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The effect of energy price shocks on commodity currencies during the war in Ukraine☆

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A B S T R A C T

The ongoing geopolitical crisis that has emerged due to the war in Ukraine has created economic winners and losers. We adopt the DS-ARDL and Cross-Quantilogram approaches to examine the effect of higher energy prices on commodity currencies during this war. Our findings based on 4-h time frame data between January and November 2022 indicate a significant positive effect of energy price hikes on the value of the Australian dollar relative to the Japanese yen, Euro, and British pound. The comparison of the effects of gas and oil price hikes on the exchange rates reveals that these exchange rate movements have been mostly due to gas price shocks. Considering the effects of this war on the international economy, the most critical policy implications to improve the financial health of the economies are provided.

1. Introduction

The ongoing geopolitical crisis that has emerged as a result of the Russian-Ukrainian war has magnified the adverse effects of corona epidemic in both developed and developing countries. In particular, the supply chain disruptions and bottlenecks that have hit many economies at the outset and during the corona epidemic have gained new momentum during the Russian-Ukrainian war, especially after the imposition of various economic sanctions on Russia (including its exports of commodities) and the response of Russia to them. As a result of these developments, the gas, oil, and grain exports of Russia have been severely restricted. And this coupled with the limitations in the grain exports of Ukraine due to prevailing war conditions worsened the global socio-economic stability dramatically. The increase in global inflation in 2022 seems to have been fueled not only by the rising prices of energy, food, and other commodities (caused by aforementioned adverse supply shocks due to war) but also by the expansion in global demand for goods and services which, in turn, has been adding to pressures on commodity prices. The observed increase in the global demand for manufactured goods and services could partly reflect the postponed consumption and investment spending by households and firms, especially during the first year of corona epidemic.

The rising prices of commodities (especially those of gas and oil) are naturally expected to affect different economies in different ways particularly depending on whether or not the economy in question is an exporter or an importer of commodities in general (Krugman, 1983a; Lee et al., 2023a). The macroeconomic impacts of commodity price hikes are likely to manifest themselves (in both exporters and importers) through alternative channels both in the impact period and in the subsequent periods as well. In other words, such shocks have the potential to affect the economies in question dynamically both in the short- and long-run (Golub, 1983; Chen et al., 2018, 2021; Tiwari et al., 2022; Lv et al., 2023).

One critical channel through which commodity price shocks generate macroeconomic effects (on the cost of production, inflation, domestic output, employment, investment, savings, consumption, budget balance, trade balance, economic growth, etc.) is the exchange rate channel. Intuitively one would expect the currencies of commodity-exporting countries to appreciate against other currencies in response to an increase in the global prices of commodities and an increase in their export revenues in the impact period. However, as the experience of certain countries has shown, the medium- and long-term

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macroeconomic effects of such appreciation could vary dramatically between different sectors and regions of the country in question (Krugman, 1983b). For example, if the relative size of the manufacturing sector in domestic output and employment is large enough, then the negative effects of appreciation of domestic currency on the competitiveness of that sector in global markets against foreign rivals can have dramatic contractionary effects on the output and employment in that sector. On the other hand, sectors and regions concentrated on the production and exports of commodities will naturally experience a booming economic adctivity as output, employment and incomes rise due to higher export revenues. In relation to these asymmetric effects of commodity price shocks in different sectors and regions of exporting countries Krugman and Obstfeld (2009) give the example of Canada: following a Canadian dollar appreciation due to a positive commodity price shock in the mid-2000s, while commodity-producing and exporting eastern regions were positively affected, western regions (producing and exporting manufactured products) were adversely affected in terms of falling exports, production, and employment.

If each commodity exporting and importing country can be affected differently depending on its structural characteristics in terms of relative weights of commodity producing and exporting sectors in domestic production and employment as well as in total exports, then the dynamic response of the exchange rate of each country to a given positive commodity price shock could vary depending on the duration of the time period chosen for analysis. Theoretically, there are a large number of factors affecting the exchange rate of the currency of any country. Some of these exert their effects in the short run while others are likely to show their effects in the medium and long term. In the short run changes in interest rates and expectations about the future values of the exchange rates are likely to be the critical factors in determining the direction and magnitude of the changes in currency values (Sarno and Frankel, 2002; Zhong et al., 2022; Abakah et al., 2023). The interest rate parity theorem (in terms of both its uncovered and covered versions) is generally the main theoretical framework through which this short-run association between exchange rates and interest rates and expectations about future exchange rate changes is formulated. However, in the medium term, the changes in the differentials between income growth rates of different countries are likely to affect the values of national currencies against each other.

It is worth noting that the monetary theory of exchange rates and the theory of exchange rates based on trade flows could have opposite predictions regarding the likely impact of changes in income levels on bilateral exchange rates (Salvatore, 2011; Huang et al., 2021; Liu and Lee, 2022; Nie and Lee, 2023). One important distinction between the two theories is the fact that while monetary theory is based on the changes in relative demands for domestic currencies in response to changes in income levels, the latter theory focuses on the changes in the relative demand for foreign exchange as a result of rising imports due to expansion in economic activity and income levels. On the other hand, according to Purchasing Power Parity theorem, the main determinant of bilateral exchange rates, in the long run, are the changes in the relative price levels or the inflation differentials between the countries (Copeland, 2008). Some of the critical factors determining the changes in relative price levels include not only the differences between the monetary growth rates of the countries in question but also changes in relative productivity levels, shifts in domestic and foreign consumers' preferences, and trade restrictions. Furthermore, at a given point in time, the exchange rate of the currency of a country can move under the influence of many of these short-run, medium-run, and long-run factors making it very difficult to identify the main causal factor behind the observed behavior of the exchange rate.

In light of the points raised above determining the causal effect of any possible factor on exchange rates should ultimately be considered an empirical matter. In particular, the qualitative nature of the commodity price hikes on the exchange rates of commodity importing and exporting countries can only be examined through careful empirical analysis, especially in the impact periods during which shocks take place. In this regard, early theoretical work specifically on this issue suggests that there are potential ambiguities (resulting from a variety of factors) regarding the nature of the effects of commodity price shocks on the bilateral exchange rates. Much of the subsequent empirical literature has not been able to shed light on this issue particularly because of the different kinds of weaknesses of the statistical methodologies they employed. Some of these studies and the corresponding methodological deficiencies that limit the reliability of their results are briefly discussed in the next section.

In light of the above discussion, the main motivation of this study is to empirically examine the effect of the changes in the prices of oil and gas (that took place over a certain period after the start of the Russian-Ukrainian war) on the bilateral exchange rates of the Australian dollar (AUD) against Euro (EUR), British pound (GBP) and Japanese yen (JPY). While Australia is a key exporter of various commodities (that include not only gas and some oil but also food and metals such as iron), the Euro Zone (as a block), the UK and Japan are major importers of commodities including gas and crude oil. According to OECD (2021), Australia is the largest exporter of Liquefied Natural Gas (LNG) in the world with an export capacity of 87.6 million metric tons per year, and Japan is the leading export destination for Australia. In addition to LNG, Australia exports both refined petroleum products and crude petroleum to Asian and Pacific countries.

The present study is an attempt to examine the nature of the exchange rate effects of the changes in the prices of gas and oil by applying two relatively new statistical methods to high-frequency data obtained over a certain time period after the onset of the Russian-Ukrainian war in early 2022. These two complementary statistical methodologies are Dynamic Simulated Autoregressive Distributed Lag (DS-ARDL) and Cross-Quantilogram (CQ) approaches and are expected to produce relatively more reliable estimates regarding the true nature of the impact of shocks to commodity prices on exchange rates, especially in the wake of Russian-Ukrainian war.

In comparison to traditional ARDL models, the DS-ARDL approach developed by Jordan and Philips (2018) allows for interpreting the nature of the short-run and long-run effects of changes in the independent variables on the dependent variable relatively more accurately. In using the DS-ARDL method, the explanation of complex lag structure is not required because the output of the analysis is illustrated as a graph. Besides, this method addresses the problem of endogeneity which is often ignored by researchers. The CQ technique also works well in analyzing financial variables (that are usually heavy-tailed) because instead of using usual test statistics for directional predictability, this technique uses quantilogram.

Our CQ analysis compares the response of exchange rates to energy market trends in different quantiles of exchange rates and oil and gas prices. In the other words, it investigates the predictability from energy prices to exchange rates under different market conditions specifically during the bullish (or bearish) states of energy markets. Besides, our DS-ARDL analysis depicts the overall response of exchange rates to energy price hikes over time after a shock to oil and gas prices. Therefore, the CQ and DS-ARDL techniques together can provide a complete picture of the exchange rates-energy prices nexus. Besides our selected dataset help study how this relationship has changed during the war. Moreover, the current study uses high-frequency data obtained at 4-h intervals between January and November 2022 and is expected to further enhance the reliability of the empirical results obtained with the application of these relatively more advanced new methodologies.

Our study contributes to this line of research by employing the above-mentioned complementary techniques and high-frequency data to analyze the effects of war-related energy price hikes on the exchange rates of commodity-exporters and -importers.

The importance of obtaining relatively more reliable estimates about the nature of the effects of commodity price hikes on the bilateral exchange rates of commodity-exporting and importing countries or blocks (such as the Euro Zone, UK, and Japan) cannot be overemphasized. Obtaining reliable estimates about the nature of the likely impact of a given shock to prices of oil or gas on the bilateral exchange rates of AUD against GBP, EUR, and JPY are likely to provide critical information both for international currency traders (or speculators) as well as all other global economic actors in the following sense: (i) Traders in the currency markets will be able to make more informed (buy and sell) decisions in response to (a particularly unanticipated) shock to gas and oil prices. This naturally implies lower risks in terms of potential losses or alternatively higher likelihood of obtaining profits both of which imply higher expected profits from any kind of buy or sell decision taken in response to new information about changes in gas and oil prices. (ii) It will increase the forecasting capacity of both domestic (Australian) and foreign firms and potential investors in terms of not only the overall growth prospects of the Australian economy in the short and long term but also the comparative analysis of the profitability of alternative investment projects for different sectors, particularly in relation to traded goods vs. non-traded goods sectors. (iii) And last but not least it can help the global (foreign) competitors of Australian exporting firms to make more accurate predictions about the likelihood of potential gains (in terms of market penetration) in both global markets (such as China) but also in domestic markets of Australia where they are competing with Australian firms.

The rest of the paper is organized as follows: the next section provides the theoretical background of the present study. Section 3 summarizes not only the main findings of the relevant empirical literature and the shortcomings of the methodologies they applied but also briefly mentions the basic insights of the key theoretical literature. Sections 4 and 5 describe the data and methodology employed in our analysis. The discussion of results is provided in section 6. The last section concludes and provides policy implications.

2. Theory

In this section, we attempt to summarize the critical aspects of the most commonly used approaches and theorems developed in the context of exchange rate determination. We particularly focus on specifying the main variables that are hypothesized to be the main determinants of exchange rates for each case.

Eiteman et al. (2014) classify alternative approaches and theorems into four general categories as follows: The first approach is based on utilizing different kinds of 'Parity Conditions'. The most important ones of these parity conditions include the 'Purchasing Power Parity (PPP)' and 'Interest Rate Parity (IRP)' theorems. The former has two versions known as 'Absolute PPP' and 'Relative (or Dynamic) PPP' theorems. The main hypothesis of the former one is that, under conditions of free trade, the exchange rate between any two currencies (of the given two countries) will always converge to a value (known as the equilibrium level of the exchange rate) that will ensure the equality of the purchasing power of each unit of these two currencies in both countries when these currencies are expressed in terms of a common currency via the exchange rate. And this equilibrium exchange rate is given by the ratio of the domestic country's general price level to that of the foreign country. In the case of the 'Relative PPP' theorem, the prediction is that the rate of change in the exchange rate (of the two currencies) will always converge to its equilibrium rate given by the inflation differential of the two countries. For example, if the inflation rate of the first country is higher than the second one, the currency of the first one will depreciate against the second one at a rate equal to the excess of its inflation over the inflation rate of the second country. In both versions of the PPP theorem (if these parity conditions are violated) the adjustment either in the actual level or the rate of change of exchange rate to their respective equilibrium values will happen through the changes in trade flows (exports and imports) between the two countries. For example, if the inflation in the domestic country rises above that of the foreign country the domestic products will lose competitiveness in both domestic and foreign markets leading to an increase in import demand and loss of export revenue both of which will excess demand for foreign currency causing depreciation of the domestic currency.

On the other hand, 'IRP' condition has three alternative versions known as 'Uncovered', 'Covered', and 'Real Interest Rate' Parity conditions. Under the conditions of perfect capital mobility and risk neutrality of investors, all of these three conditions suggest (both spot and forward) exchange rates continuously adjust to generate equal (expected) rates of returns (either in nominal or real terms) on identically same domestic and foreign assets (such as bonds) when these returns are expressed in terms of a common currency via the exchange rate. The main driving forces of exchange rate movements in these theorems are the changes in the expectations about the future value of the exchange rate and the changes in the prices of assets (bonds) which in turn cause changes in the (expected) relative rates of returns of domestic and foreign assets. For example, an increase in the supply of bonds in the domestic country will decrease their market prices leading to a rise in the rate of interest on such bonds. This in turn causes an immediate capital inflow as investors attempt to sell foreign bonds and buy domestic bonds which is accompanied by the appreciation of the domestic currency. Similarly, expectations of a higher rate of depreciation of domestic currency make foreign bonds more attractive causing capital outflow which leads to actual depreciation of the domestic currency (Copeland, 2008).

The second approach used in explaining the determinants of exchange rates is the 'Balance of Payments' approach. This approach is based on the idea that the driving forces of the supply and demand for currencies in the foreign exchange markets are the changes in the trade flows and capital flows that are reflected in the current account and the financial account of the balance of payments statistics. For example, any improvement in export earnings that leads to an improvement in the current account balance (either by raising the surplus or reducing the deficit) or alternatively any improvement in the financial account balance (for example through additional inflows of portfolio capital investment or foreign direct investment) is expected to cause an appreciation of domestic currency by generating an excess supply of foreign currency in the currency markets.

The third approach known as the 'Monetary Approach' postulates that the exchange rate (between the currencies of two countries) is simply determined by the 'relative money stocks' and 'relative money demands' of the two countries in question. In its original form of this theorem, money demand in each country is assumed to depend only on income level. Another assumption is that the PPP theorem holds continuously so that any increase in the ratio of the general price level of the domestic country to the foreign price level automatically leads to the depreciation of the domestic currency. The increase in the domestic price level can result from an increase in the money supply or a decrease in the demand for money in the domestic country. For example, a decrease in real income (or even expectations of a decrease in income) will lead to falling demand for money. This, in turn, causes an excess supply of money leading to additional spending on goods which brings about an increase in the price level. Higher prices are inevitably accompanied by depreciation of the domestic currency which is necessary to maintain the PPP condition. Another crucial aspect of this model is the implicit assumption about the perfect substitutability of domestic and foreign bonds so that they don't play any role in exchange rate determination. But in the case of the fourth approach known as the 'Assets Markets Approach' domestic and foreign assets (such as bonds) are assumed to be imperfect substitutes. This means that any change in the relative rates of returns between domestic and foreign assets (caused by changes in the relative supplies or demands for such assets) leads to changes in the exchange rates. Therefore, changes in the relative supplies and demands for domestic and foreign assets are the main determinants of exchange rates according to this approach which is also known as 'Portfolio Balance Approach' (Rivera-Batiz and Rivera-Batiz, 1994).

It is worth noting that most (if not all) of these approaches or theorems briefly explained above could not explain the relatively high volatility of exchange rates especially after the adoption of floating exchange rate regimes by an increasingly larger number of countries. And to this end, alternative theoretical models have been developed to explain this phenomenon. The most noteworthy of such models is that of the 'Overshooting model' of Dornbusch (1976). The main assumption of this model is the sluggishness of price adjustment (in the goods market) in response to different kinds of shocks. In contrast, financial markets adjust continuously to clear the markets. For example, a given monetary expansion leads to more than proportionate increase (depreciation) in the exchange rate relative to its new long-run equilibrium value. And this is necessary to maintain the interest rate parity condition satisfied in the sense that (given rational expectations) agents start expecting appreciation of the domestic currency after the initial overshooting of the exchange rate. And as prices start to rise due to expansion in demand for output this leads to rising demand for money which in turn is accompanied by rising interest rates and appreciation of the domestic currency. This process continues until output returns back to its initial level and price level and exchange rate converge to their new long-run equilibrium values. The proportionate increase in price level and the exchange rate are exactly the same as the initial percentage increase in the domestic money stock.

The theorems or approaches that we have summarized above naturally provide a general perspective regarding how one should think about the main factors responsible for the movements in exchange rates. In particular, they do not specifically focus on the impact of a variety of individual variables that can drive the changes in the general variables that these theorems or approaches specify as the main determinants of exchange rates. One of these individual variables that can directly or indirectly affect these general variables in these theorems or approaches is the oil/gas (energy) prices. We present the basic insights of selected theoretical literature that specifically attempt to link the oil/gas prices to exchange rates in the next section.

3. Literature review

Krugman (1983a, b) and Golub (1983) provide two of the earliest theoretical work on the subject of the impact of oil price shocks on the exchange rates. However, it needs to be underlined the fact that both of these studies represent an attempt to analyze the possible effects of shocks to the price of oil (which was assumed to be produced exclusively by OPEC) on the bilateral exchange rates of the currencies of oil-importing countries such as US, Germany and the UK. The models developed in these studies show how ambiguous the nature of the exchange rate effects could be depending on specific assumptions about oil-importing and -exporting countries. The degree of ambiguities dramatically increases once one takes into account the fact that exchange rate is affected not only by the corresponding changes in trade flows between oil exporting and importing countries (which in turn change the relative demands and supplies of the currencies involved) but also the change in the relative demand for the assets of oil importing countries by the oil exporting countries following a shock to price of oil. This becomes a critical source of ambiguity, particularly when the oil-exporting country saves at least some part of the additional export revenues (earned as a result of an increase in the price of oil) and uses these extra savings to invest in the assets of oil importing countries. If they do not save at least some part of the extra income but spend it on foreign goods (produced by oil importers) then the differences between the marginal propensities to import of the exporter from oil-importing countries and the respective shares of oil-importing countries in total imports (of the exporting country) are critical in determining the nature of the change in the bilateral exchange rates not only between the currencies of oil importers but also between the oil-exporting country's currency and the respective currency of each oil importing country. Same kind of ambiguity results in case the oil-exporting country decides to save all of the extra income following an increase in the price of oil and invest all of this extra savings in the assets of oil importers. If the resulting capital outflow (from oil exporting country) is accompanied by the increase in the relative demand for the assets of one country (as opposed to other) then the exchange rate of the currency can appreciate not only against the currency of the other oil importer but also against the currency of the oil exporting country. In addition to these factors, the work of Krugman (1983a a,b) and Golub (1983) point out that differences in the price elasticity of demand for oil in importers and the ease with which domestic firms and residents of these countries can substitute other sources of energy in place of oil or gas could be critical in determining the nature of the exchange rate effects of shocks to oil or gas prices.

The subsequent theoretical work by Amano and Van Norden (1998a, b) suggests another channel (namely terms of trade channel) through which the effect of oil price shocks can transmit to exchange rates. His theoretical framework is based on a two-sector model of the economy in the form of traded goods and non-traded goods sectors. Each sector uses energy as input in the production process. But the sector that uses energy relatively more intensively naturally experiences a relatively larger increase in the unit cost of production following a positive shock to oil prices. In case the traded goods sector is a relatively more intensive user of energy in its production, the relative price of traded goods (against non-traded goods) rises. However, since the international (dollar) price of traded goods is constant, this inevitably leads to a relatively larger depreciation of the domestic currency in response to a given rise in the price of oil.

A relatively more recent study by Ready (2018) focuses on examining empirically the degree of correlation between stock market returns and oil prices for which simple regression results show almost zero correlation over the period 1986–2011. Ready proposes and uses an innovative method to differentiate the oil price changes resulting from demand and supply side factors. He shows that while stock market returns are positively correlated with the increases in oil prices caused by rising demand for oil, they are negatively correlated in case oil price increases are caused by adverse shocks to supply of oil. Furthermore, his empirical results show the specific kinds of firms whose stock market returns are more likely to be affected positively in case of demand versus supply-driven oil price increase. Even though this study is about the impacts of oil price shocks on stock market returns, nevertheless it provides critical insights about the potential sources of additional ambiguities regarding the nature of the effects of any kind of commodity price shock on exchange rate.

Numerous studies investigate the effect of energy prices on financial markets (e.g., Lee and Lee, 2023; Liu et al., 2023; Lee et al., 2022a,b; Lee and Wang, 2022; Yahya and Lee, 2023; Zhang et al., 2023). More specifically, some studies explore the effect of changes in oil prices on the composition and volume of trade between oil-exporting and oil-importing countries (e.g., Chen and Rogoff, 2003; Zhao et al., 2021; Sokhanvar and Sohag, 2022; Sohag et al., 2022; Lee and Hussain, 2023). Buetzer et al. (2012) and Wang et al. (2022) have produced statistical evidence of the appreciation of the currencies of oil-exporting countries in response to a positive shock in oil prices. And this has been shown to be accompanied by the worsening of trade balances and depreciation of the domestic currency of oil-importing countries (Sokhanvar and Bouri, 2023; Fratzscher et al., 2014). Shang and Hamori (2021), Shankarnarayan and Ramakrishna (2021), Yıldırım et al. (2022), Hashmi et al. (2022), Baek (2023), and Kumeka et al. (2022) are other recent empirical studies that focus specifically on the Forex market and report a significant relationship between energy prices and exchange rates.

The empirical literature that examines the link between exchange rates and energy prices has employed alternative methodologies. In general, these methodologies fall into either one of the following three classes. First, application of vector autoregression (VAR) models or cointegration or causality tests. Some studies such as Brooks (2014) argue that these methods are not suitable for the analysis of time series on the grounds that they are unable to show not only the nature (sign) of the detected effect between variables but also the duration of time it requires for the corresponding effect to take place. The second class of methodologies is known as GARCH (Generalized Auto-Regressive Conditional Heteroskedasticity) type of methodologies. This methodology has been particularly used for analyzing the impact of volatilities in energy prices on currency markets as well as others. And the third kind of methodology is called ARDL (Autoregressive Distributed Lag) models which have been used to investigate the effects of movements in the prices of different sources of energy on exchange rates. As pointed out earlier in the first section, Jordan and Philips (2018) underline the potential shortcomings of ARDL type of models that result particularly from their inherently complex specifications (structure), the empirical estimates obtained from these models are very difficult to interpret in terms of the estimated effects of explanatory variables on the dependent variable. In what follows we report the findings of the selected literature for each type of methodology.

Among the studies that have applied the first type of methodology, some of the most noteworthy ones include Lizardo and Mollick (2010), Bouoiyour et al. (2015), Zhang et al. (2016), Beckmann and Czudaj (2013), Sadorsky (2000), and Sari et al. (2010). The first three of these studies report that there exists a causal effect of energy prices on exchange rates. On the other hand, the results of Beckmann and Czudaj (2013) suggest the presence of a bi-directional causal relationship between energy prices and exchange rates. In addition, based on their findings they report that oil price hikes granger cause depreciation of the US dollar. The analysis of Sadorsky (2000) is based on a cointegration test which shows that prices of energy and exchange rates are cointegrated and shocks are transmitted from energy prices to exchange rates and not from exchange rates to energy prices. On the other hand, Sari et al. (2010) examine the same relationship using VAR analysis but their results do not show any kind of significant evidence of a link between exchange rates and energy prices. It is worth noting the finding of Fratzscher et al. (2014) in relation to the possibility of varying degrees of correlation between exchange rates and energy prices between different episodes of financial conditions such as crisis versus non-crisis periods. Using a VAR model, they show that during times of financial crisis (worsened financial stability) the degree of correlation between the two variables diminishes.

As noted before, the causality and cointegration tests and VAR models suffer from a common deficiency in the sense that they cannot reveal the nature (or sign) of the relationship between the variables in question. In addition, they do not tell much about the extent of the time period over which the detected effects last. There has been some attempt to overcome at least some of the limitations of these methods by certain researchers by applying variance decompositions and/or impulse responses function to identify relatively more accurately the nature of the response of a variable to shocks to other variables specified in the model (e.g. Diebold and Yilmaz, 2012; Coudert et al., 2011; Lee et al., 2023b). But again, these methods have their own limitations in the sense that their results are likely to be dependent on the number of variables included in the VAR model; as a result, the estimation results obtained from them are also likely to have limited reliability.

The second type of methodology used to study the presence or absence of an association between energy prices and exchange rates has been the GARCH type of methodology. Most of the time this methodology has been used to estimate the effects of volatilities in energy prices on currency markets and the volatilities in exchange rates on markets for energy. One of the studies in this regard is that of Ding and Vo (2012) who analyze the nature of the interaction between oil markets and foreign exchange markets by applying the multivariate GARCH method which allows them to forecast the future volatilities in both markets. Their major finding is that while the latter model is superior in predicting the volatility of exchange rate, the former model yields relatively more accurate outcomes in forecasting the volatilities in oil prices. A study by Tian and Hamori (2016) examines specifically the extent of spillover effects of volatilities from one market to another and the transmission of time-varying price shocks from commodity markets to currency markets. Their results suggest that the effects of such shocks on exchange rate volatility in currency markets take place gradually over time. In relation to transmission of volatilities between markets, Anjum (2019) produced evidence of transmission from energy prices to exchange rates in the presence of structural breaks. This result is obtained by the application of bivariate and univariate GARCH models. By the application of a variant of GARCH methodology known as VAR-BEKK-GARCH (which is specifically used for forecasting), Ahmed and Huo (2020) produce (statistically significant) evidence of the existence of a dynamic link between returns and volatility of currency and energy markets. However, it needs to be underlined that one of the major deficiencies of the GARCH type of models is the fact that they are inherently symmetric in the specification of volatility models. And this automatically means that these models are unable to detect any kind of asymmetry in the behavior of foreign exchange markets (or financial markets in general) or the possible quantile dependence between different variables.

As stated earlier some researchers investigating the nature of the interaction between energy prices and exchange rates have applied a third type of methodology known as ARDL type of models. One of such studies is Singhal et al. (2019) which focuses on the case of Mexico. This is a peculiar (country) case study because Mexico is both exporter and importer of energy in different forms; while it exports crude oil to other countries at the same time it imports refined petroleum products. The empirical results of this study suggest that in the long run increases in oil prices are associated with negative (in the sense of depreciation) effects on the exchange rate of Mexican currency. The empirical results of Baek and Kim (2020) show evidence of similar negative impacts of an increase in the volatility of oil prices on the exchange rates of sub-Saharan countries both in the short-run and long-run. This study employed a variant of ARDL models known as non-linear ARDL method to examine the relationship between the volatility of oil prices and the exchange rates of the domestic currencies of the African countries included in their sample. However almost all variations of ARDL models suffer from one common weakness; due to the fact that they are relatively complex models in the sense that their structure not only includes the contemporaneous and lagged values of the dependent and independent variables but also their first differences, it is not easy to interpret both the short-run and long-run effects of the regressors (Jordan and Philips, 2018).

One common feature of all the studies that are listed above (regardless of the type of their methodology) is the fact that their sample periods correspond to periods prior to the start of the Ukraine- Russia war which has led to dramatic supply disruptions not only in gas and oil markets but also in other commodities (particularly grains) as well. This is a critical point in the sense that as Kilian (2009) and Ready (2018) show the impact of changes in commodity prices in general (and energy prices in particular) on financial markets (such as stock and currency markets) could vary depending on whether the rise in commodity (energy) prices is demand-driven or supply driven. This fact forms one of the main motivations of the present study which attempts to examine the nature of the impact of the energy prices (particularly those of gas and oil) on the bilateral exchange rates between energy-importing countries (or a block of countries) and a selected case of one energy exporting country namely Australia by using high-frequency data that pertain to the period after the beginning of Russian-Ukrainian war in the early months of 2022. The fact that this period represents an episode of major supply disruptions in terms of energy for many industrialized countries or blocks of countries such as the Euro Zone, UK, and Japan, and Australia being one of the major exporters of LNG type of energy (besides oil and other commodities) in the world, it is expected that the present study can reveal interesting insights about the true nature of the impact of energy prices on the bilateral exchange rates between the currencies of importers and the exporters of energy. One important aspect of the current study that differentiates it from most (if not all) of the past studies is the fact that it employs a relatively new methodology known as CQ type of method in addition to the DS-ARDL method. The CQ approach is expected to overcome most of the deficiencies associated with the three methodologies employed by most of the literature that is briefly discussed earlier in this section. One critical property of the CQ method is the fact that it provides a much more comprehensive analysis of the nature of the links between the series in different quantiles; this in turn allows to detect the presence or absence of directional predictability between the series of data.

4. Data

We adopt 4-h-timeframe data on crude oil and gas prices and three exchange rates including AUD/JPY, EUR/AUD, and GBP/AUD from 2022-01-03 to 2022-11-01, the interval of the rise of conflicts between Russia and Ukraine. The percentage change in natural gas and crude oil price relative to the 3rd of January 2022 is illustrated in Fig. 1. The graphs show how sanctions on Russia's energy exports have led to energy price hikes after the start of the war in February 2022. Fig. 2 shows the percentage change in AUD/JPY, EUR/AUD, and GBP/AUD exchange rates relative to the 3rd of January 2022. The increase in the value of AUD relative to EUR, GBP, and JPY since March 2022 is remarkable.

The return on each of the values of the series is calculated by using Equation (1). The return series will be used in the CQ analysis in the next step. The ERS unit root test based on Elliott et al. (1996) is employed to identify the integration order of variables. The unit root test results in addition to the descriptive statistics of the dataset are provided in Table 1. The results show that all series are stationary.

$$Return\ (x)_t = \frac{x_t - x_{t-1}}{x_t} \times 100 \tag{1}$$

5. Methodology

This study applies the dynamic simulated autoregressive distributed lag (DS-ARDL) model as a complement to the Cross-Quantilogram (CQ) approach to model how war-related energy price hikes have affected the exchange rates.

5.1. CQ

The CQ technique suggested by Han et al. (2016) is employed in this study to examine the existence of predictability from one series to another. Compared to the techniques employed in the literature on predictability, this technique has some advantages. First, instead of using usual test statistics for directional predictability, this technique uses quantilogram which is conceptually easy to interpret. Second, financial time series are usually heavy-tailed (Ibragimov et al., 2009; Yahya et al., 2023). Therefore, the statistical tests defined based on the normal distribution assumptions can rarely provide accurate results in studying financial datasets. The CQ technique works well for heavy-tailed variables because it uses quantile hits and doesn't need to identify moment conditions.

Equation (2) presents the magnitude of serial dependence between two events $\{X_{1t} \le q_{1t}(\tau_1)\}$ and $\{X_{2t-k} \le q_{2t-k}(\tau_2)\}$. In this equation, $\varphi_a(u) \equiv 1[u < 0] - a$ and $q_{it}(\tau_i)$ is the corresponding quantile function for $\tau_i \in (0, 1)$. $X_{i,t}$ denotes stochastic stationary processes. i is 1, 2, or 3, representing exchange rate and gas or oil prices. t denotes time ($t = 1,2, \ldots$T), and k shows the lag lengths ($k = \pm1, \pm2$) for a specific pair of $\tau = (\tau_1, \tau_2)'$.

$$\beta_\tau(k) = \frac{E[\varphi_{\tau_1}(X_{1t} - q_{1t}(\tau_1))\varphi_{\tau_2}(X_{2t-k} - q_{2t-k}(\tau_2))]}{\sqrt{E\left[\varphi_{\tau_1}^2(X_{1t} - q_{1t}(\tau_1))\right]}\sqrt{E\left[\varphi_{\tau_2}^2(X_{2t-k} - q_{2t-k}(\tau_2))\right]}} \tag{2}$$

The CQ approach measures the serial dependence between variables and remains unchanged when any monotonic transformation is applied to series. $\beta_\tau(k) = 0$ means no cross-sectional dependence from the event $\{X_{2t-k} \le q_{2t-k}(\tau_2)\}$ to event $\{X_{1t} \le q_{1t}(\tau_1)\}$. The Box–Ljung test is used to estimate the statistical significance of $\beta_\tau(k)$. Equation (3) defines the test statistic:

$$Q_\tau^*(p) = T(T+2)\sum_{k=1}^{p}\widehat{\beta}_\tau^2(k) \,/\, (T-k) \tag{3}$$

The cross-quantilogram $\widehat{\beta}_\tau(k)$ in equation (3) can be obtained by using equation (4).

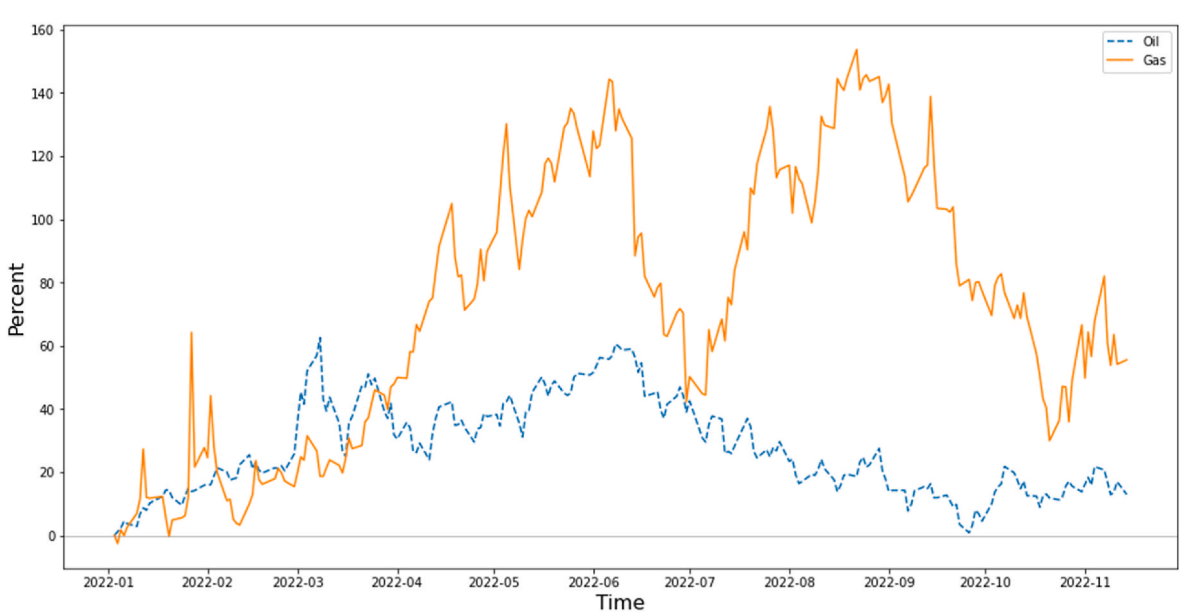

Fig. 1. Percentage change in gas and oil prices relative to their value on 2022-01-03.

Fig. 2. Percentage changes in AUD/JPY, EUR/AUD, and GBP/AUD exchange rates relative to their value on 2022-01-03.

Table 1
Descriptive statistics and unit root test results.

	Count	Mean	Median	Standard Deviation	Kurtosis	Skewness	Minimum	Maximum	ERS
AUD/JPY	1260	90.8325	92.8305	4.8006	−0.7396	−0.8535	80.6350	98.2870	
EUR/AUD	1260	1.5082	1.4950	0.0442	−0.7927	0.5639	1.4318	1.6178	
GBP/AUD	1260	1.7766	1.7604	0.0619	−0.2615	0.7848	1.6530	1.9155	
Gas	1260	6.6313	6.7175	1.6725	−1.2080	−0.0500	3.7170	9.6800	
Oil	1260	97.1833	95.2500	11.4723	−0.8758	0.3188	76.0800	123.7000	
Return on AUD/JPY	1259	0.0006	0.0005	0.0079	−0.0453	0.0734	−0.0219	0.0237	−5.277***
Return on EUR/AUD	1259	0.0000	−0.0007	0.0064	0.5156	−0.0721	−0.0251	0.0159	−4.411***
Return on GBP/AUD	1259	−0.0001	−0.0006	0.0060	3.6517	0.3902	−0.0246	0.0300	−4.164***
Return on Gas	1259	0.0044	0.0049	0.0635	13.8323	1.3891	−0.2595	0.4648	−7.067***
Return on Oil	1259	0.0011	0.0034	0.0314	1.0011	−0.3856	−0.1213	0.0835	−5.120***

Notes.
Return on series is the percentage change of each value relative to the previous value.
ERS is Elliott et al. (1996) unit root test statistic.
*** shows the rejection of the null hypothesis at 1% level of significance.

$$\widehat{\beta}_{\tau}\left(\mathrm{k}\right)=\frac{\sum_{t-k+1}^{T}\varphi_{\tau_1}(X_{1t}-\widehat{q}_{1t}(\tau_1))\varphi_{\tau_2}(X_{2t-k}-\widehat{q}_{2t-k}(\tau_2))}{\sqrt{\sum_{t-k+1}^{T}\varphi_{\tau_1}^2\left(X_{1t}-\widehat{q}_{1t}(\tau_1)\right)}\sqrt{\sum_{t-k+1}^{T}\varphi_{\tau_2}^2(X_{2t-k}-\widehat{q}_{2t-k}(\tau_2))}} \tag{4}$$

where $\widehat{q_{it}}(\tau_i)$ represents the estimated quantile function.

5.2. DS-ARDL

The DS-ARDL technique suggested by Jordan and Philips (2018) is used in our study to produce models of the responses of exchange rates to energy price hikes. This approach can simulate the impact of shocks in any of the independent variables and allows us to interpret the nature of the short- and long-run effects of changes in the independent variables on the dependent variable more accurately. The main reason for the relative inferiority of standard ARDL models is the fact that they include not only multiple lags and first differences but also lagged first differences of the variables in the dynamic specifications. These features make it very difficult to interpret the true nature of the effects of each explanatory variable on the dependent variable. DS-ARDL method is expected to overcome this problem through visualization of the impact of a shock to each explanatory variable on the dependent variable.

Equations (5) and (6) represent the DS-ARDL (p, q, r) models considered in this study.

$$Ln\_ER_t=\sum_{j=1}^{p}\varphi_j Ln\_ER_{t-j}+\sum_{j=0}^{q}\theta_j Ln\_OP_{t-j}+\varepsilon_t \tag{5}$$

$$Ln\_ER_t=\sum_{j=1}^{p}\varphi_j Ln\_ER_{t-j}+\sum_{j=0}^{q}\theta_j Ln\_GP_{t-j}+\varepsilon_t \tag{6}$$

where ER_t is the exchange rate, OP_t is oil price, GP_t is gas price, ε_t is the error term and φ_j is the autoregressive parameter

6. Results

6.1. Results of CQ analysis

The responses of exchange rates to gas and oil price movements are analyzed by employing the CQ approach and the results are illustrated in Figs. 3 and 4. In these figures, positive and negative effects are illustrated by blue and red cells respectively; the vertical and horizontal axes indicate the quantiles of energy prices and exchange rates respectively; the asterisk (*) indicates significance at 5% level.

In Fig. 3, heatmap A shows that higher oil prices have a negative

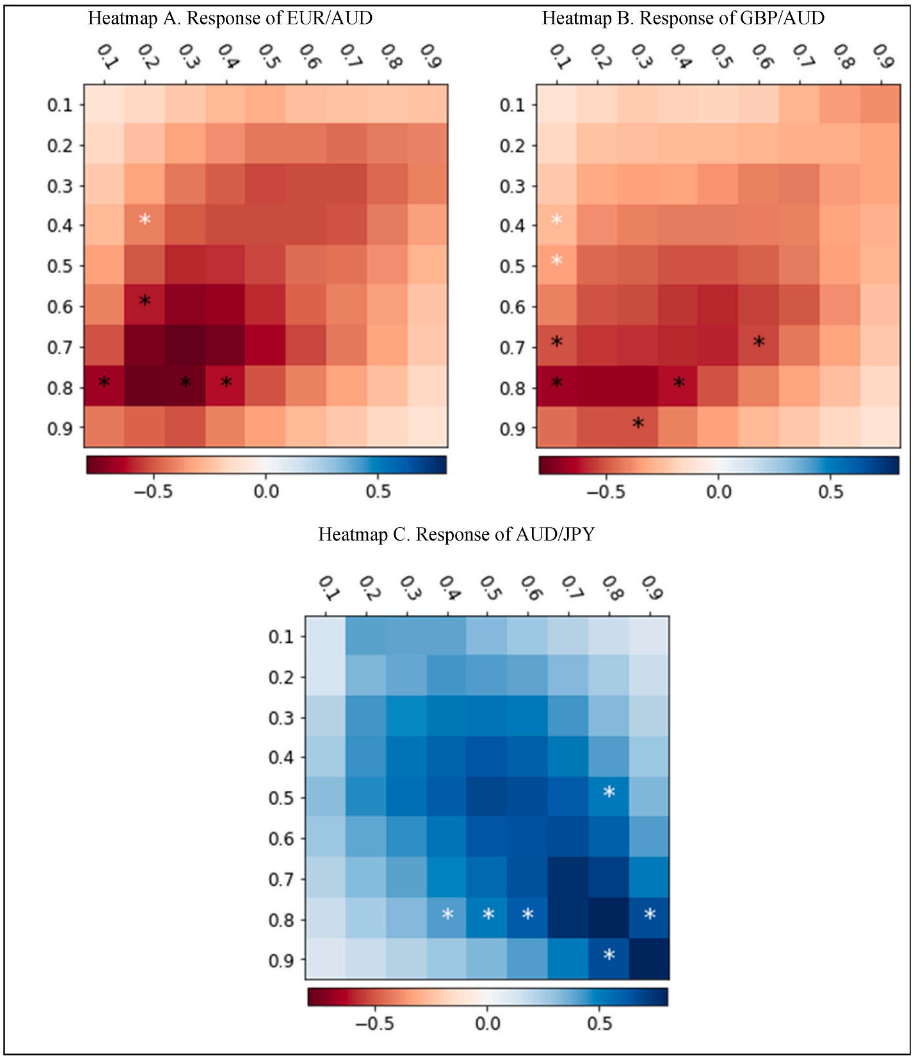

Fig. 3. Effect of a positive oil price shock on the exchange rates.
Notes: Positive and negative effects are illustrated by blue and red cells respectively. The vertical and horizontal axes indicate the quantiles of energy prices and exchange rates respectively; Asterisk (*) indicates significance at 5% level.

effect on EUR/AUD in 0.4–0.8 quantiles of oil price and 0.1–0.4 quantiles of EUR/AUD. Heatmap B indicates that higher oil prices have a negative effect on GBP/AUD in 0.4–0.9 quantiles of oil price and 0.1–0.6 quantiles of GBP/AUD. Heatmap C shows that higher oil prices have a positive effect on AUD/JPY mostly in 0.8–0.9 quantiles of oil price and 0.4–0.9 quantiles of the AUD/JPY.

In Fig. 4, heatmap A shows that higher gas prices have a negative effect on EUR/AUD in 0.2–0.9 quantiles of gas price and 0.1–0.8 quantiles of EUR/AUD. Heatmap B indicates that higher gas prices have a negative effect on GBP/AUD in all quantiles of gas price and 0.1–0.9 quantiles of GBP/AUD. Heatmap C shows that higher gas prices have a positive effect on AUD/JPY in 0.1–0.8 quantiles of gas price and 0.1–0.7 quantiles of AUD/JPY.

The comparison of the effects of oil and gas price hikes on the exchange rates in Figs. 3 and 4 reveals that depreciation of EUR, GBP, and JPY relative to the Australian dollar has been mostly due to gas price shocks.

Our empirical results on the significant responses of exchange rates to an increase in energy prices are consistent with recent empirical research that utilized quantile-based techniques. For instance, the results of Sokhanvar and Lee (2022) based on CQ analysis and Sokhanvar and Bouri (2023) based on quantile regression analysis show the depreciation of the currency of energy importers against the currency of energy exporters due to energy price hikes.

6.2. Results of DS-ARDL analysis

The simulations of the effects of energy price hikes are presented in Figs. 5 and 6. In these figures, time = 10 is the moment of occurrence of shock. Dots display the average predicted values, and shaded lines (from darkest to lightest) indicate the 75%, 90%, and 95% confidence intervals.

Fig. 5 illustrates the impacts of two standard deviations positive shock to oil prices on the exchange rates. The shock decreases both EUR/AUD and GBP/AUD exchange rates and increases AUD/JPY. Fig. 6 illustrates the impacts of two standard deviations positive shock to gas prices on the exchange rates. The shock decreases both EUR/AUD and GBP/AUD exchange rates and increases AUD/JPY. The effects of oil and gas prices are significant at 10% and 5% levels respectively.

The comparison of the results in Figs. 5 and 6 reveals that the depreciation of EUR, GBP and JPY relative to the Australian dollar has been mostly due to the gas price shocks. This could be due to the dominance of gas in Australian exports. This country is the largest exporter of LNG in the world and is obviously benefited from gas price hikes during the war in Ukraine.

The ongoing geopolitical crisis that has emerged due to the war in

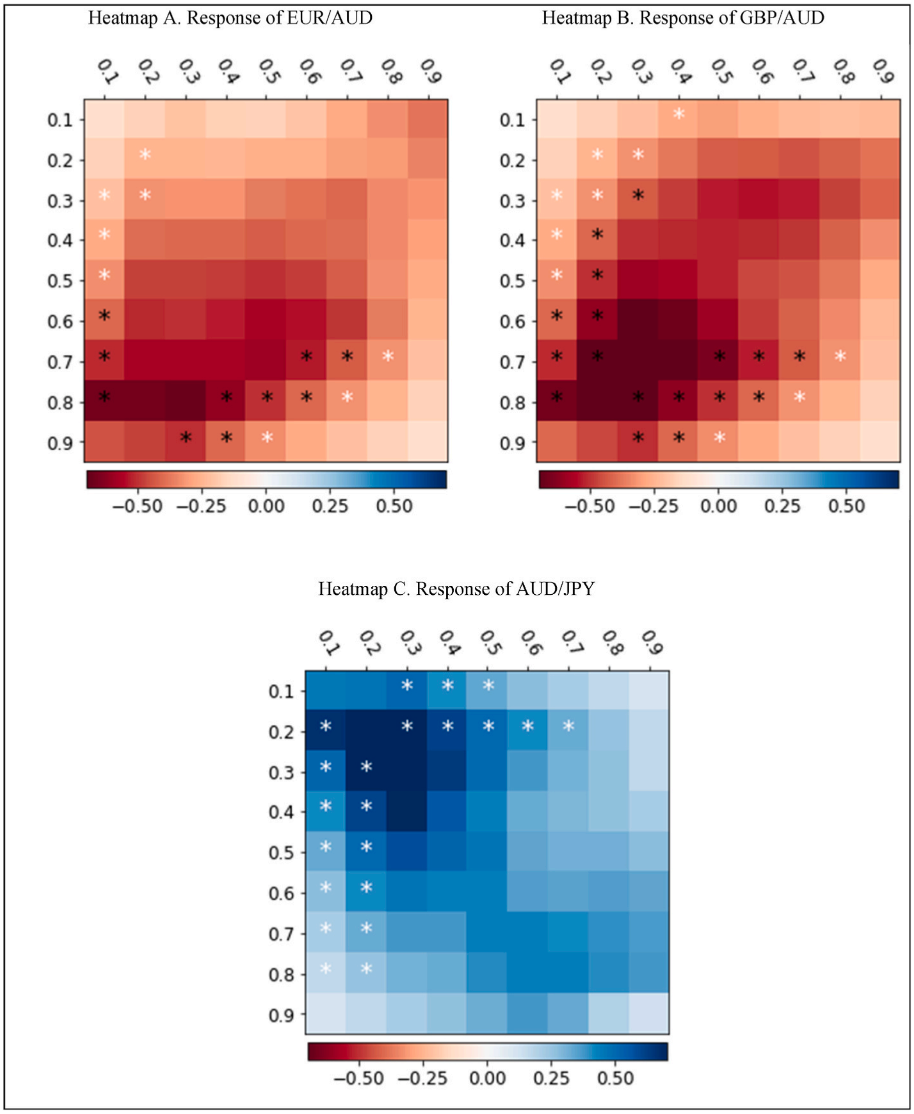

Fig. 4. Effect of a positive gas price shock on the exchange rates.
Note: See the notes to Fig. 3.

Ukraine has magnified the adverse effects of COVID-related supply chain disruptions. The supply Bottlenecks have worsened especially after the imposition of various economic sanctions on Russia (including its exports of commodities) and the response of Russia to them. These developments have severely restricted the energy exports of Russia, pushed up prices, and added to inflation. Japan and European economies are highly affected by this inflation as they are importers of energy and therefore their local currencies are depreciated. In comparison to the EU, the UK has fewer direct economic links to Russia. However, the war could still have a crucial effect on the UK economy. In 2019, the UK imported around 13 percent of its total fuel from Russia. Besides, disruptions in the supply of energy to Europe affect wholesale prices in the UK.

On the other hand, Australia is the key exporter of commodities where Ukraine and Russia are the main exporters. Energy exports of Australia hit a record high because this war sparked a rebound in this economy's trade surplus. Fig. 2 shows how AUD has appreciated due to the commodity price hikes in 2022. All of these facts are well depicted in the findings of the present study that confirm the AUD appreciation relative to EUR, GBP, and JPY due to higher energy prices.

6.3. *Robustness check*

Theoretically, there is a strong relationship between exchange rates and stock markets (Branson, 1983; Frankel, 1983; Wan and Lee, 2023). To check the robustness of our results, in this section, we use the daily return on Australian stock market index as a control variable and use the partial CQ to estimate the predictabilities from energy prices to exchange rates. The robustness check results presented in Appendix A (Figures A1 and A2) are consistent with the main results presented in Figs. 3 and 4. The heatmaps estimated in these figures confirm first, the appreciation of AUD relative to EUR, GBP, and JPY due to the energy price hikes and second, the dominance of gas price hikes in the exchange rate movements.

7. Conclusions and policy implications

The war in Ukraine and economic sanctions against Russian exports in 2022 have had an outsized impact on the global supply chains and caused energy prices to reach their highest level since 2013. Although prices peaked in 2022, they are expected to remain higher than previous projections. In this situation, commodity currencies such as the Australian dollar may appreciate as Australia is a key exporter of

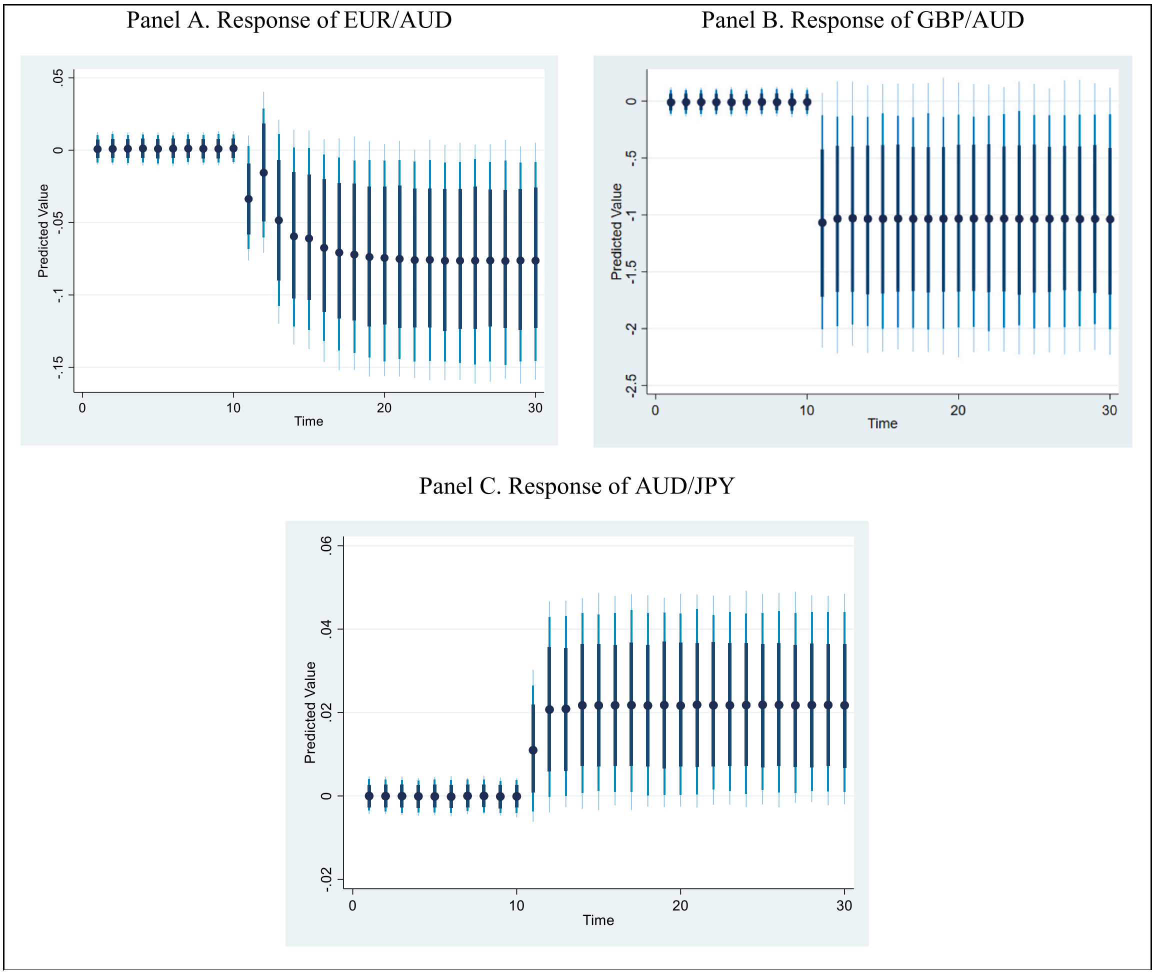

Fig. 5. The effect of a positive oil price shock on the exchange rates.
Notes: Time = 10 is the moment of occurrence of shock. Dots display the average predicted values, and shaded lines (from darkest to lightest) indicate the 75%, 90%, and 95% confidence intervals.

commodities where Ukraine or Russia are the main exporters.

This study constitutes the first attempt to empirically investigate the effects of the war-driven energy price hikes on the depreciation of major currencies relative to the Australian dollar. Our findings based on the Cross-Quantilogram and DS-ARDL techniques depict how energy price hikes during the war affect the foreign exchange market.

Our findings indicate a significant relationship between energy price hikes and exchange rate movements. The war-driven energy price hikes lead to the appreciation of the Australian dollar relative to the Japanese yen, Euro, and British pound. While Japanese and European economies (as importers of raw materials and energy) are affected negatively, the Australian economy gains from the conflicts as the war may cause a commodity crisis across the globe. The Australian trade balance has never looked better even in comparison with the mining boom of 2010, and another mining boom could be on the way for Australia.

The empirical findings of this research have critical implications for investors and policymakers. Our results imply that war-related uncertainties in energy markets can immediately be transmitted to the foreign exchange markets. It subsequently reshapes global trade and investment because companies reassess geopolitical risks and move production away from riskier countries. The war came at a difficult time for the Japanese and European economies. They were just recovering from the COVID crisis and now the war-driven disruptions add to price pressures and curb growth. Besides, depreciation of their domestic currency drives inflation even higher.

The recent policy responses in European countries have been focused on subsidies, price controls, and more restrictions on trade with Russia that have exacerbated shortages. Comparing the present episode with previous commodity price hikes could be helpful in designing optimal macroeconomic policies. Previous energy price hikes caused reduced demand through the substitution of other types of energy and efficiency improvements as well as the emergence of new supply sources. Therefore, decision-makers have to focus on investment facilitation for new sources of zero-carbon energy and encourage improvements in energy efficiency.

Our empirical results also suggest that forex traders must be mindful of the role of energy price shocks in volatilities in the foreign exchange market. In the case of oil and gas price hikes, betting against the British pound, Euro, and Japanese yen and at the same time investing in commodity currencies such as the Australian dollar can be profitable. Simply put, buying AUD/JPY and selling EUR/AUD and GBP/AUD are the best trades in the case of surging energy prices.

The findings of our study are likely to have critical implications for domestic (Australian) firms and foreign firms which are exporting not only to Australia but also to other countries where they compete with Australian firms, particularly in relation to manufactured products. The finding that hikes in energy prices are likely to lead to the appreciation of the Australian dollar (against the currencies of three countries or block all of which are not only commodity importers but also manufacturing-based exporters) suggests that Australian firms that are

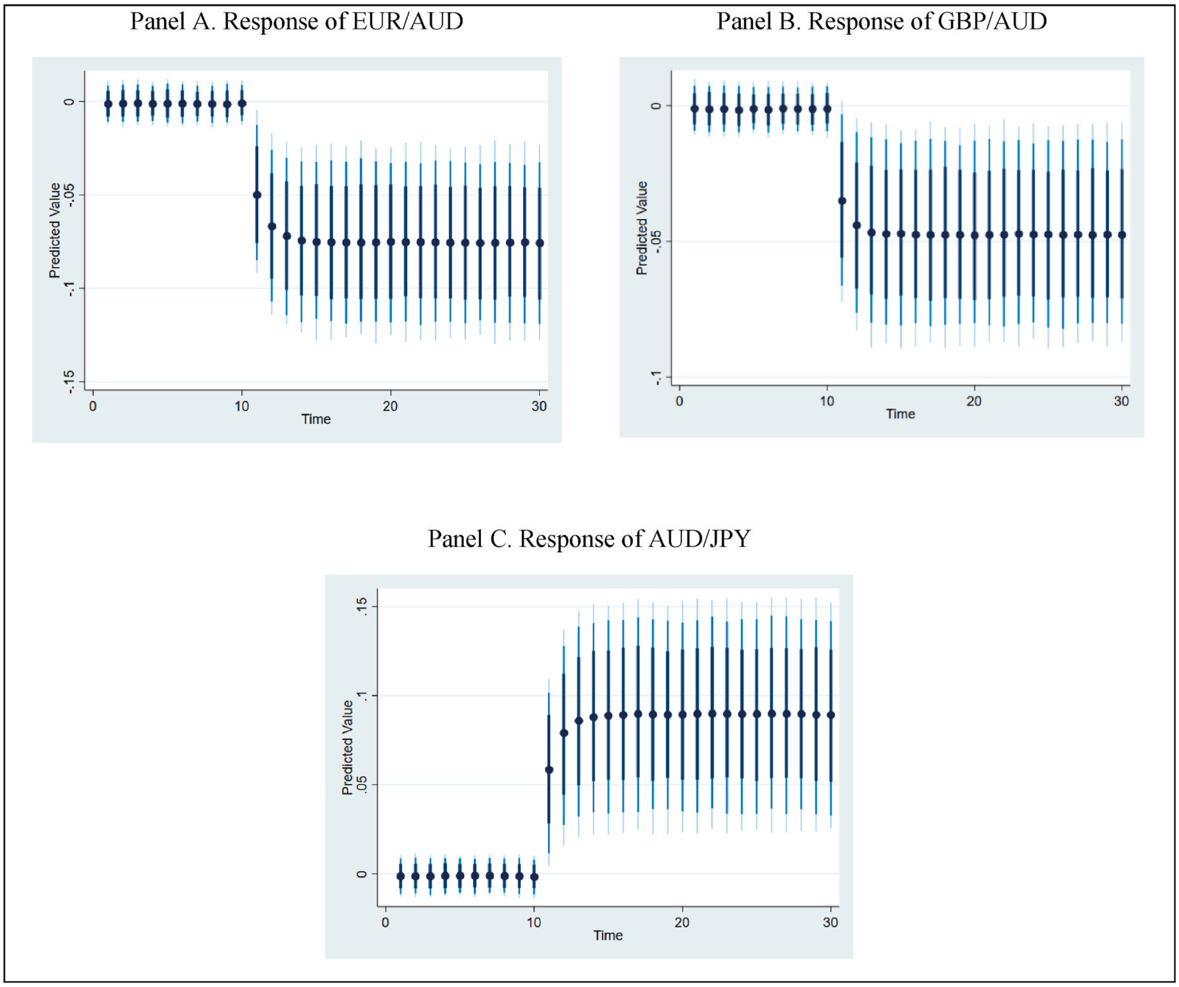

Fig. 6. The effect of a positive gas price shock on the exchange rates.
Note: See the notes to Fig. 5.

producing exportables or import substitutes are likely to lose competitiveness both at home and their foreign export markets against foreign rivals. In contrast, foreign firms exporting to Australia and the domestic importers of foreign products are likely to expect rising market shares and profits in the domestic market. Similarly, those Australian firms which use intensively foreign (imported) products are likely to expect higher profitability due to lower (domestic currency) costs of production. To the extent that the managers of these domestic and foreign firms expect the given hikes in energy prices and the resulting appreciation to be relatively persistent, they can benefit from planning to either expand or downscale their operations. Domestic firms producing (non-energy) traded goods (such as manufactured products) either for home or export markets can find it rational to downscale or even cancel the new planned investment projects. In contrast, the managers of foreign firms (especially those from the UK, EU, and Japan) exporting to Australia or to other foreign markets (such as China where they are competing with Australian firms) can find it profit maximizing to consider expanding the scale of their operations or their planned investment projects.

The empirical results of the present study have some interesting implications in terms of the validity of the alternative approaches or theorems that have been briefly discussed in section 2. The fact that the price hikes in oil/gas prices have been found to be associated with the appreciation of the Australian dollar against the currencies of three of the major energy importers lends support, particularly to the 'Balance of Payments Approach' which predicts that changes in trade flows and/or capital flows are the main driving force of movements in exchange rates. In this case, higher export earnings of Australia resulting from the rise in oil/gas prices seemed to have caused an excess supply of currencies (of particularly energy importing countries) relative to the supply of the Australian dollar in foreign exchange markets leading to the appreciation of the Australian dollar. Having said this it is worth noting that the long-run effects of this appreciation (if it persists sufficiently long time) on the main non-oil/gas producing traded goods sectors (such as manufacturing) in terms of their output, employment, and export earnings may not be that positive. In light of this, we can say that practitioners that are particularly involved in forecasting currency values may be better off to use the 'Balance of Payments Approach' for short and medium-term forecasting and not for long-term forecasting.

At the time of conducting our analysis, the data was only available for less than 10 months after the start of the war in Ukraine. As the war is still going on, it is not possible to talk about the overall effects of the war-related commodity crisis on the world economy. Passing the time will provide more data for researchers to investigate the effects of this war on different financial markets. Ultimately, this should inspire future studies.

Ethical approval

This research does not contain any studies with human participants or animals performed by any of the authors.

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Credit author statement

Amin Sokhanvar: Software, Data curation, Writing – original draft. **Serhan Çiftçioğlu**: Data curation, Methodology. Chien-Chiang Lee: Conceptualization, Supervision, Funding acquisition, Writing – review & editing.

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.

Appendix A. Robustness Check Results

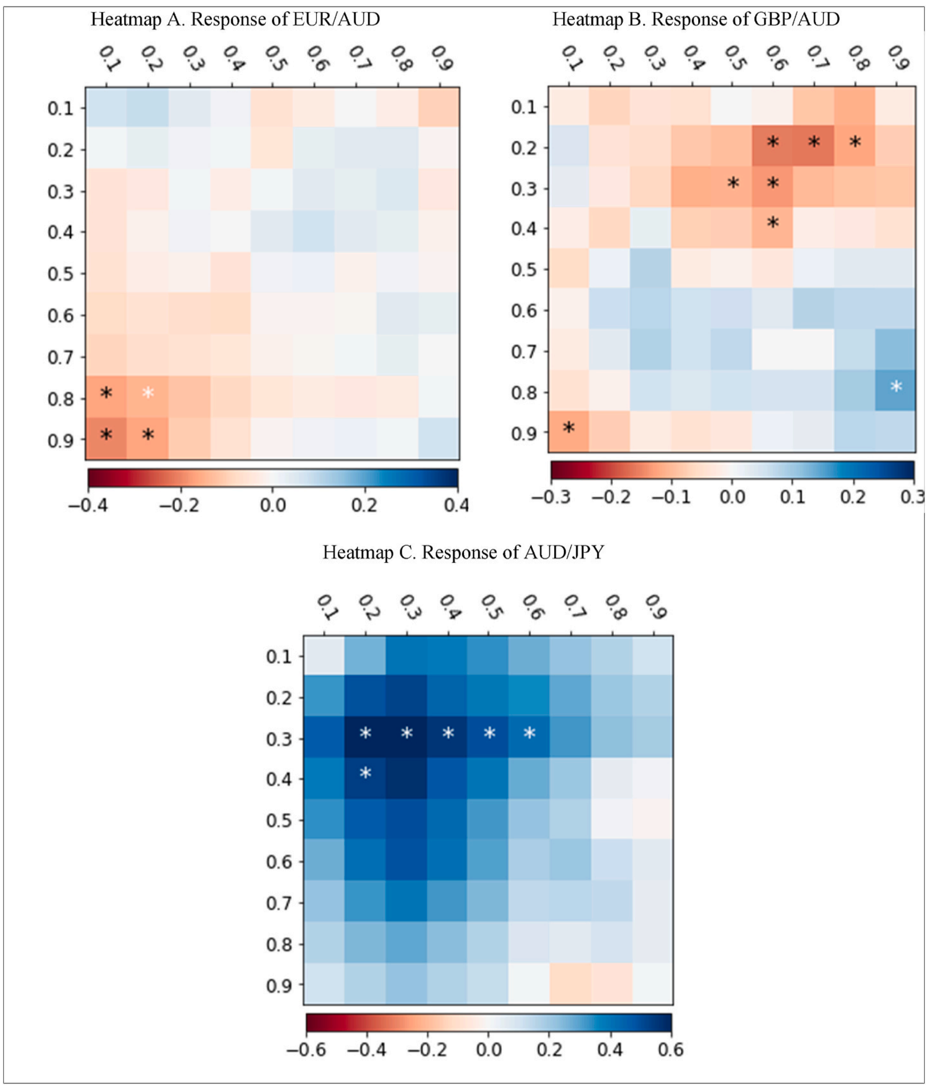

Fig. A1. Effect of a positive oil price shock on the exchange rates.
Note: See the notes to Fig. 3.

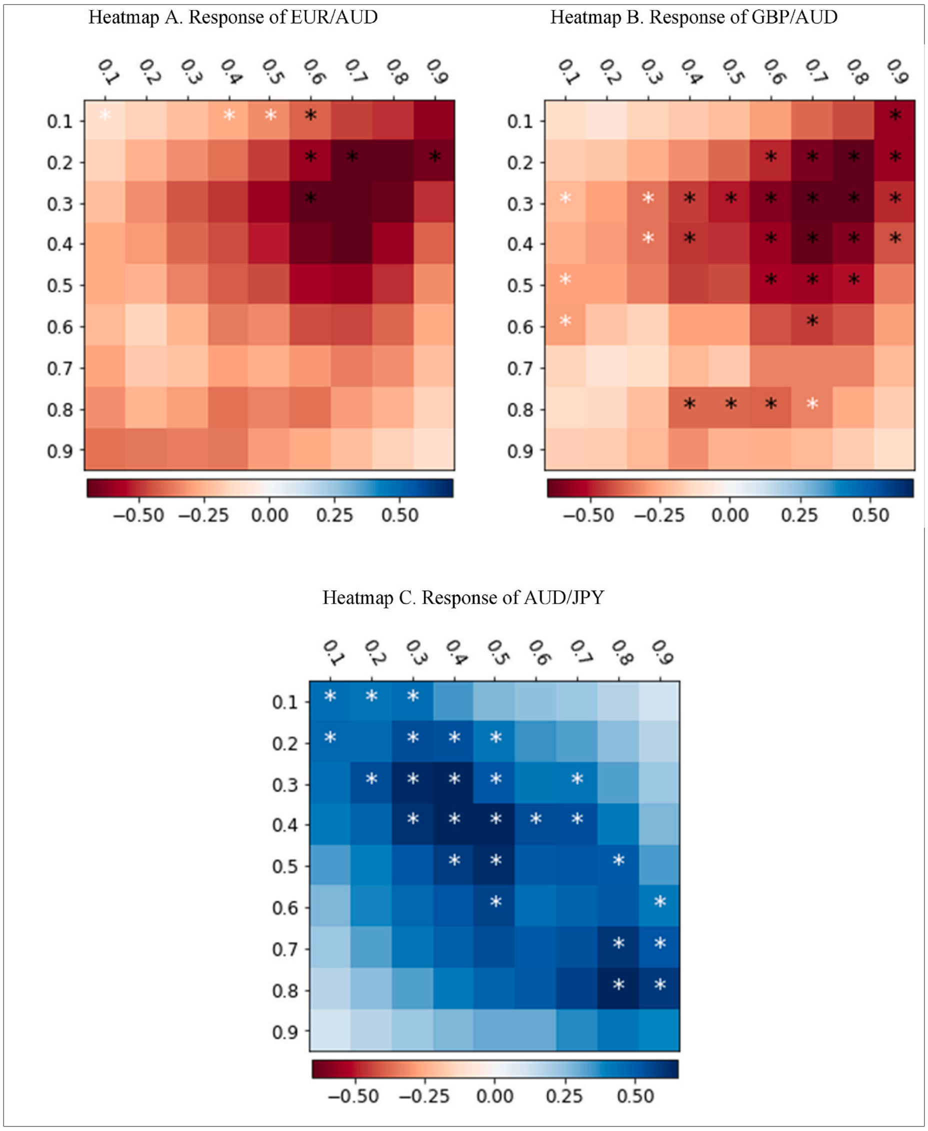

Fig. A2. Effect of a positive gas price shock on the exchange rates.
Note: See the notes to Fig. 3.

References

Abakah, E.J., Nasreen, S., Tiwari, A.K., Lee, C.C., 2023. U.S. leveraged loan and debt markets: implications for optimal portfolio and hedging. Int. Rev. Financ. Anal. 87, 102514.

Ahmed, A.D., Huo, R., 2020. Linkages among energy price, exchange rates and stock markets: evidence from emerging African economies. Appl. Econ. 52 (18), 1921–1935.

Amano, R.A., Van Norden, S., 1998a. Exchange rates and oil prices. Rev. Int. Econ. 6 (4), 683–694.

Amano, R.A., Van Norden, S., 1998b. Oil prices and the rise and fall of the US real exchange rate. J. Int. Money Finance 17 (2), 299–316.

Anjum, H., 2019. Estimating volatility transmission between oil prices and the US dollar exchange rate under structural breaks. J. Econ. Finance 43 (4), 750–763.

Baek, J., 2023. Supply and demand shocks in the global oil market: how much do they matter for exchange rates in OPEC members? Resour. Pol. 81, 103306.

Baek, J., Kim, H.Y., 2020. On the relation between crude oil prices and exchange rates in sub-saharan African countries: a nonlinear ARDL approach. J. Int. Trade Econ. Dev. 29 (1), 119–130.

Beckmann, J., Czudaj, R., 2013. Oil prices and effective dollar exchange rates. Int. Rev. Econ. Finance 27, 621–636.

Bouoiyour, J., Selmi, R., Tiwari, A.K., Shahbaz, M., 2015. The nexus between oil price and Russia's real exchange rate: better paths via unconditional vs conditional analysis. Energy Econ. 51, 54–66.

Branson, W.H., 1983. Macroeconomic determinants of real exchange rate risk. In: Herring, R.J. (Ed.), Managing Foreign Exchange Rate Risk. Cambridge University Press, Cambridge, MA.

Brooks, C., 2014. Introductory Econometrics for Finance. Cambridge university press.

Buetzer, S., Habib, M.M., Stracca, L., 2012. Global Exchange Rate Configurations: Do Oil Shocks Matter? Working Paper Series No. 1442. European Central Bank.

Chen, P.F., Zeng, J.H., Lee, C.C., 2018. Renminbi exchange rate assessment and competitors' exports: new perspective. China Econ. Rev. 50, 187–205.

Chen, Y.C., Rogoff, K., 2003. Commodity currencies. J. Int. Econ. 60 (1), 133–160.

Chen, Y., Cheng, L., Lee, C.C., Wang, C.S., 2021. The impact of regional banks on environmental pollution: evidence from China's City commercial banks. Energy Econ. 102, 105492.

Copeland, L., 2008. Exchange Rates and International Finance, fifth ed. Prentice Hall, Essex, England.

Coudert, V., Couharde, C., Mignon, V., 2011. Does euro or dollar pegging impact the real exchange rate? The case of oil and commodity currencies. World Econ. 34 (9), 1557–1592.

Diebold, F.X., Yilmaz, K., 2012. Better to give than to receive: predictive directional measurement of volatility spillovers. Int. J. Forecast. 28 (1), 57–66. https://doi.org/10.1016/j.ijforecast.2011.02.006.

Ding, L., Vo, M., 2012. Exchange rates and oil prices: a multivariate stochastic volatility analysis. Q. Rev. Econ. Finance 52 (1), 15–37. https://doi.org/10.1016/j.qref.2012.01.003.

Dornbusch, R., 1976. Expectations and exchange rate dynamics. J. Polit. Econ. 84, 1161–1176.

Eiteman, K.D., Stonehill, I.A., Mofett, H.M., 2014. Multinational Business Finance, twelfth ed. Pearson, Boston.
Elliott, G., Rothenberg, T.J., Stock, J.H., 1996. Efficient tests for an autoregressive unit root. Econometrica 64 (4), 813–836.
Frankel, J.A., 1983. Monetary and portfolio balance models of exchange rate determination. In: Bhandari, J.S., Putnam, B.H. (Eds.), Economic Interdependence and Flexible Exchange Rates, 84–115. MIT Press, Cambridge, MA.
Fratzscher, M., Schneider, D., Van Robays, I., 2014. Oil Prices, Exchange Rates and Asset Prices. Working Paper Series No. 1689. European Central Bank.
Golub, S.S., 1983. Oil prices and exchange rates. Econ. J. 93 (371), 576–593.
Han, H., Linton, O., Oka, T., Whang, Y.J., 2016. The cross-quantilogram: measuring quantile dependence and testing directional predictability between time series. J. Econom. 193 (1), 251–270.
Hashmi, S.M., Chang, B.H., Huang, L., Uche, E., 2022. Revisiting the relationship between oil prices, exchange rate, and stock prices: an application of quantile ARDL model. Resour. Pol. 75, 102543.
Huang, B.N., Lee, C.C., Chang, Y.F., Lee, C.C., 2021. Dynamic linkage between oil prices and exchange rates: new global evidence. Empir. Econ. 61, 719–742.
Ibragimov, R., Jaffee, D., Walden, J., 2009. Nondiversification traps in catastrophe insurance markets. Rev. Financ. Stud. 22 (3), 959–993.
Jordan, S., Philips, A.Q., 2018. Cointegration testing and dynamic simulations of autoregressive distributed lag models. STATA J. 18 (4), 902–923.
Kilian, L., 2009. Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market. Am. Econ. Rev. 99 (3), 1053–1069.
Krugman, R.P., Obstfeld, M., 2009. International Economics: Theory and Policy, eighth ed. Pearson, Boston.
Krugman, P., 1983a. Oil shocks and exchange rate dynamics. In: Frenkel, J.A. (Ed.), Exchange Rates and International Macroeconomics. University of Chicago Press, Chicago.
Krugman, P., 1983b. Oil and the dollar. In: Bhandari, J.S., Putnam, B.H. (Eds.), Economic Interdependence and Flexible Exchange Rates. Cambridge University Press, Cambridge.
Kumeka, T.T., Uzoma-Nwosu, D.C., David-Wayas, M.O., 2022. The effects of COVID-19 on the interrelationship among oil prices, stock prices and exchange rates in selected oil exporting economies. Resour. Pol. 77, 102744.
Lee, C.C., Olasehinde-Williams, W., Gyamfi, B., 2023b. The Synergistic Effect of Green Trade and Economic Complexity on Sustainable Environment: A New Perspective on the Economic and Ecological Components of Sustainable Development. Sustain. Dev. 31, 976–989.
Lee, C.C., Wang, C., 2022. Financial development, technological innovation, and energy security. Energy Econ. 112, 106161.
Lee, C.C., Hussain, J., 2023. An assessment of socioeconomic indicators and energy consumption by considering green financing. Resour. Pol. 81, 103374.
Lee, C.C., Lee, C.C., 2023. International spillovers of U.S. monetary uncertainty and equity market volatility to China's stock markets. J. Asian Econ. 84, 101575.
Lee, C.C., Feng, Y., Peng, D., 2022b. A green path towards sustainable development: the impact of low-carbon city pilot on energy transition. Energy Econ. 115, 106343.
Lee, C.C., Wang, C.W., Thinh, B.T., 2023a. Green development, climate risks, and cash flow: International evidence. Pac. Basin Finance J. 79, 102021.
Lee, C.C., Yuan, Z., Lee, C.C., Chang, Y., 2022a. The impact of renewable energy technology innovation on energy poverty: does climate risk matter? Energy Econ. 116, 06427.
Liu, M., Choo, W., Lee, C.C., Lee, C.C., 2023. Trading volume and realized volatility forecasting: evidence from the China stock market. J. Forecast. 42, 76–100.
Liu, T.Y., Lee, C.C., 2022. Exchange rate fluctuations and interest rate policy. Int. J. Finance Econ. 27 (3), 3531–3549.
Lizardo, R.A., Mollick, A.V., 2010. Oil price fluctuations and US dollar exchange rates. Energy Econ. 32 (2), 399–408.
Lv, C., Fan, J., Lee, C.C., 2023. Can green credit policies improve corporate green production efficiency? J. Clean. Prod. 397, 136573.
Nie, C., Lee, C.C., 2023. Synergy of pollution control and carbon reduction in China: Spatial–temporal characteristics, regional differences, and convergence. Environ. Impact Assess. Rev. 101, 107110.
OECD, 2021. OECD Economic Surveys: Australia. OECD Publishing, Paris.
Ready, R.C., 2018. Oil prices and the stock market. Rev. Finance 22 (1), 155–176.
Rivera-Batiz, L.F., Rivera- Batiz, A.L., 1994. International Finance and Open Economy Macroeconomics, second ed. Prentice-Hall, Inc., New Jersey.
Sadorsky, P., 2000. The empirical relationship between energy futures prices and exchange rates. Energy Econ. 22 (2), 253–266.
Salvatore, D., 2011. International Economics, tenth ed. John Wiley and Sons, Singapore.
Sari, R., Hammoudeh, S., Soytas, U., 2010. Dynamics of oil price, precious metal prices, and exchange rate. Energy Econ. 32 (2), 351–362.
Sarno, L., Frankel, A.J., 2002. The Economics of Exchange Rates. Cambridge University Press, Cambridge.
Shang, J., Hamori, S., 2021. Do crude oil prices and the sentiment index influence foreign exchange rates differently in oil-importing and oil-exporting countries? A dynamic connectedness analysis. Resour. Pol. 74, 102400.
Shankarnarayan, V., Ramakrishna, H., 2021. Comparative study of three stochastic future weather forecast approaches: a case study. Data Sci. Manag. 3, 3–12.
Singhal, S., Choudhary, S., Biswal, P.C., 2019. Return and volatility linkages among International crude oil price, gold price, exchange rate and stock markets: evidence from Mexico. Resour. Pol. 60, 255–261.
Sohag, K., Sokhanvar, A., Belyaeva, Z., Mirnezami, S.R., 2022. Hydrocarbon prices shocks, fiscal stability and consolidation: evidence from Russian Federation. Resour. Pol. 76, 102635.
Sokhanvar, A., Bouri, E., 2023. Commodity price shocks related to the war in Ukraine and exchange rates of commodity exporters and importers. Borsa Istanbul Review 23 (1), 44–54. https://doi.org/10.1016/j.bir.2022.09.001.
Sokhanvar, A., Lee, C.C., 2022. How do energy price hikes affect exchange rates during the war in Ukraine? Empir. Econ. https://doi.org/10.1007/s00181-022-02320-7 (in press).
Sokhanvar, A., Sohag, K., 2022. What does the clean energy transition look like for Russian oil exports? Energy Sci. Eng. 10 (12), 4512–4519.
Tian, S., Hamori, S., 2016. Time-varying price shock transmission and volatility spillover in foreign exchange, bond, equity, and commodity markets: evidence from the United States. N. Am. J. Econ. Finance 38, 163–171.
Tiwari, A.K., Abakah, E., Adewuvi, A., Lee, C.C., 2022. Quantile risk spillovers between energy and agricultural commodity markets: evidence from pre and during COVID-19 outbreak. Energy Econ. 113, 106235.
Wan, J., Lee, C.C., 2023. Corporate investment and the dilemma of the monetary policy: Evidence from China. Econ. Anal. Pol. 78, 106–121.
Wang, J., Niu, X., Zhang, L., Liu, Z., Wei, D., 2022. The influence of international oil prices on the exchange rates of oil exporting countries: based on the hybrid copula function. Resour. Pol. 77, 102734.
Yahya, F., Abbas, G., Lee, C.C., 2023. Asymmetric effects and volatility transmission from metals markets to solar energy stocks: Evidence from DCC, ADCC, and quantile regression approach. Resour. Pol. 82, 103501.
Yahya, F., Lee, C.C., 2023. The asymmetric effect of agriculturalization toward climate neutrality targets. J. Environ. Manag. 328, 116995.
Yıldırım, D.Ç., Erdoğan, F., Tarı, E.N., 2022. Time-varying volatility spillovers between real exchange rate and real commodity prices for emerging market economies. Resour. Pol. 76, 102586.
Zhang, H.J., Dufour, J.M., Galbraith, J.W., 2016. Exchange rates and commodity prices: measuring causality at multiple horizons. J. Empir. Finance 36, 100–120.
Zhang, X.M., Zhang, X., Lee, C.C., Zhao, Y., 2023. Measurement and prediction of systemic risk in China's banking industry. Res. Int. Bus. Finance 64, 101874.
Zhao, J., Jiang, Z., Sun, M., 2021. A review on the gray market business using a data-driven approach. Data Sci. Manag. 1 (1), 38–47.
Zhong, Q., Wen, H., Lee, C.C., 2022. How does economic growth target affect corporate environmental investment? Evidence from heavy-polluting industries in China. Environ. Impact Assess. Rev. 95, 106799.