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Received: 10/06/2024 Revised: 29/08/2024 Revised: 04/10/2024 Accepted: 12/10/2024 Published: 15/10/2024

Academic Editor:

Dr. Alexandros Bartzokas-Tsiompras

DOI: 10.48088/ejg.a.alv.15.4.232.243

ISSN: 1792-1341



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Research Article

Changes in Fuel Prices and the Use of Public Transport: Insights from the European Union following the Invasion of Ukraine



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Abstract: Rising fuel prices are known to affect public transport (PT) demand. However, the impact of the oil market inflation and subsequent energy crisis following the 2022 Russian invasion of Ukraine on mobility behaviour in Europe has received little attention. This study examines shifts in fuel prices and PT mobility across 25 European Union countries between February and May 2022. Weekly variations in PT mobility were correlated with diesel and gasoline prices, and a multiple linear regression was conducted to assess the influence of contextual factors in explaining variations in PT usage. The results indicate a significant increase in PT mobility across all countries after February 2022, which was positively associated with rising fuel prices. Approximately 84% of the variance in mobility was explained, with more pronounced increases observed in countries characterised by lower telecommuting prevalence, higher housing costs relative to household income, greater price differentials between gasoline and diesel, lower adoption of alternative fuels, and higher motorisation rates. These findings suggest that the surge in fuel prices, driven by the 2022 energy crisis, may have stimulated an increase in transit ridership.

Keywords: public transport; mobility patterns; fuel price; transport geography; Russian-Ukrainian war; Google community mobility reports

Highlights:

- The rise in PT usage in the EU correlated with higher fuel prices post-Ukraine invasion.
- Temporal and spatial patterns varied across countries, indicating contextual influences.
- Five key indicators explained disparities in PT mobility changes among EU countries.

1. Introduction

The escalation of the Russian-Ukrainian conflict in early 2022 triggered a multifaceted crisis with far-reaching global consequences, extending beyond immediate geopolitical concerns and leading to significant impacts on energy markets and food supplies (Colgan et al., 2023; Kalogiannidis et al., 2022). To urge war de-escalation multiple sets of international sanctions were applied in reaction to Russia's military activities. These sanctions, predominantly led by Western nations, have had considerable effects on the global economy exacerbating the economic turmoil (Saridakis et al., 2022; Yeoman, 2022). The inflationary process particularly affected energy products, as Russia is one of the world's top producers and exporters of oil and gas (Kutcherov et al., 2020; Ratner et al., 2012; Vatansever, 2017). Brent crude oil prices surged above \$100 per barrel, marking one of the largest increases in recent decades and signalling a new global energy crisis (Alam et al., 2022; Van de Graaf et al., 2023; Yeoman, 2022). Among the earliest and most significant impacts of this crisis was the sharp rise in refined petroleum — a critical commodity for the functioning of modern societies, affecting both remote, vulnerable regions and major urban centres (Addison et al., 2018). The rising oil prices had a major influence on daily life and economic activity, as European gas and fuel prices increased sharply (Directorate-General for Energy, 2022; Lambert et al., 2022; Liadze et al., 2022).

Past geopolitical uncertainties have led to fluctuations in Brent oil prices (Ratner et al., 2012), but the European Union (EU) has been particularly vulnerable to its historically high dependency on Russian fossil fuels (Bradshaw, 2009; Liu et al., 2023; Ratner et al., 2012). This dependency resulted in heightened volatility in the energy market and led to policy reforms centred on natural gas supply, energy-related infrastructure, and electricity production (Colgan et al., 2023; de Jong, 2024). Higher energy prices have increased household energy costs for heating, cooling and mobility, indirectly raising the cost of other goods and services throughout global supply chains (Guan et al., 2023). As a result, daily life has been affected, particularly in terms of food, housing, and mobility (Krog Juvik, 2024; Liobikienė et al., 2023). Although fiscal policy adjustments were introduced to alleviate the burden on citizens (Drolsbach et al., 2023), there has been limited research on how rising fuel prices have impacted public transport (PT) mobility patterns during the first moments of inflation. Existing studies have largely focused on the energy security implications of the Russia-Ukraine conflict and the economic burden of fossil fuel expenditures (Ahlawat et al., 2022; Colgan et al., 2023). However, analyses examining the impact of fuel prices on mobility behaviours are scarce. Understanding how future fluctuations in fuel prices will affect daily mobility patterns is crucial, and current transport research remains insufficient (Zhou et al., 2023).



This study hypothesises that the 2022 surge in Brent oil prices, and a corresponding rise in gasoline and diesel prices, has influenced mobility patterns leading to increased PT ridership across EU countries. To investigate this hypothesis, aggregate mobility data are examined, and the correlation between changes in fuel prices and variations in PT use in EU countries following the 2022 invasion of Ukraine is analysed. A regression model is employed to explore the role of contextual factors in predicting shifts in PT mobility. Following the introduction, Section 2 presents a literature review on the relationship between fuel prices and PT usage. Section 3 details the data and methods employed, including the sources of fuel and transit data and the contextual variables considered. Section 4 presents the findings, including descriptive statistics on fuel prices and PT mobility, correlation analysis, and the outcomes of the regression model. Section 5 discussed these results, exploring the implications, limitations and recommendations for further research. Finally, Section 6 summarises the key findings, highlighting the observed patterns and the impact of high fuel prices on transport behaviour.

2. Literature Review

The selection of travel modes is a complex, non-linear phenomenon (Cheng, Chen, De Vos, et al., 2019; Ding et al., 2017), influenced by a range of factors that can be broadly categorized into internal (direct) and external (indirect) determinants (Taylor & Fink, 2003). External factors, which are exogenous to the transport system, include population density, income, education, land use, and the characteristics of the built environment (Buehler, 2011; Chiou et al., 2015; Taylor et al., 2009). Moreover, demographic variables such as age (Li et al., 2012) and gender (Queiros et al., 2016) also shape preferences for mode choice (Cheng, Chen, Yang, et al., 2019). Of external factors, fuel prices emerge as particularly influential, often prompting shifts from private vehicles to PT in contexts of high fuel prices (Chi, 2022; Lane, 2010; Leung et al., 2019; Sagner, 1974; Taylor & Fink, 2003). Internal factors, which are typically subject to the management of transit authorities, encompass aspects such as accessibility, transit infrastructure, service types, and policies on tariffs and service provision (Swimmer & Klein, 2010; Taylor et al., 2009). For instance, the monetary cost of fares is a crucial external determinant of PT demand, as higher fares tend to reduce demand elasticity, discouraging PT use in favour of private transport (Sianturi et al., 2022; Silver et al., 2023; Urbanek, 2019).

The relationship between fuel prices and PT usage has long been debated in academic literature. Newman and Kenworthy (1989) observed that the dominance of oil as a transport fuel has made its fluctuating prices a key driver of transport trends. Whether driven by market dynamics or policy interventions, rising fuel prices typically reduce car usage while promoting a shift to PT (Bastian et al., 2016; Chi, 2022; Haire & Machemehl, 2007; Mattioli et al., 2018; Nowak & Savage, 2013; Wang & Skinner, 1984). However, the effects are heterogeneous, with car-dependent contexts and lower-income individuals being more severely impacted (Haire & Machemehl, 2007; Jung et al., 2016; Leung et al., 2019). Recent studies offer additional insights into this relationship. Vojtěch and Barbora (2023) estimated that a fuel price increase by one Czech crown resulted in approximately 494 thousand additional trips on average across several Czech cities. Similarly, Zhang and Burke (2021) found that higher gasoline prices in New South Wales led to increased PT usage, with an estimated elasticity of around –0.04. Additionally, Bas-tian et al. (2015) demonstrated that fuel prices, alongside GDP, accounted for 80% of the variance in car travel distances in Sweden.

Historically, fuel prices in the EU have been closely linked to international oil prices, making them highly susceptible to conflicts and external shocks (Albulescu & Mutascu, 2021; Moutinho et al., 2017), with profound implications for mobility patterns. For instance, oil price shocks in the latter half of the 20th century were associated with lasting effects on inflation rates in several European countries (Cunado & Pérez de Gracia, 2003), while geopolitical instability in the Middle East and North Africa have periodically exacerbated this volatility (Ratner & Nerurkar, 2011). More recently, the Russian invasion of Ukraine caused considerable disruptions to energy supply chains across Europe (Zakeri et al., 2022). These impacts stem from the EU's structural dependence on external oil suppliers, despite recent efforts to reduce this reliance (Acevedo & Lorca-Susino, 2021). Over the past few decades, the use of PT within the EU has varied significantly, with fuel price fluctuations often influencing travel mode choice. For example, in Germany, rising fuel prices have been linked to increased PT ridership (Frondel & Vance, 2011). Bastian et al. (2016) further demonstrated that fuel prices and economic variables - representing the country's economic situation – strongly predicted reductions in car traffic across several EU countries. Similarly, Nicolas and Pelé (2017) found that the evolution of fuel prices influenced transport modes in daily commuting in Lyon (France), particularly during the 2008 financial crisis and subsequent periods of rising fuel costs.

The EU has a longstanding tradition of high PT use, although significant disparities exist between member countries (Ingvardson & Nielsen, 2018; Minelgaité et al., 2020). In recent decades, car use for commuting in the EU has increased, with road networks, car ownership, and daily car mobility registering an upward trend in the last three decades (European Commission, 2023). In the years immediately preceding the COVID-19 pandemic, PT modal shares varied widely across European capitals. For instance, in 2018, cities like Vilnius and Warsaw reported PT modal shares of 54%, whereas Nicosia and Dublin exhibited considerably lower figures at 2% and 21%, respectively (Noussan, 2019). By contrast, car modal shares were much higher in cities like Nicosia and Rome, at 85% and 65%, respectively. Meanwhile, cities such as Amsterdam and Helsinki exhibited more balanced transport mixes, incorporating walking, cycling, and PT. By 2018, several cities, including Belgrade, Budapest, Warsaw, Berlin, Dublin, Helsinki, Paris, Riga, Stockholm, Tallinn, and Vienna recorded higher PT modal shares than private car usage (Noussan, 2019).

The COVID-19 pandemic had a profound impact on PT usage, as lockdowns and the rise of teleworking led to a sharp decline in PT demand. Concerns about virus transmission, coupled with reduced economic activity, caused PT ridership to fall drastically (Jenelius & Cebecauer, 2020; Kellermann et al., 2022; Tirachini & Cats, 2020). According to Google's mobility data (Google, 2022), transit station activity began to recover in 2021, although unevenly across the EU and largely contingent on local epidemiological conditions and government-imposed restrictions. Nevertheless, by 2021, PT usage remained below pre-pandemic levels. In summary, while PT has historically played a pivotal role in European urban mobility, external factors such as fluctuations in fuel prices, economic crises, and the COVID-19 pandemic have substantially influenced transport mode choices for daily commuting. The energy crisis triggered by the Russian invasion of Ukraine in 2022 represents a critical area for future research, as its effects on mobility patterns within the EU remain insufficiently understood.

3. Data and Methods

This section outlines the data sources, variables considered, and methods employed to investigate the relationship between fuel prices and PT usage across EU countries during the early months of the 2022 Russian-Ukrainian conflict. The geographical scope of this study is the EU, but due to data availability issues, only 25 countries were considered, with Cyprus and Malta being excluded from the analysis. Cyprus was omit-ted as relevant mobility data from Google's Community Mobility Reports (Google, 2022) were not available, while Malta was excluded due to its constant fuel prices throughout the study period, which offered no meaningful variation for analysis. A baseline period preceding the outbreak of the war was established to ensure that observed changes in fuel prices and PT usage could be accurately attributed to geopolitical developments.



As fuel prices had already begun to rise before the Ukrainian conflict, pinpointing an exact starting point for analysis proved challenging. To address this, the study employed a temporal window from the final week of January 2022 to the last week of May 2022, capturing both fluctuations in fuel prices and PT usage leading up to and following the Russian invasion of Ukraine on 24 February 2022. The analysis period was not extended beyond May, as June typically marks the beginning of reduced daily commuting due to the holiday season. This timeframe was selected to encompass the full spectrum of fuel price changes and their impact on transit behaviour during the initial three months of the conflict.

3.1. Data

3.1.1. Fuel data

Fuel price data was sourced from the European Commission's Oil Bulletin, published by the Directorate-General for Energy. This bulletin provides weekly consumer prices for petroleum products, including gasoline and diesel, across EU member states (Directorate-General for Energy, 2022). We extracted information on the prices including taxes for both gasoline and diesel. Malta was excluded since there was no per-centage change in consumer energy prices due to a government policy to freeze energy prices, in force since the outbreak of the COVID-19 pandemic (Scicluna, 2022).

3.1.2. Transit data

Transit data were obtained from Google's Community Mobility Reports (Google, 2022). This dataset is derived from anonymised aggregated data collected via the "Location History" feature, which is also used to show "Popular Times" for places in Google Maps. These reports have been widely used in academic research, particularly during the COVID-19 pandemic, and have demonstrated robustness and reliability in reflecting mobility trends (Mileu et al., 2022; Oh et al., 2021; Sulyok & Walker, 2020). The dataset reflects aggregated and anonymized movement trends across different location classes. These metrics are compared to the average observed between January 3 and February 6, 2020 (pre-pandemic context). Mobility variation is assessed based on user visits and duration of stay at various location types, including "retail & recreation", "grocery & pharmacy", "parks", "transit stations", "workplaces", and "residential" areas. However, it is worth noting that the sample has a risk of bias, as it represents only those users of Google's mobile services who have opted to share their location data. This introduces potential limitations in terms of sample representativeness. Despite this, comparative analyses have shown that trends in Google mobility data align closely with those from other sources, thus lending confidence to its use (Sganzerla Martinez & Kelvin, 2023). Our analysis specifically focused on the "transit stations" category, which reflects mobility trends related to PT. As Cyprus lacked available data in this dataset, it was excluded from the study.

3.1.3. Contextual factors

A comprehensive set of contextual variables was compiled to assess the disparities in PT usage beyond fuel prices. Drawing on existing literature, 25 indicators of aggregated statistical data were considered, encompassing economic factors, demographic variables, fiscal policies, energy dependency, and car ownership rates (see Table 1). The selection of these indicators was informed by the literature review on factors influencing PT demand, ensuring that the analysis accounted for the broader socio-economic context in which fuel price impacts and mobility patterns occurred, as well as availability for all the countries included in the study.

Table 1. Explanatory factors.

Name	Description	Date/Period	Source
Average fuel price (€/I)	The mean cost of fuel (both gasoline and diesel).	Feb-May	Directorate-General for Energy
Average gasoline-diesel price differential (€/l)	The average difference in price between gasoline and diesel.	(2022)	
Gasoline price variation (%)	The percentage change in the price of gasoline.	_	Eurostat
Diesel price variation (%)	The percentage change in the price of diesel.		
GDP per capita in PPS (€)	The gross domestic product per capita adjusted for purchasing power standards.	2022	
Urban population (%)	The proportion of the total population living in urban areas.	2022	
Real GDP growth rate (%)	The annual percentage growth rate of real GDP at market prices, adjusted for inflation.	2022	
Energy imports dependency (%)	The proportion of total energy needs met by imports.	2022	
Imports of oil and petroleum products from Russia (thousand tonnes)	The volume of oil and petroleum products imported from Russia.	2022	
Debt in proportion of GDP (%)	The country's total debt to its gross domestic product.	2021 (Q4)	
Unemployment rate (%)	The percentage of the active population that is unemployed.	2021	
Tax rate on low wage earners (%)	The tax rate applied to individuals with low incomes.	2021	
Implicit tax rate on energy (€ per tonne of oil equivalent deflated)	The effective tax burden on energy consumption, adjusted for inflation, and expressed per tonne of oil equivalent.	2020	
Housing costs in disposable household income (%)	Disposable household income spent on housing costs.	2020	
Inflation rate of consumer prices (%)	Annual change in the consumer price index.	2022	



Use of renewable for transport (%)	The proportion of energy used for transport that comes from	2022		
Modal split of passenger transport (pkm)	renewable sources (i.e., biofuels, hydrogen, electric,) The distribution of passenger transport modes (e.g., car, train, bus) measured in passenger-kilometers.	2019		
Population working regularly from home (%)	Workforce that regularly works from home.	2021		
Age dependency ratio	The ratio of dependents (people younger than 15 or older than 64) to the working-age population (ages 15-64).	2020		
Annual net earnings (€)	The average annual income after taxes and social security contributions.	2021		
Motorization rate (%)	The number of passenger cars per inhabitant.	2020	ACEA	
Diesel cars (%)	The percentage of a country's car fleet that runs on diesel fuel.	2020		
Gasoline cars (%)	The percentage of a country's car fleet that runs on gasoline.	2020		
Gini index of income	A measure of income inequality within a country, where 0 represents perfect equality and 100 represents perfect inequality.	2019	World bank	
Cost of monthly transport pass (€ price in the country's capital)	The price of a monthly public transport pass in the capital city.	2022	Numbeo	

3.2. Methods

3.2.1. Correlation analysis

To explore the relationship between fuel prices and PT usage, a Pearson correlation analysis was conducted. The correlation coefficient was calculated using the weekly price of each fuel and the variation of mobility at transit stations. This analysis measured the strength and direction of the association between weekly changes in fuel prices and mobility across the 25 EU countries. Mobility data were smoothed using a 7-day moving average to align with the weekly reporting of fuel prices. No time lag was considered between fuel price and mobility data, as the analysis aimed to capture immediate effects.

3.2.2. Linear regression

A multivariate linear regression model was developed to identify the key factors explaining the observed variations in PT mobility across the EU countries. The dependent variable in this model was the change in mobility at transit stations from February to May 2022. The model incorporated various explanatory variables, including fuel prices and the contextual factors described earlier. The regression equation is represented as follows:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p + \varepsilon_i \tag{1}$$

where, Y_i represents the estimated change of mobility in transit stations for each country, X represents the explanatory variables, β denotes the slope coefficients for each variable and ε_i is the model's error term.

A stepwise algorithm was employed to ensure that only the most significant factors were included in the equation. The process began with forward selection, adding variables one by one based on significance (p < 0.05). Then, backward elimination removed variables with p-values above 0.1. This iterative approach continued until only the most statistically significant and relevant factors remained in the final model.

4. Results

This section presents the findings of the study, focusing on the relationship between fuel prices and PT usage across 25 EU countries during the period following the outbreak of the war in Ukraine in 2022. The analysis reveals distinct temporal and spatial patterns influenced by various contextual factors.

4.1. Overview of Changes in Fuel Prices and the Use of Public Transport

Following the escalation of the conflict in Ukraine, fuel prices across the EU surged to record highs. This increase was accompanied by a corresponding rise in mobility at transit stations, indicating a potential shift from private vehicle use to PT. However, temporal and spatial patterns varied across countries, highlighting inequalities in the impacts. All 25 EU countries in the study experienced rising fuel prices and increased mobility at transit stations (Figure 1). Most countries exhibited an almost linear increase in PT usage in response to rising fuel costs, as shown by the mobility data (Figure 1). More obvious cases were Portugal, Italy, Latvia, Lithuania, and Ireland. In contrast, countries such as Romania, Spain, Belgium, Germany, or Luxembourg exhibited more complex patterns, where a higher-order polynomial function provided a better fit due to the presence of multiple peaks and valleys in the data series. Despite these variations, the overall trend indicated an increase in transit station mobility concurrent with the rise in fuel prices. By the end of May, several countries, including Bulgaria (33%), Croatia (26%), Greece (25%), Slovenia (13%) and Portugal (11%), reported mobility levels surpassing pre-pandemic figures. Conversely, other countries such as the Netherlands, Finland, Sweden, and Belgium, although showing significant increases in PT usage, still had lower mobility figures than in the pre-pandemic context.

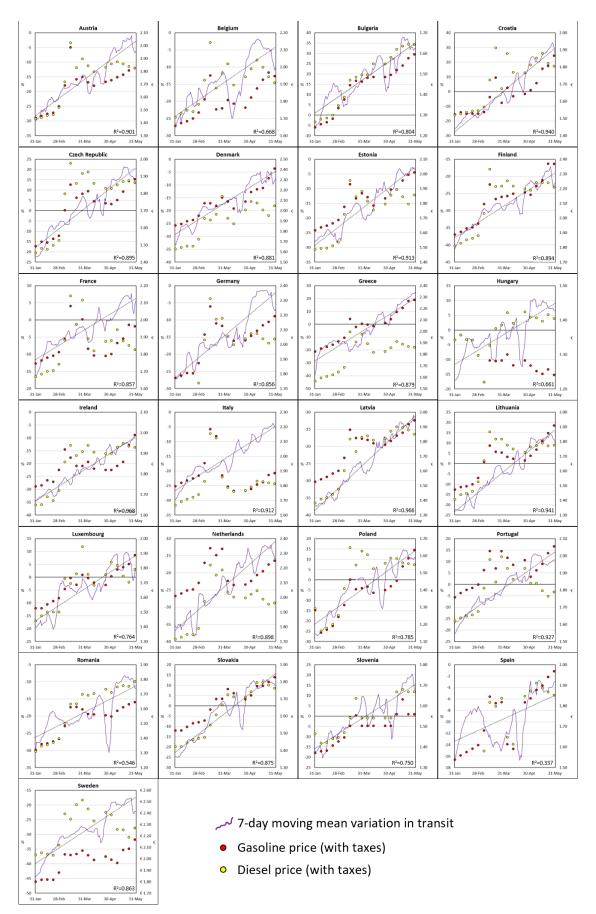


Figure 1. Fuel prices and transit ridership (R² reports to adjustment of a linear trend to the mobility data). (Source: calculated Directorate-General for Energy (2022) and Google (2022))



However, the pace of variation fluctuated monthly, with slower increments or even reductions observed. The data presented in Figure 2 reflect the changes in transit mobility by month. The greatest increases in PT usage were observed in Greece (64%), Croatia (51%), Bulgaria (38%), Poland (37%) and the Czech Republic (36%) (Figure 2), coinciding with the countries that had the largest fuel price increases in February and March, likely corresponding with the immediate impact of fuel price hikes. Several countries experienced relatively modest growth. Notably, Spain, Finland, Germany, Belgium, Luxembourg, and the Netherlands showed lower overall growth in transit usage compared to other nations, with some even experiencing declines or minimal gains in the later months, such as May. Conversely, certain countries demonstrated a more delayed response in transit mobility growth, with significant increases occurring later in the studied period, such as Estonia and Latvia. This aligns with the trend partially seen in other countries like Romania and Slovenia, where the response to rising fuel prices was not immediate. While many countries saw a clear and sustained increase in PT usage, the patterns of change varied significantly, with some showing steady linear growth and others following more complex trajectories.

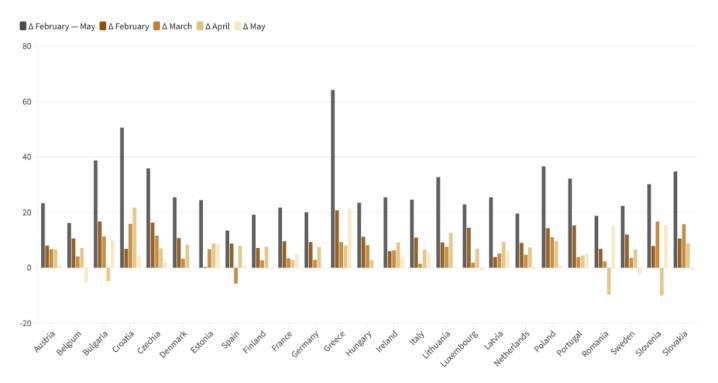


Figure 2. Variation of "Transit stations" mobility from January 31 to May 31 (Source: calculated from Google (2022))

Fuel price increases also exhibited considerable geographic variation (Figure 3). Among the countries with the highest gasoline price increases from February to May, Denmark and Lithuania topped the list with a 30% rise each. Bulgaria followed closely with a 29% increase, while Spain and Latvia saw increases of 28% and 27%, respectively. Diesel prices experienced the most substantial hikes in Romania, with a 36% increase, and in Latvia, where prices rose by 34%. Spain and Bulgaria also reported significant diesel price increases, at 30% each, while the Czech Republic saw a 28% rise. The data suggests that, with a few exceptions, countries located closer to Ukraine and those in the Mediterranean region generally experienced higher increases in fuel prices.

The relationship between fuel price increases and PT usage is evident with moderate to strong positive correlations observed across most countries (Table 2). Specifically, Austria, Bulgaria, Denmark, and Ireland exhibited particularly robust positive correlations between fuel prices and transit station activity. Conversely, Hungary showed a negative correlation between gasoline prices and mobility changes, likely due to a general decrease in gasoline prices during the study period (-8%). Mixed correlations were observed in countries like France and Spain, where diesel prices showed moderate positive correlations, while gasoline prices were less strongly correlated. These results suggest that rising fuel prices were a significant predictor of increased PT usage across the EU between February and May 2022. However, the spatial patterns of these correlations were geographically uneven. The core EU countries—France, Germany, Italy, the Netherlands, and Belgium—demonstrated weaker correlations, indicating less sensitivity to fuel price changes. In contrast, peripheral EU countries, particularly in the east (including former socialist republics) and the Iberian Peninsula, exhibited stronger correlations, indicating a greater impact of fuel price increases on PT demand in these regions. This geographical disparity implies that existing national disparities influenced responses to fuel price increases, rather than differential increases in transport costs alone.



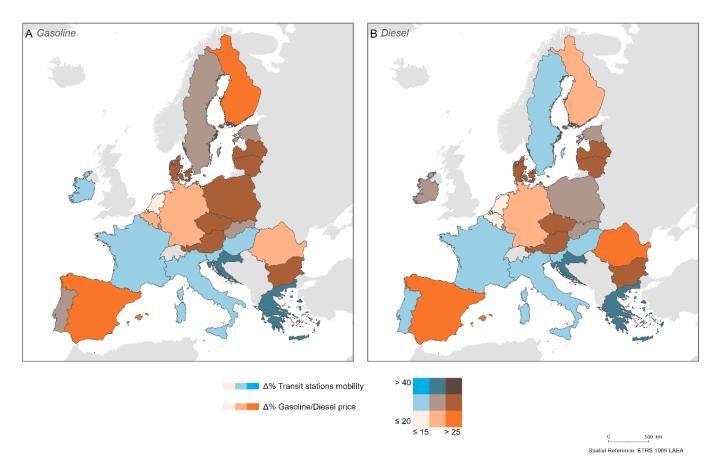


Figure 3. Bivariate relationship between changes in fuel prices and mobility from 31 January to 31 May 2022 (Source: calculated Directorate-General for Energy (2022) and Google (2022))

Table 2. Pearson correlation coefficient (R) between variation in transit stations mobility and fuel prices change.

Country	Gasoline	Diesel	Country	Gasoline	Diesel	
Austria	0.710	0.725	Italy	-0.135	0.143	
Belgium	0.706	0.666	Lithuania	0.877	0.780	
Bulgaria	0.858	0.88	Luxembourg	0.862	0.804	
Croatia	0.873	0.759	Latvia	0.877	0.888	
Czech Republic	0.803	0.734	Netherlands	0.388	0.529	
Denmark	0.903	0.841	Poland	0.904	0.838	
Estonia	0.892	0.764	Portugal	0.676	0.504	
Finland	0.905	0.801	Romania	0.650	0.669	
France	0.482	0.411	Spain	0.496	0.422	
Germany	0.684	0.576	Sweden	0.783	0.512	
Greece	0.868	0.506	Slovenia	0.899	0.864	
Hungary	-0.693	0.465	Slovakia	0.945	0.958	
Ireland	0.700	0.819	x	0.677	0.674	

4.2. Unequal patterns, different contexts?

The multiple linear regression analysis revealed that the variation in mobility across the countries studied could not be solely attributed to differences in fuel prices. The model demonstrated a good fit, with an average error of 4.378 in estimating mobility, indicating that the predictions were generally accurate, with deviations of less than five per cent.



	Model fit me	easures				
R ²	Adjus	sted R ²	Root-mean-square erro			
0.839	0.798		4.378			
Model coefficients						
Predictor	Stand. coefficient	95% CI	р	VIF		
Working regularly from home	-0.751	-0.964 — -0.538	< .001	1.229		
Differential gasoline-diesel mean price	0.398	0.152 — 0.645	0.003	1.643		
Housing costs in disposal income	0.418	0.205 — 0.632	< .001	1.235		
Use of renewables for transport	-0.403	-0.610 — -0.195	< .001	1.168		
Motorization rate	0.276	0.045 — 0.508	0.022	1.453		

Table 3. Multiple linear regression results.

The regression model explained 84% of the changes in mobility with five independent variables. Working from home emerged as the most influential factor, as evidenced by its highest standardised regression coefficient. This suggests that countries with a higher percentage of telecommuting population experienced a comparatively lesser surge in mobility. Additionally, the cost of housing relative to disposable income showed a positive coefficient, indicating that while annual income alone didn't emerge as a significant explanatory factor, the proportion of housing expenses within household income played a pivotal role in the shift towards PT amidst escalating fuel prices. The importance of alternative fuels in the transportation sector, including biofuels, biogases, electricity, and hydrogen, emerged in third place. Countries with lower incorporation of these fuels, and thus greater dependence on gasoline and diesel, showed larger increases in PT usage. The fourth most relevant variable was the differential between gasoline and diesel prices. Although the average fuel price did not emerge as significant, the significance of the differential highlights that while both variations in the price of these fuels have a positive contribution, the gasoline variation was more influential. Finally, the motorization rate also emerged with a positive correlation, indicating that PT mobility increased more in contexts with more cars per inhabitant. The shift from car use to PT inevitably occurred in regions where car ownership was prevalent, thereby underscoring the significance of this relationship. Therefore, the increase in fuel prices alone did not fully account for the observed changes in mobility. Instead, the variation in transit station usage was also significantly influenced by contextual factors being the unequal spatial patterns justified by different contexts.

5. Discussion

The primary objective of this study was to investigate the correlation between the surge in fuel prices following the 2022 Russian invasion of Ukraine and the consequent changes in PT usage in the EU. By leveraging aggregate mobility data and fuel price information, the study aimed to elucidate how external economic shocks influence mobility behaviours, particularly the shift from private vehicles to PT. This research fills a gap in the existing literature by providing empirical evidence on the immediate impacts of fuel price inflation on PT ridership in the EU after the 2022 energy crisis. Geopolitical events such as wars are known to have widespread and far-reaching impacts, influencing various sectors such as food prices (Saâdaoui et al., 2022), financial centres (Zaremba et al., 2022), energy markets (Qian et al., 2022), the environment and biodiversity (Lawrence et al., 2015) and public health (Ghobarah et al., 2004). Our research demonstrates that the Ukrainian-Russian war escalation in 2022 affected mobility patterns in several EU countries, prompting modal mobility changes in response to rising fuel prices, illustrating that the war's effects extended to everyday mobility, even in countries located more than 3000 km from the conflict.

The 25 EU countries examined in this study exhibited a shared pattern of rising fuel prices, coinciding with a notable increase in activity at transit stations following the Russian invasion of Ukraine in February 2022. Previous studies have established the relationship between fuel prices and PT use, often highlighting that higher fuel costs incentivize PT use (Bastian et al., 2015; Nowak & Savage, 2013; Zhang & Burke, 2021). However, it was not possible to calculate the price elasticity of demand, as the mobility data used pertains to aggregate changes in mobility compared to a pre-pandemic context. Our results are consistent with research suggesting that the 2022 energy crisis prompted a change in mobility behaviour, leading to reduced car use (Findenegg & Wessel, 2024; Nguyen & Pojani, 2024). Additionally, our findings extend prior evidence to PT and a broader geographical scope. Countries exhibited varying degrees of PT ridership increases, with notable examples including Greece, Croatia, and Bulgaria. In most of the countries studied, the correlation between the change in PT mobility and the increase in fuel prices was positive and strong, offering forecasting power in estimating future demand based on the evolution of the energy markets. The varying intensity can be partially explained by the fact that the increase in fuel prices varied between countries, which is aligned with previous research that identified that gasoline prices respond asymmetrically in the eurozone area (Polemis & Fotis, 2013).

A particularly noteworthy finding is the diversity in responses, underscoring the different geographical patterns in mobility changes. Among the 25 indicators considered, only five significantly explained the observed differences, highlighting the substantial disparities between EU countries that influenced how populations adapted their mobility patterns in response to high fuel prices. A secondary conclusion from the regression analysis was the impact of the temporal scale aggregation effect. While weekly mobility fluctuations showed a strong correlation with rising fuel prices, this relationship did not hold when aggregating data over the February-May period. Instead, the differential between gasoline and diesel prices emerged as significant. This was particularly notable in some countries, such as Greece, where mobility variation peaked at 64%, the highest in the dataset. In this case, diesel variation was only 5%, leading to the absence of a relationship, despite gasoline variation being 25%, which is relevant since the country had over 80% of private cars using gasoline. It is also essential to acknowledge that fuel price variation was not linear over this period. Therefore, focusing on the difference between the extremes may mask fluctuations that occur within the broader trend. This suggests that the temporal aggregation of data influenced the observed associations when examining weekly trends. Additionally, the use of aggregated variables might have hidden specific relationships due to unique factors.

The implications of this study are multifaceted. Policymakers must acknowledge the broader impacts of geopolitical events on domestic mobility patterns. The increased reliance on PT in response to rising fuel prices suggests that enhancing PT infrastructure and services could



mitigate the adverse effects of future fuel price shocks. Reducing PT fares can enhance equitable access (Silver et al., 2023), as PT demand is sensitive to fare changes. Therefore, policy measures that subsidize PT can play a substantial role in reducing the use of private cars (Bresson et al., 2003). The rise of PT use instead of personal vehicles will be relevant in energy savings (Kenworthy & Svensson, 2022), contributing to mitigating the rise in fuel prices by stabilizing demand. Different policy options may have been also relevant in explaining the unequal geography, although it could not be attested by our approach. For example, several EU countries have actively sought to mitigate the inflationary impacts by reducing fuel taxes (Drolsbach et al., 2023) and granting fuel subsidies (Bousquet & Sanin, 2024). Another example was PT subsidisation like the German "9-Euro-Ticket" to reduce the cost of transport and encourage less car use in favour of PT (Rozynek, 2024). These actions influenced the demand and supply of both car use and PT but could not be described by the type of analysis conducted.

The findings should be interpreted with caution, particularly considering scale effects in transport research, such as the modifiable areal unit problem (Horner & Murray, 2002), and aggregation bias (Fotheringham & Wong, 1991). Given the data used, it is important to acknowledge that PT mobility demand has sharply declined as a result of the COVID-19 pandemic in 2020 and 2021 (Tirachini & Cats, 2020), and Google community mobility reports may have different degrees of information accuracy for the countries studied regarding "post-pandemic" mobility patterns. The subsequent recovery in PT usage was likely influenced by the resumption of normal economic activity, but assuming that Google's data accurately reflects pre-pandemic conditions, PT usage in several countries during the analysed period exceeded pre-pandemic levels. To fully comprehend the relationship between transport cost inflation and mobility behaviour during the 2022 energy crisis, it is essential to better understand the spatial patterns of new post-pandemic mobility behaviours and the effect of telework (Buehler & Pucher, 2022; Christidis et al., 2021; Macharis et al., 2021; Vitola & Christopoulos, 2023). Also, the influence of government subsidies for PT in some EU countries may confound the relationship between fuel prices and PT usage, complicating direct comparisons across regions. Additionally, the impact of the large influx of war refugees into some European countries (Duszczyk et al., 2023) on increasing PT usage remains unclear and warrants further investigation.

Future research should seek to establish causal relationships and extend the analysis period. It is also essential to explore how fluctuations in fuel prices have affected different demographics and geographical areas within countries. The regional effects of fuel prices on mobility warrant closer examination, as these may vary significantly. Fuel inflation risk is generally higher in car-dependent communities (Mattioli et al., 2019), which are typically suburban and peri-urban areas characterized by reduced PT accessibility and lower-income populations (Allen et al., 2023). An important question arises: Is the observed dichotomy between the wealthier, more developed regions and the peripheries of the EU mirrored within countries? While metropolitan and urban areas may reflect broader national trends, rural and smaller cities might exhibit distinct patterns. Additionally, investigating preferred modes of transport and identifying geographical disparities among European cities could offer valuable insights. Incorporating qualitative data through surveys or interviews could provide a deeper understanding of the factors influencing individuals' transportation choices. It is also important to note that our analysis was limited to a period ending on 31st May, as June typically marks the beginning of reduced economic activity associated with the summer holiday season. Nevertheless, it would be worthwhile to examine how mobility trends evolved beyond this point. Specifically, it is important to determine whether demand for PT reached a saturation point and whether the impact of fuel price variations on modal shifts diminished, or if, conversely, costs were absorbed, reducing the influence of fuel prices on transportation choices.

6. Conclusions

The Russian invasion of Ukraine in 2022 triggered significant changes in energy prices, profoundly impacting mobility patterns across the EU. This study examines the relationship between rising fuel prices and increased PT usage in 25 EU countries. While most EU countries experienced a rise in transit station mobility, the magnitude and patterns of this increase varied significantly across space and time. The data suggests that rising fuel costs were a key driver of increased PT usage, particularly in countries where fuel prices spiked the most. Eastern European and Mediterranean countries seem to have been the most affected and, in certain countries, mobility associated with transit stations exceeded the pre-pandemic volumes. A multiple linear regression model, which explained 84% of the variance in PT usage, further revealed that variations in PT usage could not be solely attributed to fuel price changes, confirming the importance of additional factors. The findings highlight the nuanced responses among nations, suggesting that contextual factors such as telecommuting trends, housing costs, alternative fuel adoption, and motorization rates significantly influence PT utilization amidst fuel price fluctuations, highlighting the importance of considering broader factors when assessing the impact of economic shocks on mobility. While the study provides crucial insights, it also identifies areas for further research to develop a comprehensive understanding of PT dynamics in response to the 2022 energy crisis. Future research should explore regional variations within countries, particularly in suburban and peri-urban areas, to better understand how fuel price impacts differ across diverse geographic and socioeconomic contexts. Investigating mobility patterns beyond May 2022 could reveal whether the observed trends continued, plateaued, or shifted with ongoing geopolitical and economic developments. In summary, this study provides valuable information on the immediate effects of the 2022 energy crisis on PT usage across the EU, highlighting the influence of economic, social, and geographical factors in shaping mobility behaviours.

Funding: This research was funded by the Portuguese Foundation for Science and Technology, I.P. (FCT) (UIDB/00295/2020 and UIDP/00295/2020).

Conflicts of Interest: The authors declare no conflict of interest.

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