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Examining the patterns of disaggregate energy security risk and crude oil price: the USA scenario over 1970–2040

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ABSTRACT

Beyond the environmental drawback of fossil energy sources, energy security remains a salient concern for economic development and environmental sustainability. This explains why the influence of energy security and its components (economic, geopolitical, reliability, environmental) on the price of crude oil commodity, especially in the United States of America, is considered in this study up to the period 2040 (i.e., from 1970 to 2040). Using the Kernel-Based Regularized Least Squares (KRLS) approach supported by the robustness of the quantile regression, the result shows an increase in aggregate energy security risk spur crude oil price by an elasticity of ~0.9. With a positive impact on oil price, the economic, geopolitical, and reliability perspectives of energy security risk exhibit respective elasticity of ~2.0, ~0.6, and ~0.7, thus confirming that a positive shock in each aspect aggravates the oil price hike in the country. Contrarily, an increase in environmental risk could spiral a decline and an inelastic (~−1.5) change in crude oil price, thus suggesting a desirable net zero future and a significant crash in oil price arising from clean and alternative energy source adoption. Furthermore, retail electricity price and energy expenditures are used as control variables, and crude oil prices respond positively and negatively to the increase in energy expenditures and electricity price, respectively. Several accounts of policy insights are highlighted in these results.

1. Introduction

The science of energy security has advanced over the past two decades, from traditional political economics studies of oil supplies for industrialized democracies to a far wider variety of energy sectors and related interests (Cherp and Jewell, 2014). Due to this evolution, the scientific and policy literature now contains a bewildering array of fragmented and inconsistent views of energy security. Nevertheless, energy market remained the critical component of economic activities, thus making the fundamentals of energy prices the proxy and indirect drivers of several macroeconomic indicators. On the other hand, previous events have shown that energy prices, such as crude oil prices, tend to move in the direction of key social, economic, and macroeconomic factors. For instance, crude oil prices have been characterized with high and low regimes arising from different events overtime that include the Gulf war, on going Russian-Ukraine war, and the recent plunge in global demand for crude oil amidst increase in the crude oil inventories during the coronavirus pandemic that caused crude oil to trade below zero USD (United States Dollars) (United States Energy Information Administration, 2021). Specifically, a spike in global crude oil prices was experienced in the Summer of 1990 in response to the invasion of Kuwait by Iraq, spiralling global disruptions of crude oil supply (United States Energy Information Administration, 2011). Therefore, as highlighted by the International Energy Agency (IEA), several aspects are associated with the mechanism that prevents disruption of energy sources and their availability at an affordable price i.e., energy security (IEA, 2022). In ensuring global energy security amidst achieving the global net zero target, energy risk aspects, especially those emanating from the mismatches of demand and supply of energy commodities, would need to be continuously addressed (IEA, 2021).

Given the peculiarity of the risks associated with global energy security and the rare coverage of the subject in the literature, the current study is channelled toward exploring energy security risk and its disaggregate aspects. Thus, as an objective, this study is designed to reveal the impact of energy security risk and its disaggregate forms

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Acronyms

CBO	Congressional Budget Office
COP	Crude Oil Price
DF-GLS	Dickey-Fuller Generalized Least Squares
ECOR	Economic Risk
ENR	Energy Security Risk
ENEX	Energy Expenditures
ENVR	Environmental Risk
EPU	Economic Policy Uncertainty
GARCH-MIDAS	Generalized AutoRegressive Conditional Heteroskedasticity-MIxed-DAta-Sampling
GDP	Gross Domestic Product
GEI	Global Energy Institute
GEOR	Geopolitical Risk
GHG	Greenhouse Gas
IEA	International Energy Agency
KRLS	Kernel-Based Regularized Least Squares
QR	Quantile Regression
RELR	Reliability Risk
REP	Retail Electricity Prices
UK:	United Kingdom
USA:	States of America
USD:	United States Dollars

(economic energy security risk, environmental energy security risk, geopolitical energy security risk, and reliability energy security risk) on the crude oil price. In achieving the outlined objective, the case of the United States of America (USA) is considered appropriate given that the country is the largest economy by gross domestic product (GDP) and the world's major energy market player. Although several studies have established the drivers of energy price from different perspectives, such as geopolitical risk (Bouoiyour et al., 2019; Demirer et al., 2019; Olanipekun and Alola, 2020), policy uncertainty-related risk (Yang and Hamori, 2021), energy security via energy production-reserve ratio (Alola et al., 2022), and composite index (Mohsin et al., 2018), there is lack of evidence suggesting that the proposed objective has been considered in the literature. Because, against other forms of risk, the current study categorically employs 'energy security form of risk, i.e. energy security risk, which was constructed from 37 metrics of 9 categories of indicators (GEI, 2022). As such, the motive and approach undertaken in the investigation are considered a novel addition to the body of knowledge. This is in addition with the implementation of the appropriate empirical methods, especially the recently developed Kernel-Based Regularized Least Squares (KRLS) by Hainmueller and Hazlett (2014).

There are other parts of the study. The next section (2) highlights the concepts; investigation approaches, and results of related literature. In section 3, the dataset is described alongside the highlight of the empirical methods. Sections 4 and 5 present the discussion of the main result and the study's conclusion, respectively.

2. Related studies:a brief review

In the existing literature, geopolitical risks have been widely liked with energy prices and volatility (Bouoiyour et al., 2019; Demirer et al., 2019; Olanipekun and Alola, 2020). For instance, Bouoiyour et al. (2019) combined the econometric approaches of Fei et al. (2017) termed the 'dynamic copula with Markov-switching' with Maheu and McCurdy (2004) which respectively provides evidence of asymmetry of a high and low dependence states and the conditional variance of returns. Given these approaches, the study categorized shocks as either acts of geopolitics or threats of geopolitics, i.e. composites of geopolitical risk, thus suggesting that geopolitical risks stem from imminent threats of adverse events to the perpetration of the threats. Consequently, the relationships between these two aspects of geopolitical risks and oil prices were examined by considering several unforeseen fundamentals and accounting for contemporaneous geopolitical events across the globe. Importantly, the result found that events associated with geopolitical risk positively influenced oil price movement. In contrast, the influence of threats is either moderate or yield insignificant results. Moreover, depending on the risk category, the study hints that geopolitical risk conditionally influences oil prices.

From the geopolitical-, health- and economic-related perspectives, Yi et al. (2021) used the crude oil futures market in China to (in)validate the nexus between the volatility of crude oil futures and the uncertainty of macroeconomic indicators. Using the Generalized AutoRegressive Conditional Heteroskedasticity-MIxed-DAta-Sampling (GARCH-MIDAS) approach, the study established the role of socioeconomic and macroeconomic uncertainties in predicting crude oil futures in China, especially during the period March 27, 2018 to June 24, 2020. Notably, the result establishes that the volatility of China's crude oil future is superiorly impacted by the socioeconomic and macroeconomic indicators such as the Japan's economic policy uncertainty (EPU), the United Kingdom (UK) 's EPU, and the global EPU, the geopolitical act risk, and geopolitical risk.

On risk aspects, Yi et al. (2021) examined whether macroeconomic uncertainty factors can explain and predict China's International Energy Exchange Center (INE) crude oil futures market volatility. To examine the ability of the macroeconomic uncertainty to explain and predict, they employed the GARCH-MIDAS model. In the model, they took into account a variety of indices for geopolitical risk (GPR), economic policy uncertainty (EPU), and infectious disease pandemic (IDEMV). The empirical findings imply that the geopolitical risk, geopolitical act risk, global economic policy uncertainty, UK economic policy uncertainty, and Japanese economic policy uncertainty comprehensively integrate the information contained in the other factors and exert superior predictive powers on the future volatility of INE crude oil. Similarly, mixed data sampling (MIDAS) was utilized by Yang and Hamori (2021) to determine the systemic risk in crude oil market using monthly frequencies. The study employed connectivity indicators developed by Diebold and Yilmaz (2009, 2014) to determine the causal link between systemic risk in the crude oil market and uncertainty in global economic policy. The evidence reveals that, notwithstanding the diminished impact during financial crises, uncertainty in global economic policy is economically significant in determining systemic risk. Additionally, Hassan et al. (2021) investigated the causal relationship between Nasdaq clean energy stock price and various variables, including oil price, natural gas price, carbon price, and energy efficiency. The investigation further relies on the theoretical framework that integrates key components of energy security into the context of natural capital theory. Consequently, the autoregressive distributed lag (ARDL) technique results showed that the variables corresponding to some aspects of energy security jointly and separately explain clean energy stock price. The two crucial aspects of energy security driving the ongoing switch from dirty to conventional energy sources emerged as carbon price and energy efficiency. In addition to these studies, other related investigations have attempted to link economic and geopolitical risk to energy markets (Mohsin et al., 2018; Demirer et al., 2019; Yang and Hamori, 2021).

2.1. Significant contribution

While the studies enumerated above among several others were based on risk and uncertainty aspects of geopolitical and economic situations, Hassan et al. (2021) used the elements of energy security, which include carbon price, energy efficiency, oil price, and natural gas prices. Additionally, instead of crude oil price, Hassan et al. (2021) employed the stock price of clean energy and deployed the econometric approach of the autoregressive distributed lag method. Importantly, the result shows that energy efficiency and carbon price (components of energy security) jointly and individually drive clean energy stock prices by a notable degree, thus recognizing the two factors as valid energy transition indicators. In the study of Alola et al. (2022), the ratio of production to reserves was used to proxy for energy security in the case of the USA. By employing the econometric method of non-parametric causality-in-quantiles for the dataset that covers 1970–2040, the findings reveal a non-linear association between crude oil price and each production-reserves ratio of coal, natural gas, and crude oil. Additionally, in predicting crude oil prices, causality-in-variance outperforms causality-in-mean.

Given this obvious evidence from the literature, as established in the review of the existing literature, the current study is a significant addition to the literature because the actual index of energy security that is being utilized. Moreover, the four components of the energy security index, i.e. economic energy security risk, environmental energy security risk, geopolitical energy security risk, and reliability energy security risk, are also employed to further capture energy security thoroughly from relevant aspects.

3. Data and methodology

This section is dedicated to the description of the dataset, empirical methods, and results. Specifically, detail information and statistical properties of the dataset are provided alongside relevant guideline for the deployment of the empirical methods.

3.1. Data description

The study seeks to establish how crude oil price is impacted by energy security measured as the energy security risk index in the United States of America. For this reason, annual data from 1970 to 2040 downloaded from Global Energy Institute (GEI) is analyzed. This analysis look at the years up to 2040, which substantially accounts for the international expectation of the USA's net zero emissions ambition. Table 1 shows the definition of variables employed. The predicted variable of this study is the crude oil price. In contrast, the explanatory variables include energy security risk, economic risk, environmental risk, geopolitical risk, reliability risk, energy expenditures and retail electricity prices. According to the GEI report, the energy security risk is a component of 30 percent economic risk, 30 percent environmental risk, 20 percent geopolitical risk, and 20 percent reliability risk (GEI, 2022).

The time plots of the variables depicted in Fig. 1 show the patterns, including the forecast of all the variables employed in the study. While all the variables show an increase from 2023 to 2040, only the environmental risk index shows a decline. Several models have been developed for this investigation. Firstly, in the main model (I), the aggregated energy security is employed by controlling for the effect of energy expenditures and retail electricity prices (electricity prices is the price of other good). Secondly, disaggregated forms of energy security are employed in separate sub-indices models by controlling for the effect of energy expenditures, and retail electricity prices. Lastly, Kernel-Based Regularized Least Squares provide the coefficient estimation, while Quantile Regression (QR) developed by Koenker and Bassett Jr. (1978) offers robustness evidence.

Table 1
Details of the variables.

Variable	Abr.	Measurement	Source
Crude Oil Price	COP	2018$/bbl	GEI (2022)
Energy Security Risk	ESR	Energy Security Risk Index	GEI (2022)
Economic Risk	ECOR	Economic Risk Index	GEI (2022)
Environmental Risk	ENVR	Environmental Risk Index	GEI (2022)
Geopolitical Risk	GEOR	Geopolitical Risk Index	GEI (2022)
Reliability Risk	RELR	Reliability Risk Index	GEI (2022)
Energy Expenditures	ENEX	2018$/Household	GEI (2022)
Retail Electricity Prices	REP	cents/kWh (2018$)	GEI (2022)

3.2. Model

Blomberg and Harris (1995) poised that global oil market offers a centric system for tradable goods such that macroeconomic indicators (e.g. the exchange rate) directly influence the crude oil price. As a foundation for this insight, the seminar work of Baily et al. (1978) offers information about the dynamics of crude oil prices to changes in economic activities such that economic and macroeconomic indicators are seen as causative agents of crude oil prices. Given this background, this study projects that economic fundamentals such as energy demand, electricity price, and other factors, such as energy security and its components, account for the changes and volatility of crude oil prices.

As such, in the current context, COP is modelled as

$$COP = f(ENEX, REP, Z) \tag{1}$$

where Z is the variable of concern i.e energy security.

Subsequently, the equation above is further expressed as

$$COP = f(ENEX, REP, ESR) \tag{2}$$

while the sub-indices models are

$$COP = f(ENEX, REP, ECOR) \tag{3}$$

$$COP = f(ENEX, REP, ENVR) \tag{4}$$

$$COP = f(ENEX, REP, GEOR) \tag{5}$$

$$COP = f(ENEX, REP, RELR) \tag{6}$$

Consequently, equations (2)–(6) are henceforth regarded as models I, II, III, IV, and V respectively.

3.3. Methodology

We employ the Kernel-Based Regularized Least Squares developed by Hainmueller and Hazlett (2014) to execute the above-mentioned five models. To provide some leverage, machine learning algorithm with econometric characteristics is used in this method. In contrast to traditional econometric techniques, the KRLS method develops pointwise derivatives and mean marginal effects, does hypothesis testing, and produces solid and trustworthy estimates. Related to this, when it comes to problems with misspecification bias over statistical judgments, the KRLS technique surpasses current machine learning methods. The KRLS approach also offers variable and comprehensible parameters in classification and regression conundrums with uncertain functional forms. In other words, it establishes the data series' functional structure and safeguards practitioners from specification bias. The KRLS approach is beneficial for analysis that includes understanding the data creation process, model-driven causal inquiry, forecast, and imputation of missing data, among other things (Özkan et al., 2023; Sarkodie et al., 2021; Hainmueller and Hazlett, 2014). Meanwhile, a detailed step-by-step description of the KRLS approach is available in the study by Hainmueller and Hazlett (2014) which has been thoroughly covered in the literature. However, necessary pre-tests and estimations, such as stationarity and BDS tests were conducted before conducting the KRLS to validate its appropriateness for non-normality, non-stationarity, and non-linearity series.

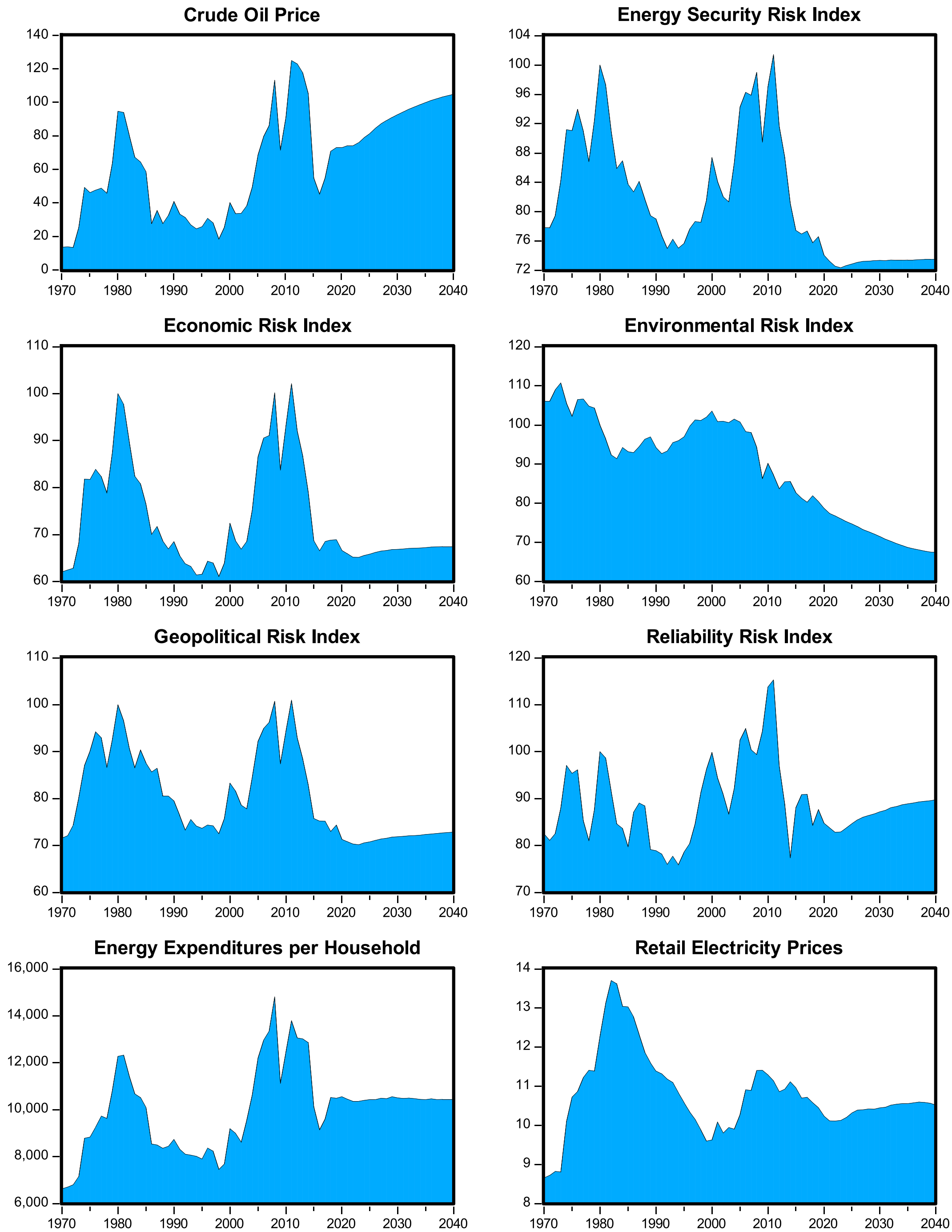

Fig. 1. Time plots of the variables.

4. Empirical results

As part of the pre-tests, the variables were transformed into their natural logarithm following Namahoro et al. (2021) to conduct a reliable analysis and resolve potential heteroscedasticity issues. However, summary statistics are computed for the natural values of the series to allow raw interpretations. Specifically, the standard deviation of ENEX followed by COP are the highest, thus affirming the sharp changes (volatility) of the variables. All the variables are positively skewed except ENVR. Similarly, kurtosis shows that all the variables have fat tails i.e., platykurtic distribution. All the variables are normally distributed except for COP, and ENEX. Lastly, the Jargue-Bera statistics largely indicate the rejection of null hypothesis for normality (see Table 2).

Two well-known unit root tests, the Ng-Perron modified unit root test (Ng and Perron, 2001) and the DF-GLS unit root test (Elliott et al., 1996), are used in the empirical analysis of this work to determine the stationary level of the study variables. Table 3 lists the outcomes of the Ng-Perron modified unit root test and DF-GLS unit root test. Both unit root test results show that, except for RELR in the DF-GLS unit root test case, the relevant variables' null hypothesis is not stationary at levels and cannot be rejected at I(0). However, they can be rejected once the first variable difference has been performed.

According to Broock et al. (1996) (non)linearity test, and as shown by the BDS statistic across the dimensions (2–6) in Table 4, the null hypothesis for independently and identically distributed is rejected for

Table 2
Summary statistics.

	Mean	Std. Dev.	Skewness	Kurtosis	JB
COP	65.284	30.889	0.028	1.795	4.305 [0.116]
ESR	81.565	8.379	0.744	2.345	7.820** [0.020]
ECOR	73.130	10.874	1.147	3.151	15.635*** [0.000]
ENVR	88.981	13.116	−0.259	1.698	5.803* [0.055]
GEOR	80.189	9.190	0.728	2.188	8.222** [0.016]
RELR	88.867	8.106	1.011	4.289	17.008*** [0.000]
ENEX	10036.74	1738.069	0.312	3.006	1.155 [0.561]
REP	10.791	1.026	0.765	4.217	11.314*** [0.003]

Note: ln, Δ, ***, **, and * represent the logarithmic values, the first difference operator, significance at the 1%, 5%, and 10% significance levels, respectively. JB is the Jarque and Bera (1980) normality test.

Table 3
The results of the unit root tests.

Panel A: Ng-Perron modified unit root test results (Ng and Perron, 2001)

	MZa	MZt	MSB	MPT
lnCOP	−1.172	−0.553	0.472	14.204
ΔlnCOP	−33.969***	−4.121***	0.121***	0.722***
lnESR	−4.365	−1.439	0.329	5.679
ΔlnESR	−33.287***	−4.079***	0.122***	0.736***
lnECOR	−4.773	−1.544	0.323	5.135
ΔlnECOR	−33.254***	−4.077***	0.123***	0.737***
lnENVR	1.516	1.360	0.897	63.175
ΔlnENVR	−34.183***	−4.134***	0.121***	0.717***
lnGEOR	−4.119	−1.431	0.347	5.953
ΔlnGEOR	−33.663***	−4.102***	0.122***	0.728***
lnRELR	−5.099	−1.575	0.309	4.862
ΔlnRELR	−1394979***	−835.158***	0.001***	0.000***
lnENEX	−2.254	−0.965	0.428	10.181
ΔlnENEX	−34.092***	−4.128***	0.121***	0.720***
lnREP	−3.282	−1.243	0.379	7.433
ΔlnREP	−27.975***	−3.736***	0.133***	0.887***
Asymptotic critical values				
1%	−13.800	−2.580	0.174	1.780
5%	−8.100	−1.980	0.233	3.170
10%	−5.700	−1.620	0.275	4.450

Panel B: DF-GLS unit root test results (Elliott et al., 1996)

	t-stats.	Test critical values	
lnCOP	−0.688	1%	−2.598
ΔlnCOP	−7.279***	5%	−1.945
lnESR	−1.479	10%	−1.614
ΔlnESR	−6.821***		
lnECOR	−1.618*		
ΔlnECOR	−6.803***		
lnENVR	1.183		
ΔlnENVR	−7.497***		
lnGEOR	−1.488		
ΔlnGEOR	−7.049***		
lnRELR	−1.617*		
ΔlnRELR	−8.131***		
lnENEX	−1.079		
ΔlnENEX	−7.393***		
lnREP	−1.282		
ΔlnREP	−5.171***		

Note:The ln, Δ, *** and * represent the logarithmic values, the first difference operator, significance at the 1% and 10% significance levels, respectively.

all the studied series, verifying the nonlinearity evidence of the series.

4.1. Results

Prior to KRLS estimation, revelations from Tables 2–4 affirms the non-normality, non-stationarity, and non-linearity of the series. Table 5 presents the findings of the KRLS test. We determine that the KRLS model's predictive power (R2) is 0.875%, 0.916, 0.885, 0.864 and 0.893 for models I to V, respectively, thereby demonstrating that the variables (namely energy security risk, economic risk, environmental risk, geopolitical risk, reliability risk, energy expenditures and retail electricity prices) explain 87.5%, 91.6%, 88.5%, 86.4% and 89.3% respectively of the variance in the dependent variable, i.e., crude oil price.

In model I, the estimated average marginal effects imply that energy security risk and energy expenditures increase crude oil prices by 0.868% and 2.142%. In contrast, retail electricity prices decrease crude oil prices by 1.019%. According to model II's anticipated average marginal effects, economic risk and energy expenditures are expected to raise crude oil prices by 2.018% and 1.229%, respectively. In comparison, retail electricity prices are expected to drive down the price of crude oil by 1.040%. Model III shows the estimated average marginal effects reveal that environmental risk and retail electricity prices decrease crude oil prices by 1.471% and 2.117%, whereas energy expenditures increase crude oil prices by 3.147%. In model IV, the estimated average marginal effect implies that geopolitical risk and energy expenditures increase crude oil prices by 0.663% and 2.308%. In contrast, retail electricity prices decrease crude oil prices by 0.858%. Finally, in model V, the estimated average marginal effects imply that reliability risk and energy expenditures increase crude oil prices by 0.625% and 2.162%, whereas retail electricity prices decrease crude oil prices by 1.432%.

Furthermore, we plot the pointwise marginal effects of energy security, economic, environmental, geopolitical, and reliability risks on crude oil prices in Fig. 2. Graphs (a), (d), and (e) in Fig. 2 illustrates that energy security risk, geopolitical risk, and reliability risk affect crude oil prices negatively (positively) up to a certain point, after which the effect increases slightly. After that, however, the positive (negative) effect on crude oil prices increases again.

On the other hand, graphs (b) and (c) in Fig. 2 show that economic risk and environmental risk negatively (positively) affect crude oil price up to a certain point, after which the effect increases slightly. And then, the negative (positive) effect on crude oil prices decreases again.

Table 4
The results of the BDS test/Broock-Dechert-Scheinkman (BDS) (Broock et al., 1996).

	Dimension				
	2	3	4	5	6
ΔlnCOP	0.035***	0.048**	0.059**	0.062**	0.067**
	[0.008]	[0.021]	[0.020]	[0.019]	[0.010]
ΔlnESR	0.038***	0.078***	0.105***	0.139***	0.163***
	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]
ΔlnECOR	0.049***	0.076***	0.097***	0.122***	0.143***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
ΔlnENVR	0.022**	0.070***	0.101***	0.123***	0.130***
	[0.026]	[0.000]	[0.000]	[0.000]	[0.000]
ΔlnGEOR	0.031***	0.049***	0.065***	0.093***	0.108***
	[0.003]	[0.003]	[0.001]	[0.000]	[0.000]
ΔlnRELR	0.019*	0.035*	0.071***	0.093***	0.103***
	[0.084]	[0.053]	[0.001]	[0.000]	[0.000]
ΔlnENEX	0.033***	0.042**	0.047*	0.058**	0.072***
	[0.009]	[0.038]	[0.059]	[0.026]	[0.004]
ΔlnREP	0.043***	0.093***	0.122***	0.149***	0.169***
	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]

Note: This table shows BDS statistics. ***, **, and * represent significance at the 1%, 5%, and 10% significance levels, respectively.

4.2. Robustness

The Quantile Regression (QR) developed by Koenker and Bassett Jr. (1978) is deployed to determine the effect of energy security, economic, environmental, geopolitical, and reliability risk on crude oil price in Fig. 3. The results obtained from the KRLS method are robust to the findings of all the relationships between the energy security components and crude oil prices as provided by the QR estimation. Finally, the findings of the study are summarily presented in Fig. 4.

Table 5
Average pointwise marginal effects.

	Model I	Model II	Model III	Model IV	Model V
ESR	0.868*** [0.000]	–	–	–	–
ECOR	–	2.018*** [0.000]	–	–	–
ENVR	–	–	−1.471*** [0.000]	–	–
GEOR	–	–	–	0.625*** [0.000]	–
RELR	–	–	–	–	0.663*** [0.000]
ENEX	2.142*** [0.000]	1.229*** [0.000]	3.147*** [0.000]	2.162*** [0.000]	2.308*** [0.000]
REP	−1.019*** [0.000]	−1.040*** [0.000]	−2.117*** [0.000]	−1.432*** [0.000]	−0.858*** [0.000]
Diagnostics					
R^2	0.875	0.916	0.885	0.864	0.893
Lambda	0.316	0.211	0.153	0.378	0.217
Sigma	3	3	3	3	3
Looloss	6.333	5.164	7.287	7.077	5.879

Note: *** represents significance at the 1% significance level.

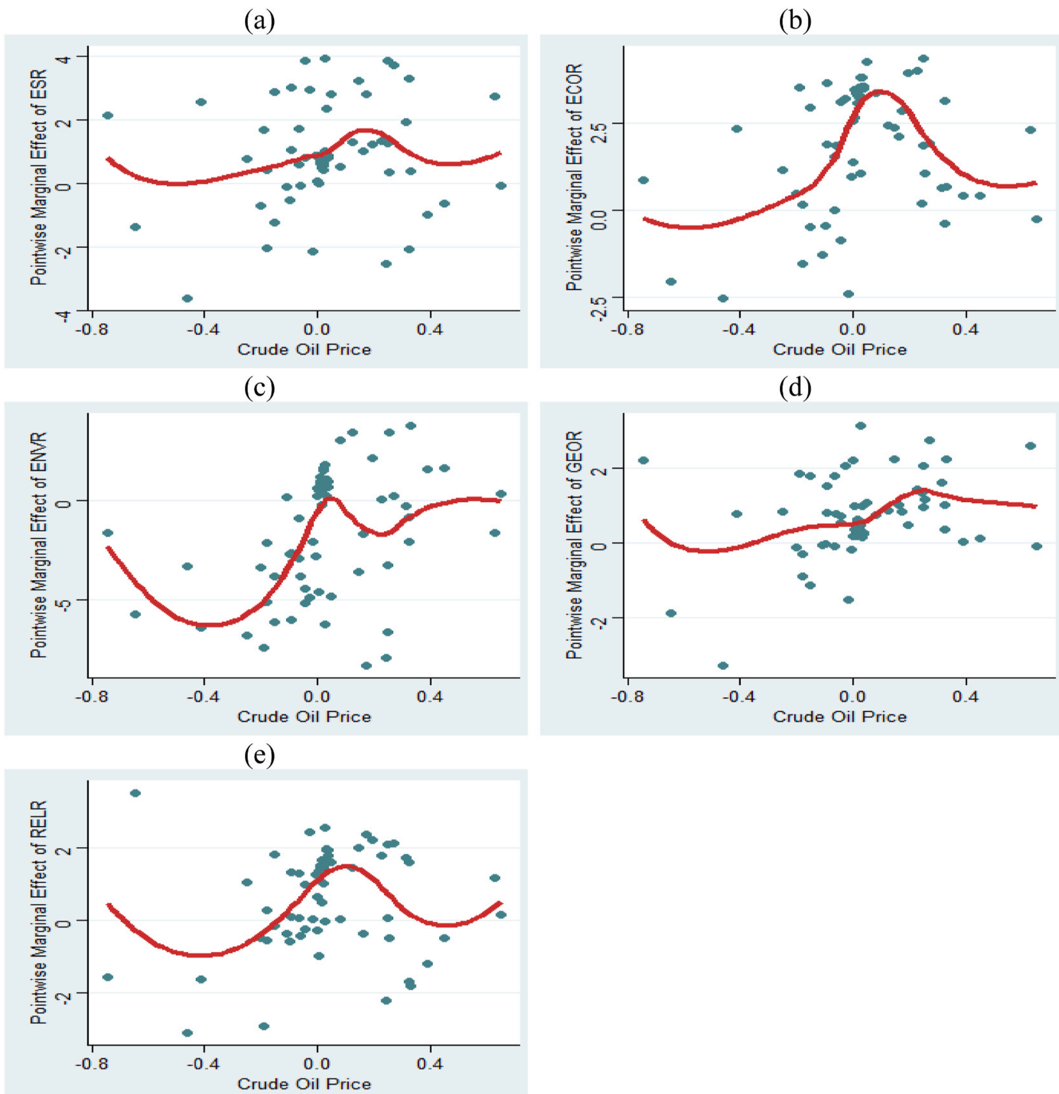

Fig. 2. Pointwise marginal effects.

5. Discussion of results

From the results in model I, an increase in energy security risk after controlling for the effect of energy expenditures and retail electricity prices (electricity prices is the price of other good) increases the price of crude oil. Energy security risk evaluates the long-term physical availability of energy supply to satisfy the rising future demand for energy. In contrast, short-term energy security accounts for the propensity of the energy system to adjust and correct a sudden imbalance in energy demand and supply (IEA, 2022). The increase in energy security risk will cause a surge in crude oil prices because the US economy and especially crude oil consumers in the country are susceptible to

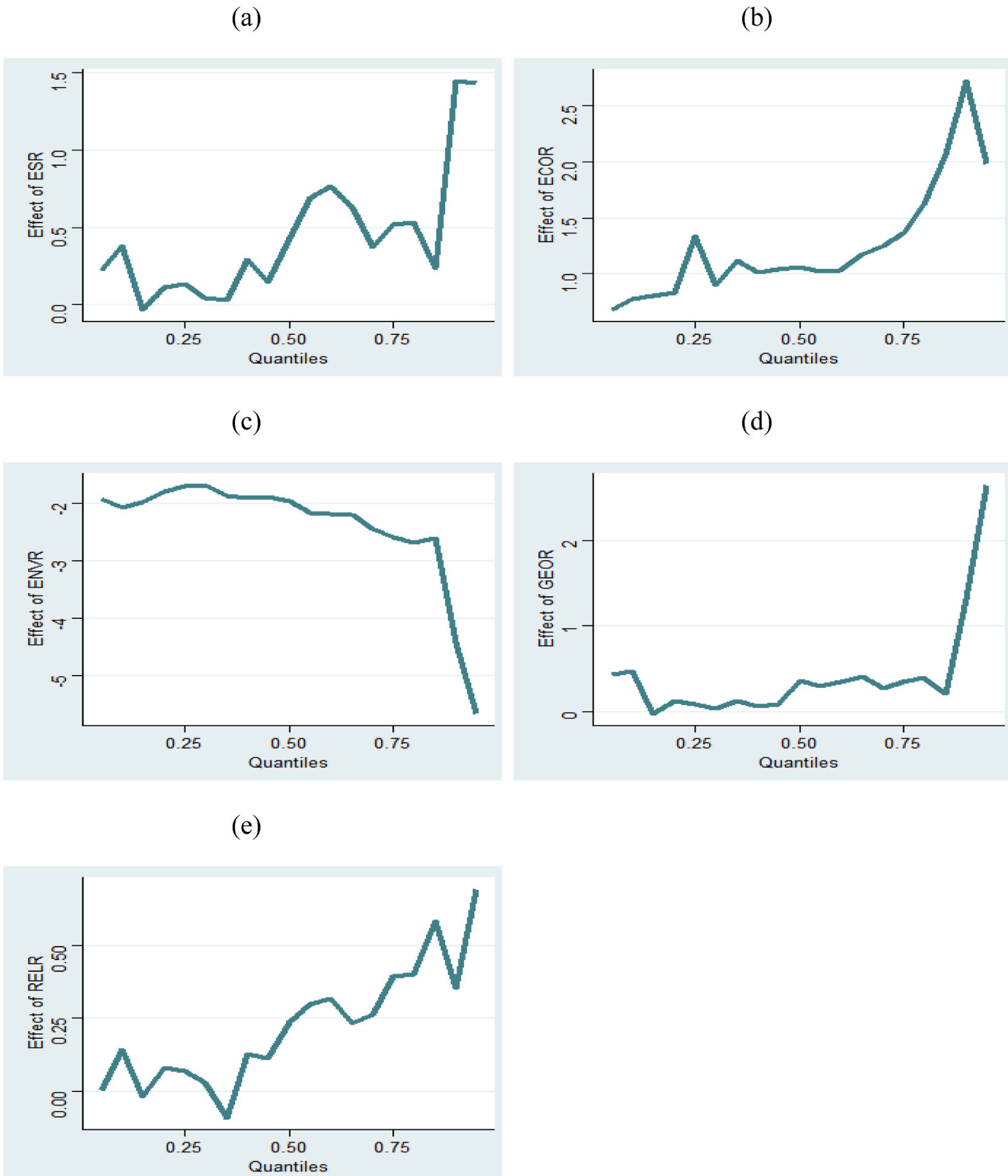

Fig. 3. Quantile regression.

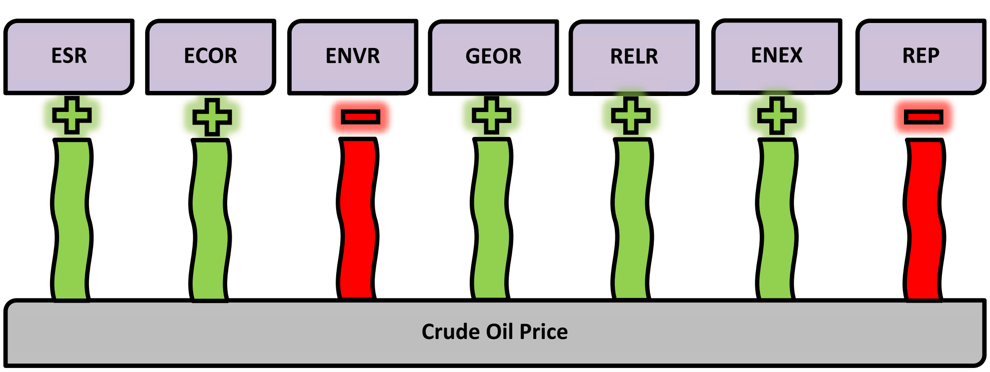

Fig. 4. Summary of the findings.

interruptions in the oil market. Importantly, such impact is likely to be more severe in the country's energy markets due to the dependence of the two major energy-consuming sectors of the US economy, transportation and electricity, on the oil sector. Transportation, in particular, largely depends on oil supplies from a worldwide energy market where disruptions might result in significant price fluctuations (CBO, 2012). Therefore an increase in energy security risk intuitively translate to an increase in the price of crude oil. This is the current situation, especially with the USA and largely across the globe, due to energy supply disruption arising from the Russia-Ukraine War since the first quarter of 2022. The literature has also affirmed that energy-related factors often predict energy prices, especially crude oil (Hassan et al., 2021; Alola et al., 2022).

On the other hand, environmental risk refers to the possibility of adverse environmental repercussions from crude oil exploration, production, and transportation. Expectedly, the current finding shows that an increase in environmental risk leads to a reduction in the price of crude oil. Intuitively, this increase in environmental risk might lead to a transition to substitutes for conventional petroleum (Farrell and Brandt, 2006). Furthermore, this type of risk, such as those caused by global warming and environmental problems, would eventually also lead to the demand for other environmentally friendly, sustainable, and efficient energy sources besides crude oil, thereby decreasing the price of crude oil. Consequently, this global aspiration now largely drives the pursuit of carbon neutrality through the prospect of achieving perfect shift from fossil fuel to renewable and clean energy sources across the globe by 2030. Although the evidence from this result is somewhat different from the current reality where crude oil price largely remained high despite environmental problems in the USA arising from GHG emissions and others, the result presents a desirable outlook up the year 2040. However, despite the outcome of this result, the outcome's desirability differs from Ngene et al. (2016) which found that environmental risk increases crude oil prices. The disparity in the result could be due to the fact that our study covers the period up to 2040 which largely accounts for the global expectation of a net zero emission future for the USA.

The result in model III further shows that an increase in economic risk/uncertainties will cause a surge in the price of crude oil while keeping the effect of energy expenditures and retail electricity prices constant. By affecting oil traders' psychological expectations and worsening the volatility of the financial market, economic risk harms the stability of the oil market (Yang and Hamori, 2021; Feng et al., 2020). This discovery is comparable to those made by Kang et al. (2017), Aloui et al. (2016) and Brogaard and Detzel (2015), whom all found that economic risk leads to an increase in crude oil price. Accordingly, stakeholders should consider economic risk when making decisions because it is crucial in setting the price of crude oil.

Additionally, an increase in geopolitical risk is found to trigger an increase in crude oil prices. Clearly, tensions from geopolitical zones, especially in major oil-producing and consuming countries such as the USA could cause a surge in the price of crude oil through their ability to disrupt production and supplies (Feng et al., 2020; Alola et al., 2022). Additionally, in the event of wars and political unrest in oil exporting nations, geopolitical risk could spiral shock in the oil market and disrupt the oil supply. As observed during the invasion of Kuwait by Iraq in 1990 (United States Energy Information Administration, 2011), heightened geopolitical tension, instability, and systemic corruption especially in oil-exporting countries can interrupt or induce uncertainty in the oil supply, which could lead to an increase in oil prices (Wang and Sun, 2017; Mohsin et al., 2018; Yi et al., 2021; Udemba and Yalçıntaş, 2022).

On the other hand, reliability also stems from oil demand and supply balance. Specifically, a nation that is not oil-producing or cannot produce enough oil within its border would need to ensure that enough imported oil is kept to increase its strategic oil reserves. This is often the policy of oil-importing states to avert devasting effect of potential shock to the oil demand-supply balance that potentially cause oil prices to skyrock (Demirer et al., 2019; Bouoiyour et al., 2019). This investigation shows that an increase in reliability risk, which measures the unavailability of a potent energy system, increases the price of crude oil. This increase in reliability risk could be fueled by uncertainty in the availability of crude oil, which leads to an increase in demand and a spike in the price of crude oil.

The impact of energy expenditures and retail electricity prices on the crude oil price is identical in all the tested models (1–5). Energy expenditure is shown to increase the price of crude oil, as more energy expenditures lead to an increase in the demand for crude oil, thereby mounting pressure on energy supply and consequently increasing energy price. On the other hand, the retail expenditure price is found to exert a negative influence on crude oil prices. This implies that an increase in the price of other substitutes to oil energy such as the electricity price (the price of other goods) plunges the price of crude oil downwards. Therefore, in line with basic economic intuition, an increase in energy expenditures and electricity prices are expected to increase and decrease the price of crude oil commodities.

6. Conclusion and policy recommendations

An evaluation of energy security in the US establishes a benchmark for policy analysis and points out the difficulties in maintaining crude oil prices. This study set out to investigate the impact of energy security risk on crude oil prices in the United States of America using data from 1970 to 2040. The KRLS approach was used for robustness since it beats current machine learning algorithms regarding bias caused by misspecification over statistical judgments. According to the KRLS, energy security risk, economic risk, geopolitical risk, reliability risk, and energy expenditures are positively correlated with the crude oil price. This result confirms that crude oil prices tend to move in the direction of key social, economic, and macroeconomic factors. The result suggests the consideration of these risks by stakeholders so that measures to reduce them can be put in place to ameliorate their effect on crude oil prices. The US can also strengthen their ties with geopolitical zones, especially those of major oil-producing countries, to ensure the stability of its countries. In contrast, environmental risk and retail electricity prices are observed to affect crude oil prices negatively. This implies that an increase in the price of other substitutes of oil energy, such as the electricity price (the price of other goods), will plunge the price of crude oil downwards. Therefore, attention can be directed towards substitutes for oil energy to stabilize crude oil prices. The QR approach was used for robustness to validate the results of the KRLS.

6.1. Policy recommendations

Overall, this study strengthens the idea that as the demand for energy security risk, economic risk, geopolitical risk, reliability risk and energy expenditures increases, there will be an increase in crude oil prices. Therefore, it is pertinent for the US to introduce policies to help abate these risks. For example, the US can further strengthen their diplomatic ties with countries rich in oil production to reduce geopolitical risk. Additionally, this study's findings have several important policy implications for future practice. First, reducing reliance on a single energy source by diversifying the US energy portfolio will enhance overall energy security. Therefore, policymakers must develop risk-reduction methods, policies, and tactics, such as a greater reliance on alternative energy sources, energy diplomacy, diversification, developing regional resources, bettering agreements, and energy-use reduction to mitigate energy security risk. Secondly, policymakers should focus more on economic risk than crude oil price, given the significant cause-and-effect relationship between economic risk and crude oil price. Thirdly, prioritizing environmental risk can considerably reduce greenhouse gas (GHG) emissions in energy-intensive industries like power and transportation and help reduce the price of crude oil by finding more sustainable, long-term energy sources (Obekpa and Alola, 2023).

Additionally, the direction of investment and production operations is determined by geopolitical risk, which is one of the main factors influencing investment decisions. Therefore, techniques for lowering geopolitical risk should be adopted. Additionally, Creating the standards and structures that enable the private sector and the general public to support national energy goals and plans, including lowering entry barriers for innovation and financial investment in energy security, could help stabilize crude oil prices. However, this research has some limitations. Further research into the potential causal connection and connectedness of these risks with crude oil prices are necessary to estimate their net connectedness because causality might change over time. Finally, using data at a higher frequency might yield further valuable insights.

Credit author statement

Andrew Adewale ALOLA: Data curation; Writing & editing and revision; Conceptualization; Formal analysis, and Corresponding. **Oktay Özkan:** Methodology and Formal analysis. **Hephzibah Onyeje OBEKPA**: Writing-review & editing and revision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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