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Time-varying Income and Price Elasticities of Oil Demand in OECD Countries

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ABSTRACT

This study examines the long-run income and price elasticities of oil demand in 21 OECD countries using quarterly data from 1980:Q1 to 2021:Q3. We find that oil demand is inelastic with respect to both income and prices at 0.117 and −0.179, respectively. The cointegration tests reveal instability in oil price elasticities over time. The time-varying panel data estimates support these findings, showing significant variations in elasticities influenced by oil market dynamics and global events. Income elasticities reached their highest levels during the COVID-19 pandemic, while price elasticities ranged from −0.396 to 0.275. Significantly, the sign of oil price elasticities shifted from negative to positive after 2015, contrary to the law of demand, probably because of declining oil prices during that period. The largest positive and statistically significant price elasticity occurred in early 2020, which can be attributed to the COVID-19-induced decline in oil prices. Overall, this analysis contributes to understanding oil demand dynamics and highlights the impact of economic and oil market factors on elasticities.

Keywords: Oil Demand, Income Elasticity, Price Elasticity, Time-varying Panel, OECD
JEL Classifications: E31, D50, Q41, C33

1. INTRODUCTION

Energy consumption is vital for human welfare and substantially affects economic growth. Oil stands out as one of the paramount energy resources, widely used in transportation, industry, and heating. Global oil demand continues to increase, with developing countries such as China and India becoming major consumers alongside Organization for Economic Co-operation and Development (OECD) countries.

Using a time-varying framework, this study estimates the income and price elasticities of oil demand in OECD countries. The time-varying estimation of oil demand elasticities is an intriguing area of research. The demand for oil products in OECD countries, which has increased consistently, relies significantly on oil imports, although oil's contribution to global demand has declined significantly. In 1980, OECD countries consumed 41,943 kilo barrels per day (kbd) of oil, representing 67% of the global oil demand. By 2020, however, demand had fallen to 42,183 kbd, representing 46%.[1]

Several factors have contributed to this decline. One factor is the rise of renewable energy sources, which are becoming increasingly affordable and efficient. This has reduced the demand for oil for electricity generation. For example, the share of oil in the energy mix of OECD countries has declined from 45.9% to 31.3% over the past four decades, whereas the share of gas has increased slightly from 24.3% to 28.2%. The share of coal has also declined, whereas the shares of nuclear and renewable energy

1 See Figure A1 in the appendix for detailed information on oil consumption.

have increased remarkably to 11.7% and 8.2%, respectively.[2] Given the documented variations in the energy demand structures of the OECD countries, the use of nonlinear and time-varying methodologies may provide a better estimation of oil demand elasticities.

The present study contributes to the literature in two distinct manners. First, it addresses the lack of research on time-varying estimations of oil demand income and price elasticities by employing a semiparametric local linear dummy variable (LLDV) estimator. This flexible and robust estimation technique allows the estimation of time-varying parameters using panel data. Second, we use a unique quarterly dataset as opposed to the annual datasets used in previous research, which allows us to draw more reliable statistical inferences regarding oil demand elasticities. Our findings can provide policymakers with valuable insights regarding the sensitivity of oil consumption to changes in income and oil prices, thereby facilitating the development of energy policies that promote sustainable economic growth.

The article is organized as follows. Section 2 presents a review of relevant literature concerning oil demand and methods for estimating elasticity. The data sources and methodologies employed are outlined in Section 3. Section 4 presents the findings. Section 5 delves into the discussion and interpretation of these results. Finally, Section 6 presents conclusions and discusses policy implications.

2. LITERATURE REVIEW

Various methodologies are used to measure the price and income elasticities of energy demand for different types of energy sources. Kilian (2022) raises concerns about the reliability of certain methodologies and questions the validity of their results.

Time-series analysis methods have been used in a variety of countries to estimate elasticities. For example, Bentzen and Engsted (2001) conducted a study on energy demand in Denmark from 1960 to 1996. They determined that the income elasticity was 0.444 and the price elasticity was −0.354. Additionally, the long-run elasticities were estimated to be 1.294 and −1.032, respectively. Based on global market data from 1918 to 1999, Krichene (2002) discovered that the short-term price elasticity of crude oil (natural gas) demand was −0.06 (−0.08, but not statistically significant), whereas the income elasticity was 0.53 (0.76). The price elasticity over the long term was −0.05 (−0.7), whereas the income elasticity stood at 0.6 (1.75). In a study conducted by Galindo (2005), it was discovered that the price elasticities for Mexico were around −0.2. This finding remained consistent for both short and long terms. In a study conducted by De Vita et al. (2006), the long-run income and price elasticities of energy demand in Namibia were estimated to be 1.27 and −0.34, respectively. In a study conducted by Altinay (2007), the long-run income and price elasticities of oil demand in Turkey were found to be 0.61 and −0.18, respectively. In a study conducted by Akinboade et al. (2008), the researchers determined the price and income elasticities of gasoline demand in South Africa be −0.47 and 0.36, respectively. In a study conducted by Ghosh (2009), it was found that India has crude oil long-run income and price elasticities of 1.97 and −0.63, respectively. In a study conducted by Sa'ad (2009), the income and price elasticities of petroleum demand in Indonesia were estimated to be 0.88 and −0.16, respectively.

Applying the time-varying co-integration method to the USA, Park and Zhao (2010) estimated the income and price elasticities of gasoline demand as 0.073 and 0.247, respectively. Iwayemi et al. (2010) estimated the long-term income and price elasticities of energy demand in Nigeria as 0.66 and −0.106, respectively. Ziramba (2010) reported long-term price and income elasticities of −0.147 and 0.429, respectively, for crude oil demand in South Africa. Moore (2011) reported estimated price and income elasticities of -0.55 and 0.91, respectively for Barbados. Neto (2012) estimated the time-varying income and price elasticities of gasoline demand in Switzerland as 0.692 and −0.167, respectively. Also focusing on Switzerland, Baranzini and Weber (2013) estimated the price elasticities of fuel and gasoline demand for 1970-2008. The long-run price elasticities were −0.34 and −0.27, respectively, while the short-run elasticities were −0.09 and −0.08, respectively. The long-run income elasticities were 0.67 and 0.76, respectively whereas the short-run elasticities of income demand were statistically insignificant. Kim and Baek (2013) estimated the price and income elasticities of demand for crude oil in Korea as −0.43 and 1.31, respectively. Agrawal (2015) reported price elasticities of crude oil, diesel, and petrol demand in India between 1970 and 2012 as −0.42, −0.71, and −0.85, respectively, while the income elasticities were 0.97, 1.2, and 1.4, respectively. Ozturk and Arisoy (2016) estimated the income and price elasticities of the demand for crude oil imports in Turkey to be 1.182 and −0.026, respectively.

Using an ARDL model on Pakistan, Jebran et al. (2016) discovered that the price elasticity of crude oil demand was −1.06, while the income elasticity was 3.35. Dash et al. (2018) found that India's oil import demand had a price elasticity of −0.43. Marbuah (2018) estimated Ghana's income and price elasticities for crude oil demand to be 1.638 and −1.277, respectively. Shin et al. (2018) estimated Korea's income and price elasticities for crude oil demand to be 1.086 and 0.177, respectively. Gorus et al. (2019) estimated that the long-term price and income elasticities for crude oil import demand in Turkey are −0.110 and 1.042, respectively. Raghoo and Surroop (2020) estimated Mauritius' long-run fuel oil price and income elasticities to be −0.431 and 1.19, respectively.

Utilizing time-varying coefficient cointegration, Mikayilov et al. (2020) found that the long-run income and price elasticities for Saudi Arabia varied between 0.6 and between 1.1, and −0.5 and −0.1, respectively. Ghoddusi et al. (2022) estimated Iran's fuel demand income elasticity between April 2005 and March 2015. For gasoline, the short-, intermediate-, and long-term price elasticities were estimated as −0.065, −0.207, and −0.291, respectively; for diesel, they were −0.023, −0.059, and −0.116, respectively. Javid et al. (2022) estimated that Pakistan's natural gas demand income elasticity for all sectors varies from 0.45 to 0.73.

2 The energy mix of OECD countries is presented in Figure A2 in the appendix.

Other scholars have employed time-series analysis methods to examine selected groups of countries. Al-Faris (1992) estimated short- and long-term elasticities of gasoline demand in the OAPEC. Short- and long-term price elasticities ranged from −0.08 to −0.48, and from −0.24 to −1.62, respectively. The short- and long-run income elasticities ranged from 0.11 to 0.86, and from 0.92 to 0.86, respectively. Dahl (1992) estimated the energy demand elasticities of 50 developing countries and found average price and income elasticities of −0.33 and 1.27. Ghouri (2001) estimated the price elasticities for the USA, Canada, and Mexico as −0.045, −0.06, and −0.13, respectively, while the income elasticities were 0.98, 1.08, and 0.84, respectively. Cooper (2003) estimated the price elasticities of crude oil demand in 23 countries and found values ranging from 0.38 to −0.568. Asali (2011) estimated the short- and long-run price and income elasticities of oil demand for BRICS and G7 countries. The average short- and long-term income elasticities were 0.41 and 0.78, respectively, while the average short- and long-term price elasticities were −0.05 and −0.15, respectively. Labandeira et al. (2017) conducted a meta-analysis of the empirical literature to determine the estimated values of price elasticities of energy demand. Reviewing 428 articles estimating 966 and 1010 short- and long-run price elasticities, respectively, they concluded that the price elasticity of energy demand was approximately −0.21 and −0.61 in the short and long run, respectively. Eleyan et al. (2021) estimated the separate price and income elasticities of oil demand for BRICS countries and reported income elasticities of 0.888, 0.743, 0.664, 0.781, and 0.761 for Brazil, Russia, India, China, and South Africa, respectively. Notably, price elasticities were statistically significant for Brazil, Russia, and China, with values of −0.032, −0.265, and −0.089, respectively. Focusing on gasoline demand in China, India, the USA, Russia, and Japan, Lee and Olasehinde-Williams (2021) reported largely negative individual price elasticities and positive income elasticities. For 12 major European countries, Pellini (2021) found that estimated long-term income and price elasticities of residential electricity demand ranged from 0.93 to 0.00, and from −0.80 to −0.08, respectively.

The final group of studies used panel data methods to estimate income and price elasticities. Such methods have been used less frequently than time-series methods, and have only recently gained popularity. Gately and Huntington (2002) estimated the income elasticities of energy and oil demand for 96 countries, categorized as OECD and non-OECD, using a panel fixed-effects model. The long-run income elasticities for OECD countries for energy and oil demand were 0.5 and 0.6, respectively, whereas those for non-OECD countries were 1.0 and 0.5, respectively. Narayan and Smyth (2007) employed a panel cointegration test to estimate the income and price elasticities of oil demand, finding values of 1.014 and −0.015, respectively. Dargay and Gately (2010) reported income and price elasticities of 0.80 and −0.29, respectively for total oil demand in OECD countries during 1971-2008. Karimu and Brännlund (2013) used a nonparametric panel data method to estimate the price elasticity of energy demand at −0.2. Yousef (2013) applied the FMOL and DOLS methods to seven OPEC countries for 1980-2010 to estimate the income and price elasticities of gasoline, diesel, and kerosene demand. The FMOLS results showed income elasticities of 0.53, 0.08, and 0.78, respectively, while the DOLS results showed income elasticities of 0.57, 0.05, and 0.73, respectively. Javan and Zahran (2015) employed the dynamic panel data method to estimate the price and income elasticities of oil demand in 25 countries. The short- and long-run income elasticities ranged between 0.15 and 1.09, and between 0.21 and 1.54, respectively. The short- and long-run price elasticities ranged between −0.05 and −0.20, and −0.11 and −0.36, respectively. Csereklyei (2020) estimated the price and income elasticities of residential and industrial electricity demand in the EU. The long-term price elasticity of residential electricity ranged between 0.53 and 0.56, while the price elasticity of industrial electricity ranged between 0.75 and 1.01. The average long-term income elasticity of residential electricity was 0.61, whereas that of industrial electricity ranged between 0.76 and 1.08. Sharma et al. (2021) investigated six middle-income South Asian countries from 1988 to 2016. The income elasticity of crude oil demand, based on long-run coefficients, ranged between 0.47 and 0.54. However, crude oil prices did not significantly affect crude oil demand. Finally, analyzing 49 countries/regions from 1995 to 2017, Zheng et al. (2022) found that the long-run income elasticity of oil demand ranged from 1.16 to 3.35.

To the best of our knowledge, only four studies have examined the time-varying price and income elasticities using panel data models (Liddle et al., 2020; Gao et al., 2021; Liddle and Parker, 2022; Liddle et al., 2022). Liddle et al. (2020) analyzed the income and price elasticities of energy demand for 26 middle-income countries, considering the dynamic nature of these elasticities over time. The estimated average income elasticity was 0.7, whereas the price elasticity coefficient was statistically insignificant. Gao et al. (2021) applied a panel data approach to 65 countries from 1960 to 2016. They found income and price elasticities of energy demand ranging from 0.6 to 0.8, and from −0.1 to −0.3, respectively. Liddle and Parker (2022) employed a time-varying fixed-effects panel data model to analyze the income and price elasticities of gasoline demand in 17 OECD countries from 1960 to 2017. The absolute value of price elasticity peaked during the energy crises between 1973 and 1985 before declining. Meanwhile, income elasticities, although not constant over time, remained relatively close to the estimates that were time-invariant and showed minimal deviations. Finally, Liddle et al. (2022) analyzed income and price elasticities of road fuel in 26 countries from 1990 to 2019 and found that the income elasticity ranged between 1 and 0.8, while the price elasticity was approximately −0.2.

Our analysis employs the same methodology as that used in these four studies. However, rather than analyzing oil demand using annual frequency data, our study adopts a time-varying panel data approach using quarterly data. This enables a more precise examination of the variations in elasticities and a more accurate assessment of structural changes in elasticity.

3. MODEL SPECIFICATION AND DATA

Consistent with the literature, we consider oil prices and economic activity to be the primary factors influencing oil demand. To interpret the coefficients as elasticities, we formulate our model in a double-log form. Unlike previous studies that rely on annual data, we use quarterly data from 21 OECD countries. The data span the period from the first quarter of 1980 to the third quarter of 2021.

The linear form of the estimated panel data is formulated as follows:

$$lQ_{it} = \beta_0 + \beta_1\, lY_{it} + \beta_2\, lnP_{it} + \varepsilon_{it} \quad (1)$$

In this equation, Q_{it} denotes the demand for oil products, measured in million tonnes of oil equivalent; Y_{it} is an indicator of economic activity proxied by the real Gross Domestic Product (GDP) in 2009 prices. P_t represents the real price of oil, calculated by multiplying the average prices of crude oil from three major spot markets (Dubai Fateh, West Texas Intermediate, and Dated Brent) by the nominal national currency to USD exchange rate and dividing it by each country's implicit GDP deflator. All variables are sourced from the Refinitive Eikon DataStream database (Refinitiv Eikon Datastream, 2022). The estimation sample is determined by the availability of the oil demand variables for each country.[3]

Because our estimation sample includes important economic events and periods affecting oil demand in the analyzed countries, we utilize a time-varying nonparametric panel data model based on a local linear dummy variable estimator. Based on this framework, the nonparametric model is as follows:

$$\Delta lQ_{it} = f(t) + \beta_1(t)\Delta ly_{it} + \beta_2(t)\Delta lp_{it} + f_i(t) + \varepsilon_{it} \quad (2)$$

where Δ stands for the first-difference operator; $f_i(t)$ represents unknown individual trend functions; $\beta_j(t)$ for $j = 1,\ldots,N$ shows the time-varying coefficients. The error term, ε_{it}, is assumed to be stationary for each cross-section. That is, it follows a stationary process and is not systematically related to the explanatory variables or time-varying coefficients. Because oil demand varies across countries, we allow each country's oil demand to follow both common and additive country-specific trends, that is, $f_i(t)$. Hence, the common trend component is used to capture the shared factors influencing oil demand across the investigated nations.

3.1. Linear Panel Data Estimation Results

We first check for cross-sectional dependence using the CD test developed by Pesaran (2004). Table 1 shows that the null hypothesis is rejected at the 1% significance level, indicating that the variables exhibit cross-sectional dependence. This finding suggests that a shock in one country may propagate to other countries. In addition, we evaluate the homogeneity of the slope coefficients using the homogeneity test by Pesaran and Yamagata (2008). The test results listed in Table 2 indicate that the slope coefficients are not homogeneous.

After testing for cross-sectional dependence and heterogeneity, we use the CIPS panel unit root test by Pesaran (2007) to determine the integration order of the variables. The results in Table 2 show that all variables exhibit first-order integration *I(1)*.

3 The descriptive statistics for the variables are presented in Table A1 in the appendix.

Table 1: Cross-section dependence and homogeneity test results

Cross-section dependence test	Statistic	P-value
LM	6.710	0.0000
LM adj*	2.327	0.0000
LM CD*	65.590	0.0000
Homogeneity test	$\tilde{\Delta}$	$\tilde{\Delta}_{adj}$
Test statistic	181.40	183.62
P	0.0000	0.0000

Table 2: Pesaran (2007) CIPS panel unit root test results

Variables	lq_{it}	ly_{it}	lp_{it}
Level	−2.253	−2.231	−2.209
First difference	−6.138***	−6.14***	−6.19***

***Significance at the 1% level. Critical values are−2.08, −2.16, and−2.3 for 10%, 5%, and %1 significance levels, respectively

Given the extended time span of our sample, we conduct further analysis to assess the stationarity of the variables while considering the possibility of structural breaks using the PANKPSS test developed by Carrion-i-Silvestre et al. (2005). Table 3 displays the results under both homogeneity and heterogeneity assumptions. The null hypothesis is rejected for all variables, indicating non-stationarity. Consequently, we consider the first difference between the variables and repeated the test. All bootstrapped values exceed 0.05, indicating that the variables are stationary. Therefore, the stationarity test suggests that all variables exhibit an order of integration of order one, *I (1)*.

Consequently, we analyze the long-run relationship using the panel cointegration test developed by Westerlund (2007) while allowing for cross-sectional dependence among individuals. The test results presented in Table 4 confirm the long-run relationship according to the robust P-value statistics at the 1% level.

We then use the test proposed by Westerlund and Edgerton (2008) to examine the presence of structural breaks in the cointegrating relationship while accounting for cross-sectional dependency. Table 5 presents the results for various scenarios, including the no-shift, level-shift, and regime-shift cases. In all cases, the null hypothesis of no cointegration with a structural break is rejected. These results further confirm the existence of a long-term relationship between the variables in the oil demand equation.

To estimate the long-run coefficients, we use the AMG estimator proposed by Eberhardt and Bond (2009), assuming that all variables are *I* (*1*) and exhibit a cointegration relationship. The results presented in Table 6 indicate that a 1% rise in GDP increases oil demand by 0.11%, while a 1% increase in oil prices falls oil demand by 0.17%. Absolute coefficient values of less than one suggests that oil demand is income and price inelastic.

Moreover, this conclusion is supported by examining the cross-sectional long-run parameters at the disaggregated level. Of the 21 countries analyzed, 14 have positive and significant income elasticity coefficients. In the remaining 7 countries, namely Denmark, France, Germany, Italy, Japan, Sweden, and Switzerland, oil can be considered an inferior good because the

Table 3: Results of PANKPSS unit root test with structural breaks

Variables	Level		First difference	
	Homogeneous	Heterogeneous	Homogeneous	Heterogeneous
lq_{it}	4.6298	5.0541	−1.5281	0.6745
	(0.0000)	(0.0000)	(0.9368)	(0.2500)
ly_{it}	15.9121	14.0084	−2.1434	−0.6883
	(0.0000)	(0.0000)	(0.9840)	(0.7544)
lp_{it}	4.2622	3.3669	−2.0199	−2.1894
	(0.0000)	(0.0004)	(0.9783)	(0.9857)

The null hypothesis is that the series is stationary. The maximum number of allowed structural changes was set to five. Bootstrapped P values are reported in parentheses. The model assumes a shift in both the mean and slope. The estimations were conducted using the Gauss Carrion library, including the compiled codes developed by Carrion-i-Silvestre et al. (2005). Breaking dates for each cross-section are not reported but are available at the request of the corresponding author

Table 4: Westerlund (2007) cointegration test results

Statistic	Value	Z	P	Robust P value
Gt	−4.430	−10.361	0.0000	0.0000
Ga	−27.866	−8.898	0.0000	0.0000
Pt	−19.698	−10.215	0.0000	0.0000
Pa	−26.758	−11.031	0.0000	0.0000

Table 5: Westerlund and Edgerton (2008) panel cointegration with structural break test results

Model	Z_τ (N)		Z_ϕ (N)	
	Test statistics	P	Test statistics	P
No shift	−9.832	0.000	−11.942	0.000
Level shift	−3.786	0.000	−3.767	0.000
Regime shift	−2.774	0.003	−2.981	0.001

The estimations were conducted with the Gauss Westerlund library, including the compiled codes developed by Westerlund and Edgerton (2008)

increase in per capita income in these countries has led to a decline in oil demand. This observation aligns with Bernardini and Galli's (1993) dematerialization theory. They suggested that, as income increases, there is a shift from heavy to light industry, resulting in a decrease in the energy input per unit of output. Regarding price elasticities, all parameters are significant, except for Turkey and the USA. Notably, Austria, Belgium, and Spain have significantly positive price elasticities, contrary to the law of demand. Therefore, oil can be considered as a Giffen good in these countries.

3.2. Time-varying Panel Data Estimation Results

This section presents the time-varying income and price elasticities obtained from the estimation of the nonparametric panel data model to analyze the evolution of elasticities over time, given the documented structural breaks in the oil demand equation in the previous section.

Panels (a) and (b) of Figure 1 display the time-varying income and price elasticities of oil demand for 1980-2021 while Table 7 reports the descriptive statistics for these elasticities. Notably, the estimated elasticities are not time-invariant and show remarkable changes over time.

As Panel (a) of Figure 1 shows, the income elasticities for oil demand are positive, ranging from 0.01 to 0.855, with a mean value of 0.189. This suggests that a one-percent increase in income increases oil demand by 0.89%. Furthermore, the estimated income elasticities are larger than the price elasticities throughout the analysis period. This indicates that oil demand is more responsive to changes in income levels than to changes in oil prices. Furthermore, the magnitude of income elasticities, similar to the long-run parameter estimates obtained from the

Table 6: Long-run parameter estimates based on the AMG estimator

Countries list	AMG	
	ly_{it}	lp_{it}
1. Australia	0.3910***	−0.2564***
2. Austria	0.1378***	0.2185***
3. Belgium	0.2316***	0.0438*
4. Canada	0.3732***	−0.0933***
5. Denmark	−0.1330**	−0.3498***
6. Finland	0.0402***	−0.1619***
7. France	−0.0693***	−0.0588**
8. Germany	−0.0593***	−0.2036***
9. Greece	0.0779***	−0.1786***
10. Ireland	0.3389***	−0.1801**
11. Italy	−0.1070***	−0.6352***
12. Japan	−0.1042***	−0.3345***
13. Netherlands	0.5184***	−0.4267***
14. Norway	0.1052***	−0.0779*
15. Portugal	0.1313***	−0.6388***
16. Spain	0.1726***	0.1062***
17. Sweden	−0.1552***	−0.1362**
18. Switzerland	−0.0438***	−0.1614***
19. Turkey	0.4615***	0.0047
20. United Kingdom	0.0180**	−0.2511***
21. United States	0.1409***	0.0065
Panel	0.1174***	−0.1792***

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively

Figure 1: Time-varying oil price (a) and income elasticities (b) (1980-2022)

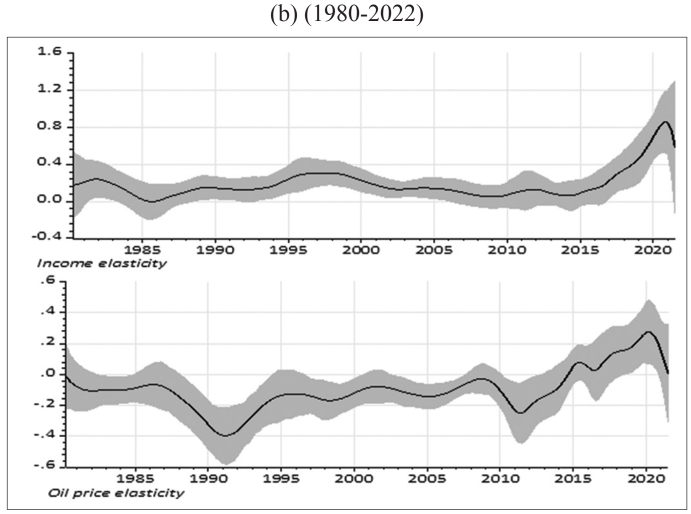

Table 7: Descriptive properties of the time-varying elasticities

Elasticities	Obs.	Mean	Maximum	Minimum	SD
Price elasticity	166	−0.098	0.275 2020:Q1	−0.396 1991:Q2	0.134
Income elasticity	166	0.189	0.855 2020:Q1	0.01 1985:Q4	0.159

SD: Standard deviation

AMG estimator, are less than unity, suggesting that oil can be considered as a necessary good.

The income elasticity estimates are significant for the majority of the estimation periods because the standard error confidence interval band in Panel (a) does not contain zero. At the start of the estimation period, the income elasticities are positive but insignificant before turning significant in the second half of the 1980s. The income elasticity reaches one of its highest levels of 0.284 in 1995:Q4. After the mid-1990s, however, the time-varying elasticities declined and became less significant, falling to 0.189 by 2000:Q4 and becoming statistically insignificant. The income elasticity estimate remains relatively stable at around 0.1 between 2000:Q4 and 2015:Q4 with some fluctuations. However, income elasticities again become significant following the drop in oil prices in 2015:Q4, peaking during the COVID-19 pandemic when oil prices dropped below $30 due to global lockdown measures and travel restrictions, which reduced economic activity, eventually leading to a substantial reduction in oil demand.

The time-varying price elasticities presented in Panel (b) of Figure 1 are <1 and range from −0.396 in 1991:Q2 to 0.275 in 2020:Q1. Elasticities lower than one support the view that oil can be considered as a necessary good because the quantity of oil demanded is not very responsive to price changes. The estimated elasticities are negative until 2014:Q4, indicating that an increase in oil prices leads to a decrease in oil demand, which is consistent with the law of demand. However, the estimated elasticities later become positive, suggesting that a higher oil price has led to an increase in oil demand, contrary to the law of demand. The estimated elasticities vary over time and are statistically significant for most periods, except for a few quarters when the two standard error bands include zero. For example, during the 1990s, the estimated elasticity was approximately −0.3, which means that a ten-percent increase in oil prices would decrease oil demand by 3%. This implies that demand for oil was relatively inelastic during this period, indicating that consumers were not very responsive to changes in oil prices. By contrast, during the 2010s, the estimated elasticity was around 0.2, which means that a ten-percent increase in oil prices would increase oil demand by 2%. This suggests that the demand for oil was more elastic during this period, indicating that consumers were more responsive to changes in oil prices.

The change in estimated elasticities over time may be related to the interaction between global economic events and oil prices. For instance, the estimated elasticities were mostly negative during the 1980s and early 1990s, a period of both low oil prices and weak global economic growth. However, the largest negative oil price elasticity was in the second quarter of 1991, which can be attributed to increasing oil prices and decreasing oil production during the First Gulf War. In contrast, the estimated elasticities became less negative during the 2000s and 2010s, which were characterized by high oil prices and strong global economic growth. The positive estimated elasticities after 2015:Q4 could be due to a change in the behavior of oil demand or the structure of the oil market, such as the emergence of new technologies, alternative energy sources, or geopolitical factors that affected oil prices and demand (Afolabi and Yusuf, 2019).

Contrary to the law of demand, oil price elasticities became positive with a decline in oil prices from $106 in 2014:Q2 to $37 in 2015:Q4. However, the positive price elasticities are mostly statistically insignificant because the two standard error confidence bands include zero. The largest positive and significant price elasticity was during 2020:Q1 at 0.28, which can be attributed to the impact of COVID-19. The pandemic led to a significant decrease in oil demand as countries went into lockdown and reduced their economic activities. This resulted in a decline in oil prices, with crude oil prices declining to $29 on the global oil market while forward spot prices even turned negative.

4. CONCLUSION

This study examined the income and oil price elasticities of oil demand in OECD countries by employing a second-generation panel time-series analysis and time-varying panel data model based on the local linear dummy variable estimator. The findings reveal the sensitivity of oil consumption to changes in income and oil prices, as well as the variation in elasticities over time and between countries.

The results indicate cross-sectional dependence and a long-run relationship between oil demand, real income, and real oil prices. The estimated long-run income and oil price elasticities are both less than unity, suggesting that oil demand is inelastic to both income and price. Specifically, the estimated income elasticity is 0.117, indicating that a one-percent increase in real income increases oil demand by 0.117%. The estimated oil price elasticity is −0.179, indicating that a one-percent increase in the real oil price decreases oil demand by 0.179%. Our findings are thus in line with research on OECD countries (e.g., Gately and Huntington, 2002; Dargay and Gately, 2010; Karimu and Brännlund, 2013; Javan and Zahran, 2015).

We examined the stability of the long-run relationship using a panel cointegration test with endogenous breaks. The results reject the null hypothesis of no cointegration, suggesting the presence of a long-term relationship among the variables in the oil demand equation, with possible structural breaks at unknown points in time. Similar results have been reported by Narayan and Smyth (2007), Karimu and Brännlund (2013), Yousef (2013), and Sharma et al. (2021).

Our analysis of the time-varying panel data estimates revealed substantial temporal variations in both income and oil price elasticities. The income elasticities range from 0.01 to 0.855, indicating that demand for oil is more responsive to changes in income levels than to changes in oil prices. Notably, income elasticities peaked during the COVID-19 pandemic, suggesting that the pandemic had a significant impact on oil consumption patterns. Similarly, Liddle and Parker (2022) found that the income elasticity of gasoline demand varies over time in OECD countries.

Our estimated price elasticities ranged from −0.396 to 0.275. Interestingly, the sign of the oil price elasticities became positive after 2015, contrary to the law of demand. This shift can be attributed to the declining trend in oil prices during this period. The largest positive and significant price elasticity was at the beginning of 2020, primarily driven by the decrease in oil prices due to the COVID-19 pandemic, and associated lockdowns and travel restrictions.

These findings have two implications for policymakers. First, the estimated elasticities provide insights into the responsiveness of oil consumption to changes in income and prices, allowing policymakers to anticipate the effects of economic growth and oil price fluctuations on oil demand. Second, the significant variation in elasticities over time underscores the need for flexible and adaptive energy policies that can respond to changing market conditions and global events. Overall, the findings highlight the inelastic nature of oil demand in OECD countries with respect to income and price. However, the time-varying analysis also demonstrates that elasticities vary significantly over time due to changes in oil prices and global events, such as the COVID-19 pandemic. These results emphasize the importance of considering the dynamic nature of elasticities when formulating energy policies and forecasting future oil demand.

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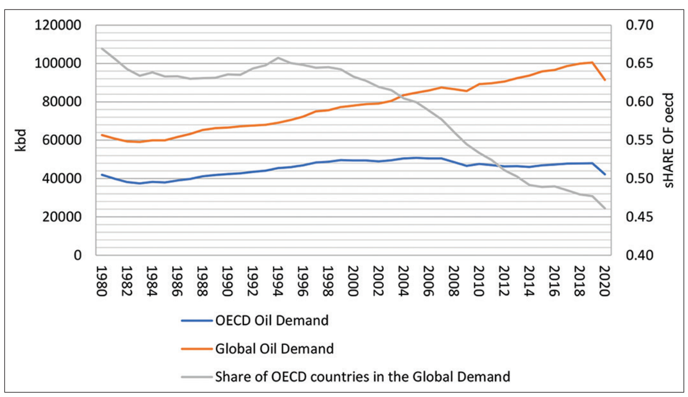
APPENDIX

Appendix 1: Cross-sectional descriptive statistics of the variables

Countries	lQ_{it}				ly_{it}				lp_{it}			
	Mean	Maximum	Minimum	SD	Mean	Maximum	Minimum	SD	Mean	Maximum	Minimum	SD
Australia	1.058	1.390	0.611	0.227	8.828	9.769	7.856	0.608	4.562	4.920	4.263	0.136
Austria	−0.177	0.061	−0.531	0.127	8.854	9.541	7.664	0.553	4.547	4.878	4.299	0.151
Belgium	0.632	0.890	0.209	0.163	8.798	9.486	7.639	0.530	4.476	4.827	4.033	0.208
Canada	1.893	2.170	1.505	0.179	8.821	9.497	7.912	0.484	4.468	4.916	4.127	0.201
Denmark	−0.461	−0.113	−0.809	0.143	9.045	9.753	7.829	0.572	4.493	4.816	4.200	0.163
Finland	−0.342	−0.151	−0.566	0.068	8.810	9.569	7.598	0.587	4.385	4.795	3.905	0.237
France	1.831	2.208	1.444	0.098	8.770	9.407	7.705	0.477	4.504	4.801	4.209	0.177
Germany	2.168	2.380	1.943	0.087	8.859	9.468	7.786	0.460	4.465	4.859	4.006	0.224
Greece	0.101	0.429	−0.318	0.190	7.786	9.047	5.488	1.052	4.417	4.787	3.950	0.216
Ireland	−0.868	−0.316	−2.426	0.404	8.746	10.178	7.090	0.913	4.461	4.862	4.133	0.202
Italy	1.706	1.973	1.043	0.190	8.519	9.308	7.113	0.643	4.477	4.787	4.232	0.131
Japan	2.774	3.011	2.350	0.144	8.913	9.437	7.666	0.474	4.489	4.912	4.127	0.221
Netherlands	0.968	1.305	0.169	0.269	8.928	9.640	7.824	0.507	4.492	4.732	4.118	0.140
Norway	−0.360	−0.115	−0.561	0.096	9.271	10.211	8.147	0.638	4.482	4.752	3.979	0.198
Portugal	−0.168	0.188	−0.628	0.204	7.862	8.805	5.962	0.838	4.493	4.734	4.102	0.157
Spain	1.400	1.708	0.946	0.191	8.215	9.162	6.659	0.755	4.529	4.810	4.222	0.161
Sweden	0.178	0.662	−0.271	0.162	9.027	9.664	7.987	0.481	4.321	4.727	3.835	0.278
Switzerland	−0.167	0.046	−0.424	0.084	9.365	10.100	8.223	0.532	4.550	4.919	4.212	0.203
Turkey	0.672	1.284	−0.215	0.349	7.139	8.084	5.926	0.643	4.292	4.899	2.797	0.427
United Kingdom	1.722	1.926	1.188	0.089	8.795	9.476	7.575	0.543	4.469	4.835	4.111	0.206
United States	4.136	4.263	3.971	0.085	9.040	9.767	8.033	0.474	4.556	5.138	4.003	0.278
All	0.890	4.263	−2.426	1.247	8.685	10.211	5.488	0.810	4.473	5.138	2.797	0.225

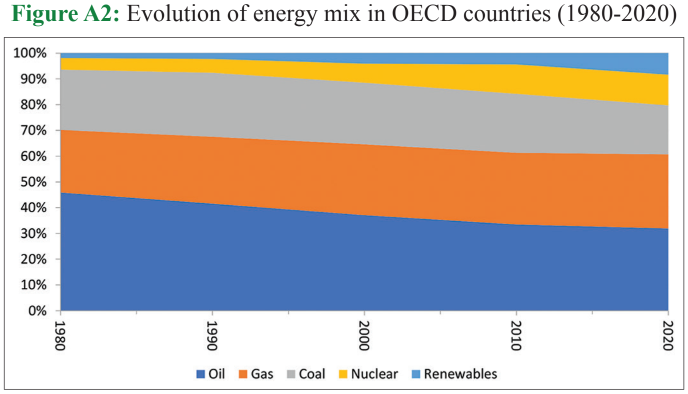
SD: Standard deviation

Figure A1: Oil demand in OECD countries (1980-2020)



Source: International Energy Agency

Figure A2: Evolution of energy mix in OECD countries (1980-2020)



Source: International Energy Agency