation, and quantification of government financial support. The Crisis Awareness Indicator is an essential factor in comprehending how public perceptions and awareness of gas crises may impact household gas consumption. Elevated levels of crisis awareness could motivate households to adopt energy-saving behaviors or modify their consumption practices in response to perceived shortages or price increases in natural gas. Similarly, Government Support measures, such as direct cash transfers, price caps, and VAT reductions, play a crucial role in alleviating the effects of energy price fluctuations on household consumption, despite their lack of significance in this model. These results emphasize the broader socio-economic context that shapes household energy consumption patterns, underscoring the importance of policy interventions and public awareness initiatives in addressing energy-related issues.

5.3. Tests

5.3.1. Durbin-Watson Test

I have conducted the Durbin-Watson test to examine the autocorrelation function (ACF) of the residuals for my FD model. The test statistics is 1.76 which indicates a slight tendency towards positive autocorrelation, however the result is not statistically significant because the p-value is 0.214 which is above the conventional threshold of 0.05 significance level. This suggests that there is no significant evidence of autocorrelation in the residual of our regression model. Consequently, no further adjustments for autocorrelation are required.

5.3.2. Breusch-Pagan Test

I have carried out Breusch-Pagan test for my FD regression model to check for the heteroscedasticity. The test statistic is 0.127 with a p-value of 0.71. The p-value higher than the conventional significance level of 0.05 suggests that there is no statistical evidence of heteroscedasticity in the residuals of the model. It suggests that the variance of the residuals appears to be constant across different levels of the fitted values implying that assumption of homoscedasticity holds for the data.

5.4. Discussion

The results obtained in this paper are at par with the standard literature results achieved by Schmitz & Madlener (2017), Ruhnau et al, (2023) and Jamissen et al, (2023), who analyzed the consumer behavior in the energy sector in Germany. The estimates suggest that households and small enterprises have exhibited notable reaction the prevalent energy crisis that kicked off natural gas price hikes since 2021. Household consumers' response to the price shocks is observed with a certain lag as compared to the big industrial consumer. The primary reason is that the shock in wholesale gas prices translates into household's gas price with a delay due to the existence of fixed gas prices contracts for households. The contracts act as a shield to protect household and small enterprises from the drastic changes in the gas prices (Ruhnau et al, 2023). Industrial consumers quickly responded to the gas price shocks as early as September 2021, however the households reduced their gas consumption in March 2022. Several factors apart from fixed price contracts influenced this delayed reduction including the essential nature of natural gas, the timing of the gas price shocks that was September 2021 meaning that peak season was ahead, therefore, household needed to consume gas for space heating and hot water preparation. Additionally, the role of public awareness, discussions about the anticipated financial support from the government etc.

This analysis reveals a significant short-term gas price elasticity for German households estimated at -0.111 meaning that 1% increase in the household gas prices causes 0.111% reduction in the household natural gas consumption holding all other influencing factors as constant during the time frame from 2018 till 2023. This figure close aligns with the gas price elasticity -0.1 estimated by Ruhnau et al (2023) analyzing German household data from 2021 to 2022. It is also in line to the long run gas price elasticity -0.94 to -4.3 estimated by Ersias & Iglesias, 2022 for 15 European countries based on data from 2016 to 2020.

The estimated gas price elasticity of -0.111 suggests that the household natural gas demand is inelastic, which is in accordance with the economic concept. Since natural gas acts as an essential good in Germany for household for home heating, water boiling and cooking etc., therefore demand is inelastic, meaning that the changes in gas prices have relatively small effect on the quantity demand. However, the 10% decline in household natural consumption in Germany observed in March 2022 reaching its zenith in September 2022 to 28% as compared to the gas consumed in the last reference year between 2018-2021 underscores the substantial impact of drastic price hikes on consumer behavior as highlighted by Ruhnau et al, (2023). These findings carry important implications for devising any energy policy.

Market prices emerge as efficient mechanisms for incentivizing and managing gas savings as witnessed by the household consumer's responsiveness to the gas price hikes. Notably, the results underscore the significance of allowing the price to signal the consumers and avoid dilution of incentives through subsidies. It is observed that despite the full-strength financial support provided by the German Federal Government households have still reduced their natural gas consumption anticipating worse case scenarios and preparing to possibly avoid the worst. Fixed price gas contracts available to the households and multipronged government support has acted as consumption smoother and mitigated the adverse effects of gas price hikes on German households.

6. Conclusion

The analytical results suggest that there is significant evidence of the causal effects of gas price hikes on the adjustment of household natural gas consumption in Germany particularly in the period extending from 2018 till 2023. This period holds immense significance because there were two distinct major events that could disturb the consumption patterns. It includes COVID-19 period where households stayed at home and the natural gas consumption increased, then the global energy crisis appeared on the onset of 2021 that has accelerated the rise in the natural gas prices. Germany has mainly suffered the crisis due to its higher reliance on natural gas (Ruhnau et al., 2023). The issue exacerbated with the advent of Russia-Ukraine crisis that completely restrained the natural gas supplies to Germany by September 2022. Consequently, it has raised the natural gas prices for the industrial sector sixfold while for the households and small enterprises witnessed a 200% rise in the prices. The existence of fixed price long term natural gas contracts for households have shielded them from the drastic rise in gas prices for some time however, eventually they have to reduce their natural gas consumption.

The results show short run gas price elasticity of -0.111 for households and small businesses in Germany during this period. The lower elasticity as compared to the drastic changes in natural gas prices also highlights the essential nature of gas commodity. The German government support including cash payments, reduction in VAT, capped gas prices, and waiver of certain months gas bill has mitigated the adverse effects of the gas price hikes for households. The significant reduction in natural gas consumption by households also supports the economic concept that the market price is an effective means of coordinating and incentivizing savings. Ruhnau et al., (2023) suggest that exposing consumers to prices and abstaining from price dilution through subsidies is important to contracted gas consumption by households. Support policies and relief instruments are needed to cushion the hardship of marginal consumers but shouldn't incentivize over consumption. I have used a crisis awareness indicator to see if it has a notable impact on the reduction of natural gas consumption. The visualized form of the crisis awareness indicator mirrors the pattern of natural gas consumption in Germany however the analysis doesn't provide statistically significant results.

Sophisticated panel data of households across the length and breadth of Germany would be required to estimate the true effects of government support on the natural gas consumption by households.

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