Net-Zero Policy vs Energy Security: The Impact on GCC Countries

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ABSTRACT

Gulf Cooperation Council countries have accumulated large oil portfolio revenues. However, the world economy is seeking to reduce carbon emissions, and in turn, its reliance on fossil fuel resources through investments in renewable energy resources. The aim of this research is to analyze oil portfolio risk from an exporters' perspective, highlighting how relevant determinants, such as the increasing penetration of renewables in the importer counterparties, and financial and policy uncertainty, increase the volatility of oil export portfolios.

We construct oil portfolios for four Gulf Cooperation Council countries (Kuwait, Oman, Saudi Arabia, United Arab Emirates) from 2008 to 2018, and compute volatility spillovers à la Diebold and Yilmaz. Then, the effects of policy and economic variables on volatility spillover indices are estimated using different panel linear regression models.

We find rising renewable market shares significantly affects oil export portfolio risks and reduces adverse impacts on importing countries of oil market fluctuations.

Keywords: Portfolio theory, Risk minimization, Directional volatility spillovers, Renewables, Energy security, Gulf Cooperation Council countries

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1. INTRODUCTION

Energy security priorities vary amongst countries according to their level of economic development, endowment of energy resources and potential exposures to global energy demand. Research on energy security generally falls into one of three perspectives, viz. political, engineering/geologic, or economic (Haar and Haar, 2019). What all three perspectives have in common is that the purpose of such research is to deal with underlying risks to energy security.

Given the critical nature of energy to an economy, public policy relating to energy security invariably focuses on lowering the probability of shocks by making energy supply reliable and prices stable. Viewed in this light, energy security policy can be seen as a form of applied risk management.[1]

1. The concept of risk it remains open to various interpretations and a univocal measure of risk has not yet been identified. Just as the definition of security is context-dependent, so too the identification of the risk and its assessment vary according to

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One of the most prominent contemporary macroeconomic risks faced by both commodity-importing and exporting countries relates to the uncertainty arising from global energy price fluctuations. Impacts on economic growth for importing nations are well known. For exporting countries, global energy price fluctuations may have the effect of threatening export earnings, driving instability of fiscal accounts and balance of payments, and adversely affecting the smooth functioning of the domestic economy.

The *energy transition* and ‘net zero’ policies will invariably increase uncertainty associated with the long run global demand for oil. At the time of writing, 131 countries covering 85% of the world’s population had committed to ‘net zero’ policies.[2] This necessarily exposes oil exporting countries to long-term structural challenges associated with a world economy less dependent on oil through two primary risks: i) loss of export revenues, and ii) an inability to monetize reserves (i.e. stranded assets). Oil exporting nations should, and are, focusing on economic adaptation strategies to delink public expenditure from happenings in the international oil market (Eneasato, 2021). As Khan and Shaheen (2020) explain, the key strategies addressing the long-term sustainability of countries whose fiscal health is tied to oil prices are: i) the fiscal diversification based on reducing risks by pooling uncorrelated income streams, ii) strategic investments, iii) enhancing economic resilience to recover swiftly from adverse conditions, and iv) preventing losses in export revenues and monetizing reserves.[3]

The purpose of this article is to examine the risk faced by four Gulf Cooperation Council (GCC) countries—viz. Kuwait, Oman, Saudi Arabia, and United Arab Emirates (UAE)—with a specific focus on their oil export portfolios and analyse how portfolio risk volatility is affected by policy and macroeconomic trends. In particular, we construct oil portfolios for the GCC countries by focusing on their five primary counterparties (i.e. importing countries) and investigate the effects on portfolio risk volatility of variables such as global market uncertainty, policy uncertainty and the market share of renewable energy sources (RES) in oil importing nations.

The method we are proposing aims at providing to those economies which heavily rely on oil revenues a theoretical framework enabling to measure and manage the risk related to oil-export portfolios. We approach this task by focusing on oil export returns and oil price fluctuations using modern portfolio theory, where a risk averse investor chooses a combination of assets (portfolio) which minimizes their variance for a given average return (Markowitz, 1952). In a similar way, risk averse countries can allocate their export shares to produce the optimal export mix (amongst counterparty countries) according to the co-variability of prices on different markets (Brainard and Cooper, 1968). To assess the risk faced by the four GCC oil exporters, optimal portfolio returns have been derived from monthly oil export growth rates and prices between 2008–2018, and volatility spillovers are estimated in a manner consistent with Diebold and Yilmaz’s directional spillover index approach.[4]

the specific energy system and the market position of a country (Novikau, 2021).

2. See Netzero Tracker at https://zerotracker.net

3. During the second half of the 20th century, vast oil and gas reserves transformed Persian Gulf monarchies into developed and affluent countries. Ironically a growing burden of subsidy-driven domestic oil and gas demand threatened the ‘rentier’ structure of these countries and consequently tax increases and subsidy reforms aimed at reducing domestic consumption (and preserving exports quantities) was pursued (Krane, 2015). Externally, GCC countries have accumulated large oil portfolio revenues. With more than 131 countries committing to ‘net zero’, any long-run sustained fall in the global demand for oil vis-à-vis rising levels of renewable energy resources poses a strategic threat from a different dimension.

4. We have focused on this period for two reasons. First, using data after 2008 we consider that during the 2007–2008 crisis oil prices were a driver of what would become the Global Financial Crisis The unprecedented volatility in oil prices during 2007 had a substantial impact on various other economic variables and interconnected markets. The conditions related

Within each GCC country's portfolio, directional spillovers to- and from- each importing nation are derived, that is, spillovers triggered by an importer country to all other importers, and those absorbed by an importer coming from all other importers, respectively. These spillovers provide quantitative assessments regarding the volatility risk of export portfolios. The effects on the directional spillovers arising from macroeconomic and policy variables, including the increasing penetration of renewables in the domestic energy production of an importing nation, and the importer-specific policy uncertainty index, are then estimated using different panel linear models.

Our substantive findings are as follows. Firstly, aggregate 'quantity' volatility spillovers are lower than 'price' volatility spillovers, which confirms the structural rigidity of oil demand. The analysis of net contributors for price and quantity volatility suggests China is a net transmitter of quantity spillovers highlighting its pivotal role in driving global oil demand dynamics and energy security. Conversely, India seems to absorb quantity and price shocks from oil markets. This finding suggests that important policy implications for GCC countries when managing their oil export portfolio, that is, GCC experiencing volatile fiscal conditions within their own economy may rebalance their oil export portfolios toward India to stabilize income streams. Secondly, increasing economic and policy uncertainty in importing nations increases the volatility of oil export portfolios. This suggests that political tensions increase oil market fluctuations and threaten the stability of GCC's oil export portfolios and revenues streams. Thirdly, broader energy policies in oil importing countries will increasingly be designed to mitigate climate change and reduce demand for fossil fuels. Our subsequent modelling finds climate change mitigation policies increase oil export portfolio uncertainty by raising volatility spillovers toward GCC counterparty countries. Oil portfolio risk management will therefore become increasingly important for GCC countries. Looking at spillovers and associated shocks from foreign markets on importing nations, our analysis confirms that rising renewable shares within the domestic energy production mix is predictable. Axiomatically, increasing renewable market shares were found to reduce volatility spillovers from foreign markets, enabling the importing nation to better absorb foreign market shocks.

The article is structured as follows. Section 2 presents a review of the related literature. Section 3 provides qualitative information on export portfolios of selected GCC countries. A description of methods is provided in Section 4, with results presented in Section 5. Section 6 provides a discussion on results and Section 7 concludes.

2. REVIEW OF LITERATURE

Our analysis has relevance to two related streams of literature: i) energy security and ii) dynamic spillover effects, as follows.

2.1 Energy Security

Despite the concept of energy security dating back almost half a century, a broadly accepted definition is yet to be achieved. Scholars and institutions have developed different interpretations of

to energy and economic variables in 2008 marked a notable structural break in the core economic fundamentals. Secondly, we encountered limitations in data availability and reliability for periods prior to 2008. As one reviewer observed, various important global events relating to the energy transition have been truncated from the period 2008–2018, including the acceleration of policy activity following the Glasgow Conference of the Parties, and the adverse impacts of reliance on natural gas following the war in Ukraine. Nevertheless, we have to mention that our primary scope is focusing on the post global financial crisis period, where important events such as Covid and Ukrainian war are not included. Adding them serve to amplify our results given large price shocks.

the concept as summarized in Ang et al. (2015) and Azzuni and Breyer (2018). Specifically, a historical difference exists according to a countries' energy endowment, given 'security' received less attention in energy exporting countries. However, energy security is now gaining political importance for several countries with large energy endowments, highlighting interpretations for importing and exporting countries differ substantially (see Karatayev and Hall, 2020). After the twin OPEC oil crises during the 1970's, energy security was defined as ensuring the supply of cheap oil under the threat of embargo or price manipulation although prevailing definitions in informal documents usually cite the concept of *energy independence* (see Metcalf, 2014). This demand-side perspective was adopted and further developed globally by different international organizations and agencies. It is noteworthy that the United States does not have a formal definition of energy security.

The International Energy Agency, (Jacoby, 2009) and the European Commission (2006) have enhanced this demand-side perspective, defining energy security in terms of physical and economic supply availability to ensure the smooth functioning of the economy. The World Energy Council (2010) introduced the so-called *Energy-Trilemma* where an energy security dimension is connected with energy equity and environmental sustainability concepts. Again, this framework has been primarily grounded on the needs and objectives of energy-importing countries.

Oddly enough, OPEC does not have its own definition of energy security. A blurred definition can be traced back to statements made by OPEC representatives (Barkindo, 2006), according to which security forms part of a universal responsibility within the global community, with supply continuity and demand being complementary issues requiring balanced solutions. Given the position of net exporting countries, OPEC's conceptual framework of security should also include an export-oriented perspective focusing on reliability and affordability of supply.

2.2 Dynamic Spillover Effects

For our four GCC countries, a critical long run interaction exists between importing countries and energy security. The interdependence of risk volatility among different countries is analytically comparable to volatility spillovers in the financial literature and to the concept of dynamic correlation (both symmetric and asymmetric). Asymmetric spillover effects of volatility between oil markets and stock markets have been analysed extensively by Li et al. (2009), Khalfaoui et al. (2019), Sarwar et al. (2019) and others. From a macroeconomics perspective, Nasir et al. (2019) analyse the impact of oil price shocks on the economies of oil exporting countries and potential feedback loops on the ability to ensure security of supply in global markets. Our proposed method, which is based on the financial literature, assesses appropriately the trade-off between price and physical supply security components using a portfolio approach to account for spillover effects.

At their core, spillover effects are externalities arising from an economic activity or process for those who are not directly involved in it. Similarly, dynamic correlations amongst country risks present asymmetric characteristics (Li et al., 2009). This is crucial from an oil exporting country point of view—if shocks adversely impact the portfolios of importers, it is likely to project a more critical situation for exporting countries in the future.

Various studies have investigated time-varying volatility and dynamic spillover effects of crude oil markets using macroeconomic and financial variables in light of major political and weather-related events for oil importing and exporting countries. For oil importing countries, Karali and Ramirez (2014) find crude oil volatility increases following major political, financial, and natural events. Chen et al. (2019) show that in the BRIC countries, the mean spillover relationship between oil prices and economic policy uncertainty is weak in the short run but strengthens in the long run. Only in Brazil and Russia is the relationship strong in both the short and long run.

Focusing on the relationships amongst volatility and the US exchange rate, Wen et al. (2020) find spillovers from exchange rates are stronger than those from oil prices. After the 2007 financial crisis, the oil-exchange rate risk dependence worsened, and risk spillovers were much stronger for oil-exporters than oil-importers. Focusing on ten oil exporting countries, Pavlova et al. (2018) find a relatively large portion of spillover effects explained by local and global factors (22.5% and 17.4%, respectively). Furthermore, they found the effects of political variables are comparably lower than oil-specific shocks. Considering both export and import countries, He et al. (2021) find volatility spillovers from oil-exporting nations are stronger than those of oil-importing countries with spillover asymmetry increasing with policy uncertainty (especially in a crisis period). Khalfaoui et al. (2019) find the magnitude of negative shocks are higher than positive shocks and to hedge such risks, investors in oil-exporting countries should hold more oil assets within their portfolios. Ashfaq et al. (2019) investigate the relationship amongst stock exchanges and spot crude oil prices for three oil exporting countries (Saudi Arabia, UAE, Iraq) and four oil importing countries (China, Japan, India, South Korea). Consistent with Wen et al (2020), results show the influence of oil price shocks are more pronounced for oil exporting countries. They also find oil assets are useful instruments to minimize portfolio risk. Furthermore, in order to form an optimal portfolio, investors should choose an equal ratio between stocks and oil assets in the case of oil exporting countries, and more stocks than oil assets in the case of oil importing countries. Guesmi and Fattoum (2014) find oil prices exhibit a positive correlation with stock markets and dynamic correlations do not differ between oil-importing and oil-exporting economies. They also find oil assets are *not* a ‘safe haven’ against stock market losses during periods of turmoil.

Naeem et al., (2020) examine connectedness amongst electricity, carbon and clean energy markets, and oil prices, demand and supply shocks. They find connectedness increased during the 2008 global financial crisis as well as throughout the shale oil/gas revolution period. Total connectedness was also found to be higher in the short run compared to the long run.

Finally, recent literature has investigated determinants of spillover volatility through a two-stage procedure. In the first step, spillover volatility indices are estimated, then in a second step, the estimated spillover volatility indices are regressed against a selected set of explanatory variables. Liow and Huang (2018) use a sample of ten real estate investment trusts in order to identify the macroeconomic contributors of detected net directional connectedness. Results show economic policy uncertainty, interest rate movements and world stock market returns are key factors. Atenga and Mougoué (2020) examine how international and regional shocks are transmitted to African equity markets, assessing the spillover channels by a linear panel regression. They conclude that oil and metal prices are the main channels through which foreign shocks spread to African stock markets. Bouri et al. (2021) investigate determinants of the volatility of 15 commodity futures, finding connectedness is robust to alternative specifications and mostly driven by economic and policy uncertainty and macroeconomic variables, including the term spread of interest rates and volatility index. Su (2020) investigates the dynamics of volatility spillovers and their determinants in G7 stock markets. These determinants have different effects on short-, medium-, and long run volatility spillovers and do not exhibit a systematic pattern. Youssef et al. (2021) investigate whether economic policy uncertainty drives connectedness between the stock market returns of nine industrialized countries. This relationship is also analysed in Wei et al. (2017), Fang et al., (2018), Canh et al., (2020), Hu et al. (2020), and finally, Nguyen and Walther (2020). They testify a strong link between economic policy uncertainty and stock market volatility in countries worldwide, but the directions of the effects are different depending on the country.

In this article, the main drivers of export portfolio directional spillovers are identified by five indices, viz. economic and policy uncertainty (WUI), market uncertainty (VIX), RES market shares in the energy production mix, exchange rate (EXC), and industrial productivity (IPI).

3. THE SELECTED GCC COUNTRIES

Given the primary task of our analysis is to examine risks faced by the four nominated GCC countries, we measure the effects of various economic and financial variables on their oil export portfolios in light of the rising role played by RES. We focus on the GCC countries because they have accumulated significant oil portfolio revenues which has enabled living standards to be dramatically increased (i.e. fiscal revenues from oil products). The selected GCC countries (Kuwait, Oman, Saudi Arabia, UAE) account for 26% of the global oil trade.[5] Consequently, our analysis seeks to evaluate how the increasing RES will impact energy security of an area that accounts for more than one quarter of global oil trade.

GCC countries rely heavily on energy exports as their main source of income and can therefore be adversely impacted by fluctuations in global final demand. Furthermore, they currently lack a diversified industrial base and lag in technology. All things being equal, any fall in global demand for crude poses a strategic threat to their financial and economic conditions via lower export revenues and government budgets. The energy transition associated with net zero targets will ultimately increase uncertainty on the longer run prospects of global oil demand. As noted in Section 1, the energy transition exposes GCC countries to two main risks: i) a loss of revenues, and ii) stranded oil reserves.

In this article, we refer to the portfolio of each selected GCC country by identifying the five main oil importing countries. It is noteworthy that some countries may appear in more than one portfolio, meaning overlaps are possible. For example, Japan and South Korea appear in all oil portfolios.

Emerging countries such as India and China are noted for increasing their shares in oil portfolios throughout our observation period. Examining the oil portfolios that incorporate these two strategic markets is particularly important when analysing future developments of RES market shares, and the implications for energy security. COP26 demonstrated that China and India are seeking to adopt more relaxed strategies during the energy transition, for example, exchanging a ‘coal phase out’ with a ‘coal phase down’ approach. However, China has an ‘authoritarian advantage’—that is, the ability to adjust, implement and execute policy quickly due to less checks and balances compared to typical democratic systems of government. As the world’s biggest polluter, China’s carbon neutral pledge is of course crucial to achieving worldwide net-zero emissions.[6]

5. Data are sourced from https://comtradeplus.un.org. We disregarded Bahrein, the smallest GCC country, since its trade is essentially integrated within the GCC area. We also excluded Qatar because the structure of its exports is more flexible being a major exporter of liquified natural gas.

6. China aimed to reduce its CO2 emissions incorporating clean energy as part of its 2021 five-year plan. However, despite impressive investments in hydro, solar and wind power, China’s large and broadening middle class population is demanding more energy. Consequently, five years plans will become even more aggressive in RES if it is to reach its carbon-neutrality pledge by 2060.

4. METHODS

In this section, we present the spillover index approach used to estimate the volatility spillovers, along with the panel model used to examine their determinants.

4.1 Volatility spillover effects

To compute directional volatility spillovers indexes, we use data of the optimal export portfolio of the four GCC countries derived from the standard risk portfolio optimization model introduced by Markowitz (1952).

A country's energy exports are given by a set of flows to different importers, which vary in volume, growth rate, and price. This set of flows can be represented as an export portfolio whose returns are the volume growth or the prices associated with different importers.

For each month t between 2008–2018, the portfolio of each GCC country m is denoted by $v_{m,t} = \left(s_{m,t,1},\ldots,s_{m,t,5}\right)$, where $s_{m,t,i}$ represents the oil import share of one of the main importer i, with $i=1,\ldots,5$. Operationally, the four portfolios $v_{m,t}$ come from the Markovitz's portfolio optimization problem, and represent the export configurations that yield the lowest variance for a given level of expected earnings. Minimization yields the efficient portfolio $v^*_{m,t} = \left(s^*_{m,t,1},\ldots,s^*_{m,t,5}\right)$ with return $\theta^*_{m,t}$ and minimum variance $\sigma^{*2}_{m,t}$, i.e., a frontier suitable for empirical estimation (Bigerna et al., 2021). $\theta^*_{m,t}$ is the geometric mean of portfolio's returns, $\theta_{m,t,i}$, with weights given by the computed optimal import shares $s^*_{m,t,i}$, as follows:

$$\theta^*_{m,t} = \sum_{i=1}^{5} s^*_{m,t,i}\theta_{m,t,i} \tag{1}$$

To assess the trade-off that oil exporters face, for each GCC country we construct two different portfolios $v^*_{m,t}$, according to two different categories of returns.

The first is the oil-export volume growth portfolio, which expresses the trade-off between higher growth of exports and concentration of purchaser countries, while a lower risk is associated with a higher diversification of purchaser countries.

The second is the oil-export price portfolio, which expresses the trade-off between higher prices received by exporter and high concentration on a few best buyers, while a lower expected return is associated with a more diversified composition of buyers. These two portfolios cover the two primary aspects of energy security from the exporter's perspective: minimizing the risk while securing demand and obtaining favourable price terms.

Regarding the oil-export volume growth portfolio, each return, $\theta_{m,t,i}$, is the monthly growth rate of the oil export volume to the purchaser i and it is given by:

$$\theta_{m,t,i} = \frac{\left(E_{m,i,t} - E_{m,i,t-1}\right)}{E_{m,i,t}} \tag{2}$$

where $E_{m,i,t}$ and $E_{m,i,t-1}$ represent the oil demand requested by purchaser i to the GCC exporter m at time t and t–1, respectively. The associated volume growth portfolio variance is measured by the variability of the export growth rate across purchasers.

Concerning the oil-export price portfolio, each return $\theta_{m,t,i}$ is the price charged the purchaser i, at time t.[7] The associated price portfolio variance is estimated by the sample variance of the weighted prices paid by each importer.

The dataset used in the analysis to define quantity and price returns is constructed using the procedure proposed by Bollino and Galkin (2021). Indeed, GCC countries do not publicly release their oil export data on open-source platforms such as the UN Comtrade Database. To circumvent this problem, we employ 'mirror' data. Specifically, we use the oil import data of the five major partners for the selected GCC countries.[8] These data are available on the UN Comtrade Database, with both annual and monthly frequencies. In this way, we obtain the monthly volume growth and prices of crude oil imports from each of the selected GCC countries between 2008 and 2018. For each GCC country, the selected five major importers represent, on average, more than 60% of the total exports.[9]

Next, for each GCC country a Vector Autogressive (VAR) structure is set to estimate the dynamic response of returns to shocks of main purchasers. For each GCC country m, the VAR specification is as follows:

$$\boldsymbol{\theta}_{m,t} = \sum_{p=1}^{P} \phi_{m,p} \boldsymbol{\theta}_{m,t-p} + e_{m,t} \tag{3}$$

where $\boldsymbol{\theta}_{m,t} = \left[\theta_{m,1,t}, \ldots, \theta_{m,5,t}\right]$ is the vector that includes the monthly export volume growth or price $\theta_{m,i,t}$, related to importer i, at time t. $e_{m,t} \sim N(0,\Sigma)$ is the vector of independently and identically distributed disturbances.

The spillover index approach introduced by Diebold and Yilmaz (2012, 2014) builds on the well-known notion of forecast error variance decomposition (FEVD). It allows to assess the contributions of shocks to forecast error variances for respective and other variables of the model. This method uses a generalized VAR framework in which FEVD are invariant to variable ordering, and explicitly include directional volatility spillovers.

Starting from the VAR representation in eq. (3), the corresponding moving average $MA(\infty)$ representation is as follows (Diebold and Yilmaz, 2012):

$$\boldsymbol{\theta}_{m,t} = \sum_{i=0}^{\infty} \boldsymbol{A}_{m,i} e_{m,i} \tag{4}$$

where the $N \times N$ coefficient matrices $\boldsymbol{A}_{m,i}$ obey the recursion $\boldsymbol{A}_{m,i} = \phi_{m,1}\boldsymbol{A}_{m,i-1} + \phi_{m,2}\boldsymbol{A}_{m,i-2} + \ldots + \phi_{m,p}\boldsymbol{A}_{m,i-p}$ with $\boldsymbol{A}_{m,0} = \boldsymbol{I}_N$ and $\boldsymbol{A}_{m,i} = 0$ for $i < 0$. Values in $\boldsymbol{A}_{m,i}$ are the impulse response coefficients.

7. The price return is represented by the free on board (FOB) price associated with each buyer in US $ 1,000 per tonne. FOB price is proxied by subtracting from the cost insurance and freight (CIF) price, the price of the shipping cost, estimated based on the historical monthly average shipping rates (expressed as US$ per nautical mile per ton of crude oil) and the distances between the major export and import ports. See Bollino and Galkin (2021).

8. The literature provides numerous methods to assess the degree of competitiveness within the industry. Among absolute structural concentration indicators, there are concentration ratio's (CR) and the Herfindahl index. Both indicators are based on the calculation of market shares. In practice, the CR is commonly quantified for the three, five or 10 strongest companies in the industry (quantification of indicators CR3, CR5 and CR10). In other studies, authors prefer indicators of CR4 and CR8. In the oil sector at country levels, CR5 is often used. See among others Mirzaei and Al-Khouri (2016), An et al. (2018).

9. From the UN Comtrade dataset, for each year from 2008 to 2018, we derived all the oil trading partners of the four GCC countries. Based on the annual average, the number of trading partners is large, ranging from 135 (Kuwait) to 164 (UAE). Nevertheless, in each portfolio, the selected major five buyers alone account for more than 60% of the total exports, on average. The other minor importers have a marginal impact on the export dynamics, and thus they were discarded from the analysis.

VAR shocks $e_{m,t}$ are generally contemporaneously correlated, whereas variance decomposition requires orthogonal shocks. The Cholesky decomposition orthogonalizes their variance-covariance matrix, but the corresponding variance decomposition depends on variable ordering. Diebold and Yilmaz (2012) circumvent this problem by exploiting the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998). This generalized framework allows for correlated shocks but accounts for them appropriately, by using the historically observed distribution of the errors (Diebold and Yilmaz 2012). As the shocks to each variable are not orthogonalized, the sum of contributions to the variance of forecast error (that is, the row sum of the elements of the variance decomposition table) is not necessarily equal to one.

Variance decompositions is a useful tool to analyse and decompose the forecast error variances of each variable according to various system shocks. Indeed, it allows us to assess the fraction of the H-step-ahead error variance in forecasting $\theta_{m,i}$ due to shocks to $\theta_{m,j} \forall i \neq j$. Forecast error for H steps ahead is calculated by detracting the expected values from real ones, as follows: $e_{m,t+H} = \boldsymbol{\theta}_{m,t+H} - E\left(\boldsymbol{\theta}_{m,t+H}\right)$ and then, the mean squared error for the variance is calculated for every element in $e_{m,t+H}$ as $E\left(\boldsymbol{\theta}_{m,t+H} - E\left(\boldsymbol{\theta}_{m,t+H}\right)\right)^2$. Then, each variance is decomposed to shares of every variable in the VAR model, $\phi_{i,j}\left(H\right)$,[10] due to shocks in individual variables as follows:

$$\phi_{i,j}\left(H\right) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_j' A_h \Sigma A_h' e_i\right)} \tag{5}$$

where Σ is the variance matrix for the error vector e_t, σ_{ii} is the standard deviation of the error term for the i-th equation and e_i and e_j are the unit vectors from matrix $\boldsymbol{I}_{Np}$.Values $\phi_{i,j}\left(H\right)$ are interpreted as shares of the variance of variable i in the forecast step H caused by the shock in variable j. That is, the numerator is the contribution of shock in market j to the variance of variable i for H steps, whilst the denominator is the variance of forecasted values of variable i. The model yields an $N \times N$ matrix $\phi = \left[\phi_{i,j}\left(H\right)\right]_{i,j=1,\dots,N}$ where the main diagonal contains the contributions of shocks i to the forecast error variance of its own variable i, the off-diagonal elements show the (cross-) contributions of the other shocks j to the forecast error variance of variables i. As explained above, the sum of elements of each row of the variance decomposition matrix is not equal to 1: $\sum_{j=1}^{N} \phi_{i,j}\left(H\right) \neq 1$. In order to use the variance decomposition matrix in the calculation of the spillover index, each entry $\phi_{i,j}\left(H\right)$ is normalized by the row sum as follows:

$$\widetilde{\phi_{i,j}}\left(H\right) = \frac{\phi_{i,j}\left(H\right)}{\sum_{i,j=1}^{N} \phi_{i,j}\left(H\right)} \tag{6}$$

Using the volatility contributions from eq. (6), the total volatility spillover index (TSI) is:

$$TSI\left(H\right) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\phi_{i,j}}\left(H\right)}{\sum_{i,j=1}^{N} \widetilde{\phi_{i,j}}\left(H\right)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\phi_{i,j}}\left(H\right)}{N} \cdot 100 \tag{7}$$

The TSI measures the contribution of spillovers of volatility shocks across the N variables to the total forecast error variance. It represents the role of the systemic risk associated to the multivariate system in the forecast error variance. Since the generalized VAR allows the generalized

10. For simplicity and clarity, we omit the apex m referring to the exporter GCC country.

variance decomposition being invariant to the ordering of variables, it allows to compute directional volatility spillovers using the elements in eq. (6).

The directional volatility spillovers from variable *i* to all other variables *j* can be expressed as:

$$DS_{i\rightarrow}(H) = \frac{\sum_{j=1;j\neq i}^{N} \widetilde{\phi_{j,i}}(H)}{\sum_{i,j=1}^{N} \widetilde{\phi_{j,i}}(H)} \cdot 100 = \frac{\sum_{j=1;j\neq i}^{N} \widetilde{\phi_{j,i}}(H)}{N} \cdot 100 \tag{8}$$

In similar fashion, the directional volatility spillovers to variable *i* from all other variables *j* can be expressed as follows:

$$DS_{\rightarrow i}(H) = \frac{\sum_{j=1;j\neq i}^{N} \widetilde{\phi_{i,j}}(H)}{\sum_{i,j=1}^{N} \widetilde{\phi_{i,j}}(H)} \cdot 100 = \frac{\sum_{j=1;j\neq i}^{N} \widetilde{\phi_{i,j}}(H)}{N} \cdot 100 \tag{9}$$

To summarise, the set of directional spillovers provides a decomposition of TSI into those coming from eq.(8) or eq.(9) to a particular variable *i*. Finally, subtracting eq.(9) from eq.(8), the net spillovers from variable *i* to all other variables *j* can be obtained as:

$$NS_i(H) = DS_{i\rightarrow}(H) - DS_{\rightarrow i}(H) \tag{10}$$

Net spillovers indicate which variable is a transmitter of spillovers in net terms.

We need to mention that Diebold and Yilmaz procedure ignores covariance dynamics and the spillover information from them. As highlighted by Fengler and Gliser (2015) and Chanatasing-Niza et al. (2022), the Diebold and Yilmaz's procedure is a univariate regression model on variance, thus neglecting the covariance channels of volatility spillovers and the joint variability of market returns. This may lead to underestimate spillover indexes and the role of the systemic risk associated to the multivariate system in the forecast error variance. This issue becomes more severe with high frequency data. Our analysis does not consider the relationships between markets due to covariance dynamics. Nevertheless, we are dealing with low-frequency data, which drastically mitigates the extent of the issue.

4.2 Econometric approach for the determinants of outward spillovers

In this second stage of the analysis, we investigate an under-researched topic, that is, we evaluate the factors contributing to volatility spillovers (to and from) in the four GCC export portfolios by utilizing panel linear models, where spillovers are the dependent variables. In each portfolio, importing markets are considered as panels *i* and *t* corresponding to years 2008–2018.

The annual directional volatility spillovers here used derive from a Generalized FEVD constructed using monthly data for each specific year from 2008 to 2018. As shown by Gorodnichenko and Lee (2020), FEVD may lead to biased estimates in small samples. They proposed a bootstrap procedure to correct for potential biases in the FEVD estimates by using local projections. Alternatively, Choi and Shin (2020) proposed a bootstrap procedure for volatility spillover indices focusing on standard errors and confidence intervals.[11] In this study, we adopt the bootstrap procedure intro-

11. The residual bootstrapping of Paparoditis (1996) is used for estimations of standard error estimates while confidence intervals are constructed from the distributions of pivots for which we consider a t-type pivot with normal quantile. This combined method has been shown to outperform other possible candidate methods in a Monte-Carlo comparison (Choi and Shin, 2018).

duced by Choi and Shin (2020) to obtain consistent and statistically meaningful directional spillover indices. Using 1000 iterations, we calculate directional volatility spillover indices for each year from 2008 to 2018. The annual indices are computed by taking the mean of the bootstrap indices. This approach enables the spillover indices to adopt a panel structure, with *t* representing the years and *i* denoting the importing countries. These annual indices serve as the dependent variables in our panel linear regression models.

Spillovers are a function of five potential channels used as explanatory variables in panel linear regression models, namely, i) economic policy uncertainty, ii) market shares of RES, iii) industrial productivity index, , iv) exchange rates, and the v) the VIX index which captures perceptions of market risk, The first four variables are country-specific indices, whilst the last is common to all countries and is used as a control variable—reflecting investor expectations of the market.

These five driving mechanisms are selected based on an extensive literature, including Karali and Ramirez (2014), Wei et al. (2017), Fang et al., 2018, Hu et al. (2020), Canh et al., (2020) Alkathery and Chaudhuri (2021), Hameed et al. (2021), and finally, Nguyen and Walther (2020).[12]

We use the Word Uncertainty Index (explained below) to depict the energy policy channel through which shocks spread to export portfolios (Ahir et al., 2022). Crude oil, as one of the most important global commodities, is materially impacted by economic policy uncertainty (see amongst others Antonokakis et al., (2017), Hu et al. (2020) and Canh et al. (2020)). Since energy is crucial to production and economic activities, the energy sector has one of the highest levels of risk transmission in the market (He et al., 2017), highlighting the importance of identifying the implications of word uncertainty (such as military tensions, disruption of political and commercial ties) on business cycles, investors' planning decisions and diversification strategies (see Bouoiyour and Selmi, 2019; Bouri et al., 2018; Charfeddine and Al Refai, 2019).

The *World Uncertainty Index (WUI)* is a quarterly index constructed for 143 countries from 1996 onwards and uses a frequency count of "uncertainty" (and its variants) in quarterly Economist Intelligence Unit (EIU) country reports (Ahir et. al, 2022). EIU reports discuss major political and economic developments in each country, along with analysis and forecasts of political, policy and economic conditions. Higher values for the index imply higher economic and policy uncertainty. raw counts have been scaled by the total number of words in each report to make the uncertainty index comparable across countries.[13] We use the annual average of quarterly indices.

VIX index is used to capture equity and bond market stress, along with investors sentiment (and panic).[14] Antonokakis et al. (2017) and Prokopczuk et al. (2019) show the significant link between uncertainty and oil volatility, highlighting common movements, especially during crisis periods. Hu et al. (2020) stress the significant predictive power of this economic risk index in driving oil market volatility. *VIX* corresponds to the risk-neutral expectation of the next 30-day volatility extracted from out-of-the-money call and put options on the S&P 500 index and is obtained from the Chicago Board Options Exchange. Higher values indicate that market participants expect stock markets to fluctuate more, reflecting an uneasy mood of market participants. Conversely, lower val-

12. The scope of our analysis does not consider the effects of oil technology developments. Acknowledging the core role of technology, this aspect deserves specific analysis to be developed in further research.

13. The index is sourced from the website www.policyuncertainty.com by Baker S.R., Bloom N. and Davis S.J. (https://www.policyuncertainty.com/wui_quarterly.html) which contains many of the indices depicting the economic and political uncertainty of countries. Among the various indices, the WUI was selected because it is the only index with an appropriate geographical coverage. All the other indices (EPU or GRI for instance) lack the relevant time series for many of the importing countries.

14. This monthly index is available at the following link: https://www.cboe.com/tradable_products/vix/vix_historical_data/.

ues suggest market participants expect the stock market to be in a state of comparative stability. In this article, we employ the monthly average of the daily closing values.

We control for *RES* shares in importer country's domestic energy mix. As *RES* are endogenous resources, increasing their share in the energy mix has been an important instrument to reduce dependence on imported fossil fuels (natural gas, liquids), achieve energy security goals and net zero commitments. Their integration in the power system defuses the impacts of price volatility which characterizes global energy markets (Gouveia et al., 2014; Rentizelas et al., 2012). To depict the role of *RES*, we use the annual share of low carbon energy production for importer countries.[15]

The last two variables depict macroeconomic factors, that is, the industrial and financial channels. The industrial dimension is expressed by the industrial productivity index (*IPI*), that is, changes in output (physical quantity) produced by manufacturing, mining, gas and electricity sectors.[16]

The exchange rate (*EXC*) represents the financial dimension and is expressed by the annual average of dollar exchange rates for each importer country.[17] Morana (2013) underlines the importance of the exchange rate regime in shaping the risk faced by exporting countries. Excluding exchange rate from the analysis may lead to serious overestimation bias, since the exchange rate is often the major pass-through channel for oil prices effects in the exporting countries. Since the U.S dollar is the major denomination currency for international crude oil trading, changes in the value of dollar exchange rates have a domino effect on crude oil prices. In recent decades, a large amount of literature provides evidence of a causality relationship that runs from exchange rates to oil prices, with a depreciation of the dollar triggering a reduction in oil prices for oil-importers (see among others Wen et al. (2020), Huang et al. (2017), and Beckmann and Czudaj (2013)). Substantial increases in aggregate demand promote and raise crude oil prices. On the supply side, oil-exporting economics prefer to increase crude oil prices to cover risk and maintain the purchasing power of their domestic currencies.

4.2.1 Model Specification

The econometric specification is as follows:

$$S_{i,t} = \beta_1 WUI_{i,t} + \beta_2 RES_{i,t} + \beta_3 IPI_{i,t} + \beta_4 EXC_{i,t} + \beta_5 VIX_t + \varepsilon_{i,t} \tag{11}$$

where, $S_{i,t}$ is the annualized spillover index of importer country $i = 1,\ldots,5$ and the year t = 2008–2018, $\varepsilon_{i,t}$ is the normally distributed error term.

The model can equally be written in a stacked form as follows:

$$\boldsymbol{S} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon} \tag{12}$$

where the *(5T×1)* vector $\boldsymbol{S} = \begin{bmatrix} \boldsymbol{S}_1 & \ldots & \boldsymbol{S}_5 \end{bmatrix}'$ contains the five *(T×1)* vectors of spillover indices of each importer, the *(5T×5T)* matrix $\boldsymbol{X} = \begin{bmatrix} \boldsymbol{WUI}_1\,\boldsymbol{VIX}_1 & \boldsymbol{RES}_1\,\boldsymbol{IPI}_1 & \boldsymbol{EXC}_1 \\ \vdots\vdots & \vdots\vdots & \vdots \\ \boldsymbol{WUI}_5\,\boldsymbol{VIX}_5 & \boldsymbol{RES}_5\,\boldsymbol{IPI}_5 & \boldsymbol{EXC}_5 \end{bmatrix}$ contains the vector of

15. Low-carbon energy is defined as the sum of nuclear and renewable sources. Traditional biofuels are not included. This annual index is sourced from https://ourworldindata.org/grapher/low-carbon-share-energy.

16. This annual index is sourced from https://db.nomics.world/IMF/PGI.

17. This index is sourced from https://data.worldbank.org/indicator/PX.REX.REER.

explanatory variables, and $\boldsymbol{\varepsilon} = \left[\boldsymbol{\varepsilon}_1 \quad \ldots \quad \boldsymbol{\varepsilon}_5\right]'$ contains the five *(T×1)* disturbance terms specific of each importer.

The variance covariance matrix of the disturbance terms can be written as follows:

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_{1,1}\boldsymbol{\Omega}_{1,1} & \sigma_{1,2}\boldsymbol{\Omega}_{1,2}\ldots & \sigma_{1,5}\boldsymbol{\Omega}_{1,5} \\ \vdots & \ddots & \vdots \\ \sigma_{5,1}\boldsymbol{\Omega}_{5,1} & \sigma_{5,2}\boldsymbol{\Omega}_{5,2}\ldots & \sigma_{5,5}\boldsymbol{\Omega}_{5,5} \end{bmatrix} \tag{13}$$

$\Omega = E\left(\varepsilon'\varepsilon\right)$ is a *(5T×5T)* matrix consisting of many block matrices $\boldsymbol{\Omega}_{i,j}$, with *i,j*=1,…,5, defining the cross-sectional correlation matrixes. This generic form of variance-covariance matrix allows for heteroskedasticity, cross-sectional and serial correlation.

The (feasible) generalized least square (GLS) estimator of $\boldsymbol{\beta}$ is given by:

$$\hat{\boldsymbol{\beta}}_{FGLS} = \left(\boldsymbol{X}\hat{\boldsymbol{\Omega}}\mathbf{X}\right)^{-1}\left(\boldsymbol{X}\hat{\boldsymbol{\Omega}}\mathbf{Y}\right) \tag{14}$$

$\hat{\boldsymbol{\beta}}_{FGLS}$ is based on the consistent estimation of the $\boldsymbol{\Omega}$ matrix.

To check the robustness of our empirical estimates, three different regression models are applied, corresponding to three different assumptions on the variance covariance matrix $\boldsymbol{\Omega}$: i) the heteroskedastic GLS (H-GLS) linear model, ii) the heteroskedastic GLS with cross-sectional correlation (HC-GLS), and iii) the heteroskedastic GLS with first order autocorrelation among panels (H-GLS(AR1)).

In the H-GLS model, the variance covariance matrix is as follows:

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_1^2\boldsymbol{I}_T & 0\ldots & 0 \\ \vdots & \ddots & \vdots \\ 0 & 0\ldots & \sigma_5^2\boldsymbol{I}_T \end{bmatrix} \tag{15}$$

In the HC-GLS model, the variance covariance matrix is as follows:

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_1^2\boldsymbol{I}_T & \sigma_{1,2}\boldsymbol{I}_T\ldots & \sigma_{1,5}\boldsymbol{I}_T \\ \vdots & \ddots & \vdots \\ \sigma_{5,1}\boldsymbol{I}_T & \sigma_{5,2}\boldsymbol{I}_T\ldots & \sigma_5^2\boldsymbol{I}_T \end{bmatrix} \tag{16}$$

In the H-GLS(AR1) model, error terms are assumed to follow a (stationary) AR(1) process:

$$\varepsilon_{i,t} = \varrho\varepsilon_{i,t-1} + \nu_{i,t} \tag{17}$$

and

$$\boldsymbol{\Omega}_{i,i} = \frac{1}{1-\rho^2}\begin{bmatrix} 1 & \rho\ldots & \varrho^{T-1} \\ \vdots & \ddots & \vdots \\ \rho^{T-1} & \rho^{T-2}\ldots & 1 \end{bmatrix} \tag{18}$$

The consistent estimations of Ω in the three different models are described in Greene (2012), Bai et al. (2021), and Abadie et al. (2023).

5. RESULTS

5.1 The volatility spillover indexes.

We start by computing the volatility spillover indices for the four portfolios. The results are based on a *VAR(p)* fitting and 10-step-ahead volatility forecast error variance decomposition. The adequate lag length for VAR models is selected according to the Akaike Information Criteria (AIC)[18]. Optimal lag lengths are shown in Table 1.

Table 1: VAR (p) model details, by exporting country' portfolio, volume growth and prices.

	Quantity	Price
	Var(p)	*Var(p)*
Kuwait	5	2
Oman	4	2
Saudi Arabia	2	3
United Emirates of Arabia	4	2
N. Observation	132	132

Note: The column "Quantity" shows the selected number of lags *p* to be included in the VAR model of each export-volume growth portfolio.
The column "Price" shows the selected number of lags *p* to be included in the VAR model of each export- price portfolio.

Generalized variance decomposition methods are usually based on the normality assumption of the time series. We check this assumption by performing both univariate and multivariate normality tests.[19] In the univariate case, for each portfolio, we consider the return vector of each importer separately, as a sample realization drawn from a univariate normal distribution and employ the Shapiro-Wilk normality test.[20] In the multivariate case, we assess whether the return vector $\theta^{*}_{m,t}$ constitutes a sample realization drawn from a multivariate normal distribution. We employ the energy multivariate normality test proposed by (Rizzo and Szekely, 2017).[21] Table 2 shows that for each portfolio tests are not significant, and we cannot reject the null hypothesis that return vectors are normally distributed.[22]

Table 3 refers to volatility spillovers among Kuwait's main importing countries. Panel A pertains to oil quantity spillovers, while Panel B pertains to price spillovers. Firstly, the TSI is approximately 40% for the quantity portfolio and 61% for the price portfolio. Looking at the Panel A, India absorbs more shocks than it spills. Indeed, the spillovers from India to other countries ("Spill.

18. Akaike information criterion is an estimator of prediction error and thereby relative quality of statistical models for a given set of data. In other words, it is a mathematical method for evaluating how well a model fits the data it was generated from.

19. We thank the anonymous reviewer for this suggestion, which enhances the robustness of the analysis and results.

20. Compared to alternative normality tests, such as the Jarque-Bera, Kolmogorov-Smirnov, or the Anderson–Darling tests, the Shapiro Wilk (1965)'s test is widely recommended since it provides higher statistical power. It is especially suitable when the sample size (n) is not large. The test is based on the correlation between the data and their corresponding normal scores. The test statistic always falls between 0 and 1, for values sufficiently close to 1 (depending on n), the null hypothesis of normality will not be rejected.

21. The asymptotic distribution of the E-statistic for the energy multivariate normality test is a quadratic form of centred Gaussian random variables and the p-value is computed using Imhof's method (Imhof, 1961).

22. Only in one case the normality assumption is rejected. We refer to the Taiwan's returns in the export-volume growth portfolio of Oman. We conclude that this single deviation from normality assumption is negligible, and it will not undermine the analysis for the mentioned portfolio.

Table 2: Shapiro-Wilk univariate test and Szekely-Rizzo test for the normality of time-series.

	Shapiro-Wilk test[a]		Szekely-Rizzo[b]	
Kuwait	**Stat.**	**p-value**	**Stat.**	**p-value**
Panel A: Quantity			1.071	0.732
South Korea	0.984	0.130		
China	0.986	0.208		
Japan	0.991	0.507		
India	0.994	0.843		
Taiwan	0.988	0.312		
Panel B: Price			1.104	0.551
South Korea	0.987	0.260		
China	0.996	0.956		
Japan	0.991	0.507		
India	0.989	0.364		
Taiwan	0.990	0.447		
Oman	**Stat.**	**p-value**	**Stat.**	**p-value**
Panel A: Quantity			1.090	0.617
South Korea	0.991	0.551		
China	0.989	0.344		
Japan	0.991	0.600		
India	0.993	0.726		
Taiwan	0.979	0.041		
Panel B: Price			1.141	0.384
South Korea	0.993	0.753		
China	0.994	0.819		
Japan	0.991	0.600		
India	0.983	0.103		
Taiwan	0.989	0.401		
Saudi Arabia	**Stat.**	**p-value**	**Stat.**	**p-value**
Panel A: Quantity			1.117	0.493
China	0.984	0.132		
Japan	0.994	0.843		
USA	0.994	0.873		
South Korea	0.996	0.968		
India	0.993	0.804		
Panel B: Price			1.002	0.936
China	0.990	0.479		
Japan	0.993	0.750		
USA	0.994	0.873		
South Korea	0.983	0.101		
India	0.992	0.689		
UAE	**Stat.**	**p-value**	**Stat.**	**p-value**
Panel A: Quantity			1.088	0.634
Japan	0.987	0.271		
India	0.983	0.091		
Thailand	0.991	0.551		
China	0.994	0.820		
Singapore	0.991	0.519		
Panel B: Price			1.099	0.604
Japan	0.997	0.993		
India	0.987	0.258		
Thailand	0.991	0.551		

(continued)

Table 2: Shapiro-Wilk univariate test and Szekely-Rizzo test for the normality of time-series *(continued)*.

	Shapiro-Wilk test[a]		Szekely-Rizzo[b]	
Panel B: Price			1.099	0.604
China	0.995	0.908		
Singapore	0.994	0.870		

Note: a: Shapiro-Wilk Test is a univariate test on the normality of the single return time series of each export-volume growth rate/price portfolio.
H_0: Time series is normally distributed.
The first column contains the value of the statistic test.
The second column contains the p-value of the test.
b: Szekely-Rizzo is a multivariate test on the multivariate normality of the 5 return time series composing each export-volume growth rate/price portfolio.
H_0: Time series are normally distributed.
The first column contains the value of the statistic test.
The second column contains the p-value of the test.

to O.") account for 3.326%, while the spillovers to India ("Spill. from O.") amount to 7.818%. The same relative pattern arises in Japan and South Korea. An opposite relationship is found in China, and Taiwan, which act as net transmitters. The net spillover index of South Korea is negligible, indicating a balanced structure. Japan instead spills to others by 6.949%, while absorbing from others 8.832%. China and Taiwan contribute to the rest of variance by 8.274% and 12.812%, respectively, while they receive 5.768% and 7.818%. This suggests potential shocks triggered in China could spill to other importing countries.

Table 3: Directional spillover index for Kuwait's exports portfolio: volume growth and price.

Kuwait								
Panel A: Quantity								
	South Korea	China	Japan	India	Taiwan	Spill. from O.	Net	N.T.[a]
South Korea	10.772	3.966	1.49	0.559	3.212	9.228	–0.623	F
China	3.124	14.232	0.750	1.074	0.819	5.768	2.506	T
Japan	1.637	0.836	11.168	0.64	5.719	8.832	–1.883	F
India	1.817	1.406	1.533	12.182	3.061	7.818	–4.492	F
Taiwan	2.028	2.065	3.175	1.053	11.679	8.321	4.491	T
Spill. to O.	8.605	8.274	6.949	3.326	12.812	39.966		
Spill. to O. including own	19.378	22.506	18.117	15.508	24.491	100		
Panel B: Price								
	South Korea	China	Japan	India	Taiwan	Spill. from O.	Net	N.T.[a]
South Korea	10.768	0.946	1.145	3.269	3.872	9.232	18.820	T
China	7.934	7.360	0.407	1.555	2.743	12.640	–10.624	F
Japan	6.644	0.219	5.565	3.402	4.169	14.435	–8.758	F
India	6.004	0.483	2.046	8.465	3.002	11.535	–0.154	F
Taiwan	7.469	0.368	2.079	3.155	6.928	13.072	0.714	T
Spill. to O.	28.052	2.016	5.677	11.381	13.786	60.913		
Spill. to O. including own	38.82	9.376	11.243	19.846	20.715	100		

Note: a: Column N.T. stands for "Net Transmitter" and indicates whether the importer is a net transmitter of shocks (T) or not (F).

Moving to the price returns portfolio, the decomposition of volatility spillovers yields a different input-output scenario. Asymmetry between contributions to- and from- is most pronounced in South Korea, China, and Japan. Shocks from South Korea to the other markets account for 28.052%, while shocks South Korea receives from others amount to 9.232%. With a value of 18.820%, South

Korea records the highest net spillover index across all four price portfolios, resulting in being a pivotal driver of the systemic risk of the Kuwait's price portfolio. China receives from others (12.640%) more than it spills to (2.016%). It is the trading partner with the largest (negative) net spillover index (–10.624%), highlighting a core role in absorbing price shocks from other markets in the Kuwait's portfolio. Japan is the markets which receives the largest contributions from others, by 14.435%, while contributing to the TSI by 5.677%, respectively. The remaining countries exhibit a comparable magnitude of spillovers to- and from-. Taiwan confirms being net transmitter, as in the quantity portfolio, while India and Japan confirm receiving more shocks than they spill.

Looking at the spillover indexes between two importers, in Panel A, the quantity directional spillover from Taiwan to Japan is remarkably high, equal to 5.719, highlighting a strong interdependency between these two countries. Specifically, within Kuwait's export volume growth portfolio, shocks occurring in Taiwan will be mainly absorbed by Japan. The same reasoning can be applied in the price portfolio regarding the spillover from South Korea to China, equal to 7.934.

Oman (Table 4) is characterized by a different structure of volatility across its main oil buyers (despite having the same buyers as Kuwait). Both quantity and price portfolios are characterized by a lower TSI, equal to 30.979% and 39.005%, respectively. Focusing on Panel A, asymmetry arises in India and Taiwan, while other importers show a symmetric structure in terms of directional spillovers. Specifically, India and Taiwan show the largest net spillover indices (in absolute value) recorded in all the four quantity portfolios, but in opposite directions. Taiwan spills to other importers by 18.524% and receives spillovers from others by 2.523%, resulting in a net transfer of 16.001%. Conversely, India contributes to other oil-importing countries by 1.723%, while the other importers spill to India by 13.866%, resulting in a net spillover index of –12.143%. Along with Taiwan, China, and South Korea act as net transmitters, albeit to a negligible extent, while Japan is a net receiver of shocks, similar to India.

Looking at the directional volatility between two countries, the spillover index from Taiwan to India reaches the highest value of 11.003%, confirming their respective roles of transmitting and absorbing shocks.

Table 4: Directional spillover index for Oman's export portfolio: volume growth and price.

Oman								
Panel A: Quantity								
	South Korea	China	Japan	India	Taiwan	Spill. from O.	Net	N.T.[a]
South Korea	17.639	0.455	1.026	0.066	0.815	2.361	0.601	T
China	0.712	16.235	0.74	0.406	1.907	3.765	0.461	T
Japan	0.769	1.750	11.536	1.146	4.798	8.464	–4.920	F
India	0.718	0.886	1.258	6.134	11.003	13.866	–12.143	F
Taiwan	0.763	1.135	0.52	0.106	17.477	2.523	16.001	T
Spill. to O.	2.962	4.226	3.544	1.723	18.524	30.979		
Spill. to O. including own	20.601	20.461	15.08	7.857	36.001	100		
Panel B: Price								
	South Korea	China	Japan	India	Taiwan	Spill. from O.	Net	N.T.[a]
South Korea	13.981	1.15	2.812	1.206	0.852	6.019	1.346	T
China	1.372	8.187	4.084	2.588	3.768	11.813	–5.711	F
Japan	4.126	1.073	11.693	1.529	1.579	8.307	3.363	T
India	1.325	1.816	2.003	13.874	0.982	6.126	0.561	T
Taiwan	0.542	2.063	2.772	1.364	13.260	6.740	0.440	T
Spill. to O.	7.365	6.102	11.670	6.687	7.18	39.005		
Spill. to O. including own	21.346	14.289	23.363	20.562	20.44	100		

Note: a: Column N.T. stands for "Net Transmitter" and indicates whether the importer is a net transmitter of shocks (T) or not (F).

Price spillovers exhibit a different structure. In Panel B, China and Japan show the highest imbalance between from- and to-spillovers, but in opposite directions. China spills to others by 6.102% while absorbing from others by 11.813%, corroborating its role as a net receiver of shocks from other markets also in the Oman's price portfolio. Conversely, Japan spills more to others (11.670%) than it absorbs (8.307%). Along with Japan, South Korea, India, and Taiwan also act as net transmitters, albeit to a negligible extent.

Table 5 shows that Saudi Arabia, amongst the GCC countries, records the highest TSI in both Panel A (quantity = 41.701) and B (price = 72.095). When comparing the quantity and price portfolios, the structure of directional spillovers is substantially different. In Panel A, all importers (except USA) exhibit asymmetric behaviour. China and Japan spill to other importers (11.612% and 13.525%, respectively) more than they are affected by shocks from others (8.729% and 9.075%, respectively). South Korea and India exhibit an opposite imbalance, acting as net receivers, spilling to others (7.912 and 1.715%, respectively) less than they absorb from others (10.914 and 5.095% respectively). USA also appears being net receiver, albeit to a limited extent. In Table 5, Panel B, unbalanced behaviour is observed for all importers except for China. Japan and South Korea are net transmitter markets and contribute to the portfolio variance by 26.753% and 22.933%, respectively, with spillovers from other importers of 12.032% and 13.190%, respectively. These asymmetries suggest that any potential shock triggered by Japan and South Korea could spill over to the rest of the oil-importing countries.

Conversely, China, USA and India behave as net receiver, shrinking the price volatility effects from other markets. Specifically, USA records the highest (negative) net spillover index of –13.529, highlighting its core role in absorbing price shocks within the Saudi Arabia portfolio.

Noteworthy is also the role played by USA and South Korea in absorbing quantity and price shocks triggered by Japan. Looking at the spillover indexes from Japan to USA, their values are equal to 3.139 and 7.474 in the quantity and price portfolios, respectively. On the other hand, the

Table 5: Directional spillover index for Saudi Arabia's export portfolio: volume growth and price.

Saudi Arabia								
Panel A: Quantity								
	China	Japan	USA	South Korea	India	Spill. from O.	Net	N.T.[a]
China	11.271	3.79	1.76	2.721	0.458	8.729	2.883	T
Japan	3.948	10.925	1.955	2.696	0.475	9.075	4.450	T
USA	2.568	3.139	12.111	1.768	0.414	7.889	–0.952	F
South Korea	3.192	4.962	2.392	9.086	0.368	10.914	–3.002	F
India	1.905	1.634	0.829	0.727	14.905	5.095	–3.38	F
Spill. to O.	11.612	13.525	6.937	7.912	1.715	41.701		
Spill. to O. including own	22.883	24.45	19.048	16.999	16.62	100		
Panel B: Price								
	China	Japan	USA	South Korea	India	Spill. from O.	Net	N.T.[a]
China	4.978	6.377	0.394	6.417	1.834	15.022	–0.645	F
Japan	3.604	7.968	0.864	6.237	1.326	12.032	14.721	T
USA	3.054	7.474	3.919	4.714	0.838	16.081	–13.529	F
South Korea	3.657	7.189	0.863	6.810	1.48	13.19	9.743	T
India	4.062	5.713	0.43	5.565	4.229	15.771	–10.292	F
Spill. to O.	14.377	26.753	2.552	22.933	5.479	72.095		
Spill. to O. including own	19.355	34.721	6.471	29.744	9.708	100		

Note: a: Column N.T. stands for "Net Transmitter" and indicates whether the importer is a net transmitter of shocks (T) or not (F).

spillover indexes from Japan to South Korea are equal to 4.962 and 7.189 in the quantity and price portfolios, respectively.

Looking at Table 6, the UAE shows a systemic risk of 34.205for the quantity portfolio and 58.519 for the price portfolio. Volatility spillovers among the importing countries of the UAE show that Japan is the main contributor, spilling to others by 11.053% in terms of quantity volatility and by 26.738% in terms of price volatility. It is also the most important net transmitter in both portfolios, with net spillover indexes of 4.039% and 17.769%, respectively.

In Panel A, Thailand and China are the other net contributors, spilling to other markets by 9.416% and 5.796%, respectively, while receiving from others 8.385% and 4.932%, respectively. Conversely, India and Singapore receive more from other markets than they spill to: 7.833% and 6.042% against 5.134% and 2.806%. Price volatility in Panel B is unbalanced. Along with Japan, Thailand spills to other markets more than it receives from others (22.021% and 9.477%, respectively). Conversely, India, China, and Singapore spill from others roughly four times more (between 12.318% and 15.133%) than they spill to others (between 2.304% and 4.363%).

Concerning the interdependencies among two countries, the price spillover index from Japan to India records the highest value of 7.954 in the UAE's price portfolio. India confirms again its pivotal role in shrinking the systemic risk. In particular, India predominantly fulfils this role in relation to the shocks caused by Japan.

Table 6: Directional spillover index for United Emirates of Arabia's export portfolio: volume growth and price.

UAE								
Panel A: Quantity								
	Japan	India	Thailand	China	Singapore	Spill. from O.	Net	N.T.[a]
Japan	12.986	1.19	5.122	0.528	0.173	7.014	4.039	T
India	3.625	12.167	2.447	1.415	0.346	7.833	–2.699	F
Thailand	4.853	1.577	11.615	0.881	1.074	8.385	1.031	T
China	1.07	1.617	1.033	15.068	1.213	4.932	0.864	T
Singapore	1.505	0.75	0.814	2.973	13.958	6.042	–3.236	F
Spill. to O.	11.053	5.134	9.416	5.796	2.806	34.205		
Spill. to O. including own	24.039	17.301	21.031	20.864	16.764	100		
Panel B: Price								
	Japan	India	Thailand	China	Singapore	Spill. from O.	Net	N.T.[a]
Japan	11.031	0.806	6.921	0.969	0.272	8.969	17.769	T
India	7.954	4.867	6.329	0.558	0.292	15.133	–10.77	F
Thailand	7.73	0.88	10.523	0.603	0.263	9.477	12.544	T
China	5.103	1.603	4.134	7.682	1.477	12.318	–9.226	F
Singapore	5.951	1.074	4.636	0.962	7.378	12.622	–10.318	F
Spill. to O.	26.738	4.363	22.021	3.092	2.304	58.519		
Spill. to O. including own	37.77	9.23	32.544	10.774	9.682	100		

Note: a: Column N.T. stands for "Net Transmitter" and indicates whether the importer is a net transmitter of shocks (T) or not (F).

To summarize the findings, *gross* volatility spillovers to others (Spill. To O. columns) for each GCC country portfolio are quite different. Similarly, differences were found vis-à-vis Spill. From O. columns. Finally, Total Volatility Spillovers of the export quantity portfolios are lower than those of price portfolios, confirming the structural rigidity of oil demand.

Regarding the three importers appearing in all quantity portfolios, China always behaves as a net transmitter, while India never acts as a net transmitter. Japan is a net transmitter only for the quantity portfolios of Saudi Arabia and UAE. Nevertheless, behaviours change substantially amongst price portfolios. For example, China never acts as a net transmitter, Japan acts as a net transmitter in the price portfolios of Oman, Saudi Arabia, and UAE, and India ceases to be a net receiver of shocks in the Oman's price portfolio.

South Korea imports oil from three of the four GCC countries and plays the role of net transmitter in all quantity and price portfolios, except for the export volume growth portfolio of Saudi Arabia. Taiwan acts as a transmitter both in the Kuwait and Oman portfolios. Singapore, Thailand, and the USA are included in just one of the four export portfolios, and only Thailand is a net transmitter vis-à-vis the UAE.

Beyond the technical results reported, it emerges that the same countries in different portfolios may show different behaviours (net-transmitter or receiver). These mixed results deepen the requirement to further analyse other macro-determinants.[23]

5.2 Macro-determinants of net spillover indexes

In this section, we analyse the effects of different institutional drivers on export portfolio volatility using panel data models. More specifically, we examine the role of economic policy uncertainty (*WUI*), financial uncertainty (*VIX*), and rising renewable market shares (*RES*) in driving directional volatility spillovers (to and from) within oil portfolios, including as control variables industrial production (*IPI*) and exchange rates (*EXC*). Heteroskedastic GLS models (H-GLS) accounting for cross-sectional correlation (HC-GLS) and serial correlation (H-GLS(AR1)) were performed.

5.2.1 Data Used in Panel Analysis

We first derive the dependent variables by computing the annual directional spillover indices (to and from) using the bootstrap procedure in Choi and Shin (2020). As in the previous step, the order of VAR is chosen according to the AIC criterion. Volatility spillovers are estimated by mean bootstrapping with B=1000 iterations.

Table 7 presents summary statistics of the directional spillover indices for both export-volume growth and price portfolios. The average bootstrap spillover indexes of the price portfolios are higher than those of volume growth portfolios, aligning with our previous results. Saudi Arabia exhibits the highest average bootstrap indexes for both volume growth and price portfolios, confirming the pattern we identified in the previous analysis.

Table 7 also provides summary statics of the main drivers of volatility, which constitute the explanatory variables in the panel linear models.[24]

The analysis reveals that the portfolios under examination exhibit a relatively similar level of economic policy uncertainty (*WUI*). However, the UAE's importing countries seem to experience a lower degree of uncertainty (11.598), both between and within countries. Conversely, the portfolio of Saudi Arabia faces a more uncertain scenario (14.900), primarily due to the presence of the USA.

Looking at the *VIX* index, which informs about the future equity price movements, shedding a light on shape of the worldwide volatility futures term structure, this index is common for all

23. The portion of export, the share of intra-GCC trade, the renewable transition of importing countries are all potential channels affecting the oil portfolio's volatility. For example, countries where energy transition has been already implemented, show higher volatility (Lisin and Senjyu, 2021).

24. The reader should note that the descriptive statistics of the explanatory variables for Kuwait and Oman are the same. This is because the two GCC countries share the same main importers; therefore, the country-specific indexes characterizing each importer are the same, as well as the aggregate summary statistics defining the oil import portfolios.

Table 7: Summary statistics of the variables (dependent and explanatory variables) used in econometric specifications by GCC country portfolios.

Kuwait portfolio—Importer countries: China, India, South Korea, Japan, Taiwan						
Dependent Variable		Mean	Std. Dev.	Min	Max	Obs.
Vl. Growth Spill. To O.	overall	13.996	8.216	2.835	37.194	N=55
	between		2.534	10.283	17.329	n=5
	within		7.891	1.192	38.544	T=11
V. Growth Spill. From O.	overall	13.996	2.724	7.777	19.620	N=55
	between		0.701	13.365	15.200	n=5
	within		2.650	6.964	19.836	T=11
P. Spill. To O.	overall	15.141	8.604	2.974	58.990	N=55
	between		2.871	11.462	19.001	n=5
	within		8.205	–0.885	57.498	T=11
P. Spill. From O.	overall	15.141	2.557	5.007	19.235	N=55
	between		0.797	14.229	16.145	n=5
	within		2.453	5.598	20.147	T=11
Explanatory Variables		Mean	Std. Dev.	Min	Max	Obs.
WUI	overall	14.442	9.917	0.000	43.488	N=55
	between		5.112	7.502	25.011	n=5
	within		8.611	–0.755	36.830	T=11
VIX	overall	19.779	6.862	11.096	32.656	N=55
	between		0.000	19.779	19.779	n=5
	within		6.862	11.096	32.656	T=11
RES	overall	10.103	3.063	6.019	18.238	N=55
	between		0.802	8.989	11.248	n=5
	within		2.964	5.518	17.093	T=11
IPI	overall	109.402	21.692	81.563	184.219	N=55
	between		11.430	90.561	126.601	n=5
	within		18.697	84.492	167.019	T=11
EXC	overall	264.972	438.805	6.143	1277.246	N=55
	between		11.566	251.251	291.815	n=5
	within		438.664	–20.011	1250.403	T=11
Oman portfolio—Importer countries: China, India, South Korea, Japan, Taiwan						
Dependent Variable		Mean	Std. Dev.	Min	Max	Obs.
V. Growth Spill. To O.	overall	13.333	5.715	1.442	26.402	N=55
	between		1.660	11.038	15.268	n=5
	within		5.515	2.436	26.494	T=11
V. Growth Spill. From O.	overall	13.333	2.082	8.926	17.280	N=55
	between		0.531	12.547	13.792	n=5
	within		2.026	8.467	17.546	T=11
P. Spill. To O.	overall	14.421	10.272	0.803	36.025	N=55
	between		2.703	11.472	18.302	n=5
	within		9.978	–0.102	38.405	T=11
P. Spill. From O.	overall	14.421	3.079	5.717	19.579	N=55
	between		0.823	13.214	15.086	n=5
	within		2.988	6.210	20.071	T=11
Explanatory Variables		Mean	Std. Dev.	Min	Max	Obs.
WUI	overall	14.442	9.917	0.000	43.488	N=55
	between		5.112	7.502	25.011	n=5
	within		8.611	–0.755	36.830	T=11
VIX	overall	19.779	6.862	11.096	32.656	N=55
	between		0.000	19.779	19.779	n=5
	within		6.862	11.096	32.656	T=11
RES	overall	10.103	3.063	6.019	18.238	N=55
	between		0.802	8.989	11.248	n=5
	within		2.964	5.518	17.093	T=11

(continued)

Table 7: Summary statistics of the variables (dependent and explanatory variables) used in econometric specifications by GCC country portfolios *(continued)*.

IPI	overall	109.402	21.692	81.563	184.219	N=55
	between		11.430	90.561	126.601	n=5
	within		18.697	84.492	167.019	T=11
EXC	overall	264.972	438.805	6.143	1277.246	N=55
	between		11.566	251.251	291.815	n=5
	within		438.664	–20.011	1250.403	T=11
Saudi Arabia portfolio—Importer countries: China, India, South Korea, Japan, USA						
Dependent Variable		Mean	Std. Dev.	Min	Max	Obs.
Vol. Growth Spill. To O.	overall	14.593	5.806	5.813	22.185	N=55
	between		6.432	5.813	22.185	n=5
	within		0.000	14.593	14.593	T=11
Vol. Growth Spill. From O.	overall	14.593	2.093	12.285	18.229	N=55
	between		2.319	12.285	18.229	n=5
	within		0.000	14.593	14.593	T=11
P. Spill. To O.	overall	15.606	2.753	10.348	17.857	N=55
	between		3.050	10.348	17.857	n=5
	within		0.000	15.606	15.606	T=11
P. Spill. From O.	overall	15.606	0.395	15.246	16.293	N=55
	between		0.438	15.246	16.293	n=5
	within		0.000	15.606	15.606	T=11
Explanatory Variables		Mean	Std. Dev.	Min	Max	Obs.
WUI	overall	14.900	9.255	0.000	43.488	N=55
	between		4.695	9.133	27.213	n=5
	within		8.078	–2.500	31.175	T=11
VIX	overall	19.779	6.862	11.096	32.656	N=55
	between		0.000	19.779	19.779	n=5
	within		6.862	11.096	32.656	T=11
RES	overall	11.324	3.555	6.019	18.238	N=55
	between		0.791	9.981	12.224	n=5
	within		3.472	5.917	17.448	T=11
IPI	overall	110.493	21.523	81.563	184.219	N=55
	between		12.117	89.923	128.845	n=5
	within		18.091	83.340	165.867	T=11
EXC	overall	259.000	442.202	1.000	1277.246	N=55
	between		11.373	245.392	285.411	n=5
	within		442.067	–25.411	1250.835	T=11
UAE portfolio—Importer countries: China, India, Japan, Singapore, Thailand						
Dependent Variable		Mean	Std. Dev.	Min	Max	Obs.
V. Growth Spill. To O.	overall	12.961	7.007	1.646	34.234	N=55
	between		3.704	9.977	17.442	n=5
	within		6.158	–2.836	29.752	T=11
V. Growth Spill. From O.	overall	12.961	2.632	7.008	18.577	N=55
	between		0.824	12.119	14.031	n=5
	within		2.525	7.850	17.906	T=11
P. Spill. To O.	overall	14.058	7.629	0.974	35.471	N=55
	between		2.415	11.721	16.928	n=5
	within		7.311	1.407	33.159	T=11
P. Spill. From O.	overall	14.058	2.586	6.717	19.062	N=55
	between		0.726	13.234	14.926	n=5
	within		2.501	7.298	18.480	T=11
Explanatory Variables		Mean	Std. Dev.	Min	Max	Obs.
WUI	overall	11.598	8.130	0.000	30.659	N=55
	between		3.036	5.902	16.120	n=5
	within		7.587	–1.353	29.960	T=11

(*continued*)

Table 7: Summary statistics of the variables (dependent and explanatory variables) used in econometric specifications by GCC country portfolios *(continued)*.

VIX	overall	19.779	6.862	11.096	32.656	N=55
	between		0.000	19.779	19.779	n=5
	within		6.862	11.096	32.656	T=11
RES	overall	6.413	4.629	0.187	18.238	N=55
	between		0.785	5.147	7.764	n=5
	within		4.567	–1.128	17.520	T=11
IPI	overall	110.320	22.540	77.137	184.219	N=55
	between		14.380	86.690	132.157	n=5
	within		17.792	79.855	162.382	T=11
EXC	overall	39.437	37.195	1.250	121.044	N=55
	between		4.452	32.938	45.409	n=5
	within		36.948	–4.598	115.072	T=11

Note: Table decomposes observation $x_{i,t}$ into a between, $\bar{x}_i$, and within $x_{i,t} - \bar{x}_i + \bar{x}$ part.
The overall mean $\bar{x}$ has to be added back to $x_{i,t}$ to make results comparable.
The overall and the within statistics are computed over the whole panel dataset of 55 observations.
The between statistics are computed over the 5 importers and the number of years is $T = 11$.
The "overall" rows of the columns "Min" and "Max" report the minimum and maximum of the whole panel dataset, respectively.
The "between" rows of the columns "Min" and "Max" report the minimum and maximum values of the averages of each panel.
The "within" rows of the column "Min" can show negative values. This is because the within number refers to the deviation from each individual's average, and naturally, some of those deviations must be negative.

countries analysed. Nevertheless, during the period considered, it records significant variability. For instance, it was notably affected by the US subprime mortgage storm—November 2008—reaching its all-time high values. Conversely, from 2015 to 2018, *VIX* reached exceptionally low prices, remaining in extremely low levels.

Looking at the penetration of renewables in the energy production mix, Saudi Arabia's importer countries exhibit the highest *RES* percentage of 11.324, which is almost double that of the UAE (6.413). The primary contributions come from the USA and South Korea, which have higher RES deployment compared to other importers. Additionally, Kuwait and Oman portfolios show an intermediate level of RES development, amounting to the 10.103%.

Figures related to the *IPI* index highlight a homogenous scenario with very small differences among portfolios, given that all these countries are developed and strongly interconnected with each other. Indeed, *IPI* ranges from 109.402 (in the Kuwait and Oman's portfolios) to 110.493 (in the Saudi Arabia's portfolio).

Given the close relationship between crude oil and foreign exchange markets, this variable has significant implications for monetary policy making, price setting, and risk management. Conversely, exchange rate varies across the analysed portfolios. Specifically, the UAE' portfolio is characterized by the lowest level at 39.44, whereas the other portfolios display higher and similar values, ranging from 264.972 to 259.

5.2.2 Estimation Results

Estimates are reported in Tables 8 and 9. Table 8 shows regression results for the models that use as dependent variables the volatility spillovers to others, quantity, and price (Panel A and Panel B, respectively). In both panels, WUI's coefficients are mainly significant and positive (ranging from 0.022 to 0.051). This result is consistent with a consolidated strand of literature that identifies significant co-movements between oil markets and policy uncertainty, highlighting that *WUI* has a predictive power in the oil market volatility dynamics. Moreover, coefficients are positive, suggesting that importer's policy uncertainty amplifies over the whole portfolio vis-à-vis the

Table 8: Panel estimation of the effects of policy and economic variables on volatility spillovers TO of export portfolios -Saudi Arabia, Kuwait, UAE, Oman (volume growth and price).

Panel A	**QUANTITY**											
	Saudi Arabia			Kuwait			UAE			Oman		
	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)
WUI	0.033**	0.039**	0.045**	0.022*	0.027*	0.029*	0.038*	0.036*	0.039*	0.040**	0.042**	0.034***
VIX	0.135*	0.130*	0.121***	0.137*	0.106*	0.059*	0.328***	0.327***	0.279***	0.147***	0.056**	0.167***
RES	0.386*	0.386*	0.424**	0.489*	0.484*	0.474**	0.325**	0.329**	0.377**	0.298*	0.246*	0.225*
IPI.	0.057***	0.057**	0.058***	0.059**	0.063***	0.077***	0.058**	0.058**	0.067***	0.080***	0.092***	0.088***
EXC	0.002*	0.002*	0.002*	0.003*	0.003*	0.003*	0.074**	0.074**	0.078**	0.002*	0.004***	0.002***
N	55	55	55	55	55	55	55	55	55	55	55	55

Panel B	**PRICE**											
	Saudi Arabia			Kuwait			UAE			Oman		
	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)
WUI	0.038**	0.044**	0.049*	0.026**	0.026**	0.035**	0.044**	0.042**	0.051***	0.047**	0.042**	0.041***
VIX	0.226*	0.209*	0.173***	0.372***	0.368***	0.276***	0.246***	0.245***	0.231***	0.085*	0.144*	0.218***
RES	0.191*	0.182*	0.222*	0.332*	0.356*	0.623*	0.176*	0.179*	0.236*	0.191**	0.179**	0.229***
IPI.	0.075*	0.074***	0.065***	0.125***	0.121***	0.129***	0.050***	0.049***	0.051***	0.120***	0.101***	0.136***
EXC	0.005*	0.005**	0.006**	0.005*	0.004*	0.002*	0.075***	0.074***	0.061**	0.007***	0.006***	0.008***
N	55	55	55	55	55	55	55	55	55	55	55	55

Note: The significance of coefficient estimates is expressed by: (i)* p-value<0.10, (ii) **p-value<0.05, (iii)*** p-value<0.01.

Table 9: Panel estimation of the effects of policy and economic variables on volatility spillovers from others of export portfolios -Saudi Arabia, Kuwait, UAE, Oman (volume growth and price).

Panel A	QUANTITY											
	Saudi Arabia			Kuwait			UAE			Oman		
	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)
WUI	0.028*	0.048*	0.037*	0.063*	0.051*	0.077***	0.022*	0.022*	0.026*	0.038*	0.025*	0.017*
VIX	0.202***	0.207***	0.217***	0.251***	0.237***	0.279***	0.221***	0.222***	0.239***	0.221***	0.101***	0.231***
RES	–0.251*	–0.238*	–0.234*	–0.417**	–0.382**	–0.414***	–0.184**	–0.187**	–0.222***	–0.178*	–0.162*	–0.183*
IPI	0.084***	0.081***	0.081***	0.124***	0.124***	0.111***	0.090***	0.090***	0.085***	0.114***	0.110***	0.100***
EXC	0.001**	0.002*	0.001***	0.001*	0.001	0	0.031***	0.032***	0.034***	0.001*	0.001*	0.001***
N	55	55	55	55	55	55	55	55	55	55	55	55
Panel B	**PRICE**											
	Saudi Arabia			Kuwait			UAE			Oman		
	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)	H-GLS	HC-GLS	H-GLS(AR1)
WUI	0.043*	0.042*	0.040*	0.041*	0.039*	0.031*	0.035*	0.057*	0.026*	0.050*	0.053*	0.043**
VIX	0.240***	0.240***	0.238***	0.172***	0.171***	0.182***	0.250***	0.246***	0.237***	0.161***	0.103***	0.189***
RES	–0.267*	–0.269*	–0.251*	–0.513	–0.419**	–0.413**	–0.289***	–0.286***	–0.285***	–0.440**	–0.238*	–0.180***
IPI	0.089***	0.089***	0.087***	0.078***	0.078***	0.084***	0.074***	0.073***	0.078***	0.062***	0.087***	0.074***
EXC	0.001*	0.001*	0.001*	0	0	0.001*	0.031***	0.030**	0.027***	0.002**	0.001*	0.002***
N	55	55	55	55	55	55	55	55	55	55	55	55

Note: The significance of coefficient estimates is expressed by: (i)* p-value<0.10, (ii) **p-value<0.05, (iii)*** p-value<0.01.

effect of a shock sourced from that importer. This positive sign confirms recent empirical research quantifying the costs of energy policy tensions on stock markets (see Berkman et al., 2011; He et al., 2017; Mnif, 2017; Bouoiyour and Selmi, 2019). This policy uncertainty creates severe financial repercussions in terms of spillover reactions to regional and international markets, leading to material losses of financial assets and the distortion of pricing dynamics. Lastly, as expected, coefficient estimates are larger in price portfolios (Panel B), confirming the structural rigidity of oil demand.

Coefficient estimates related to the *VIX* index are consistently positive and significant, confirming a direct correlation between financial uncertainty and oil market volatility. A deterioration in future market expectations increases the amplitude of shock spreads over oil export portfolios. In the export-volume growth portfolios, *VIX*'s coefficient estimates range from 0.056 to 0.328, while in price portfolios, values are larger, ranging from 0.085 to 0.372.

Looking at the effects of RES market shares, a positive effect on volatility spillover to others prevails in both quantity and price portfolios. Estimates lie between 0.225 and 0.489 in Panel A, and between 0.176 and 0.623 in Panel B. Fuel switching to domestic RES increases volatility spillover to others, and in turn, volatility over the whole oil-export portfolios. Policy implications for oil exporting countries are significant, viz. that climate change mitigation policies being undertaken worldwide threaten the stability of oil export portfolios, with predictable adverse long run consequences for revenue streams.

Estimated coefficients of industrial production (*IPI*) are positive and significant for all portfolios, confirming a close relationship between economic growth and price fluctuations in international crude oil markets (see also Van Eyden et al., 2019; Gong et al., 2020). Exchange rate (*EXC*) is also a significant determinant of spillovers to others in all portfolios. Overall, the effects are positive and more pronounced for UAE's portfolio aligning with the results of Akram (2009) and Gruber and Vigfusson (2018), where shocks to exchange rates account for a substantial share of fluctuations in commodity prices.

Table 9 shows the effects of economic and policy drivers on volatility spillovers from others which define the extent to which an importing nation can absorb shocks. Coefficient estimates for the *WUI* indices are significant and positive. In Panel A, coefficients range from 0.017 to 0.077, while in Panel B from 0.026 to 0.057. Increasing policy uncertainty in an importing country makes it more vulnerable to oil volatility, amplifying the shocks it must absorb from other importers. The same positive correlation is also found between volatility spillovers from and the *VIX* index—in Panel A, coefficients range from 0.101 to 0.279, while in price portfolios estimates lie between 0.103 and 0.250.

Looking at *RES*'s coefficients, estimates are significant and negative in most portfolios (except the H-GLS model of Kwait in Panel B). Coefficients range from –0.417 to –0.162, in panel A, and from –0.440 to –0.180, in panel B. These estimates are consistent with the findings in Rentschler (2013) who concludes that expanding renewables reduces an economy's vulnerability to oil price volatility. This result suggests that policies designed to increase RES market shares make countries with high oil export dependency less vulnerable to oil market shocks. Increasing the share of renewables in the domestic energy production mix reduces volatility spillovers from other markets. Once again, such a result highlights material implications for climate change mitigation policies, that is, such policies strengthen importers' energy security by reducing the shocks they must absorb from foreign oil exporting markets.

The effects of *IPI* are significant and positive as those recorded for spillovers to others. On the other hand, the *EX*C's effects on spillovers from others are, on average, smaller than those recorded in spillovers to others, when significant. Specifically, in the Kuwait portfolio, the effects are almost insignificant or negligible. This result is consistent with the finding in Wen et al. (2020) which suggests that the link between risk spillovers and exchange rates is much stronger for oil-exporting countries than for oil-importing countries.

6. DISCUSSIONS AND POLICY IMPLICATIONS

By employing a consolidated application of financial portfolio theory in the energy security domain, we provided a measure of risk associated with portfolio composition and assess spillover effects.

Our analysis has been undertaken in the context of an irreversible global trend: new energy policies are aiming at mitigating climate change and, by design, reducing global demand for fossil fuels[25]. GCC countries rely heavily on international oil markets as a primary source of national income. Oil portfolio risk management will become increasingly important for GCC countries given the axiomatic long-term implications of a world economy less dependent on oil. Understanding how existing oil portfolios behave vis-à-vis quantity and price volatility spillovers is an important first step in managing risk in the transitional period. Once spillovers and their relationships are understood, oil export portfolios can be re-balanced through a targeted re-weighting of export shares. This can effectively mitigate portfolio return risks, providing a relatively stable fiscal foundation for GCC countries. This stability enables them to focus on their long-term domestic economic restructuring and transition.[26]

The structural rigidity of oil demand was confirmed by the fact that quantity volatility spillovers were, on average, lower than price. The inelastic demand of major trading partners, jointly with China and India's additional oil demand, is likely to raise oil price volatility and can be expected to induce *insecurity* during supply disturbances. This establishes a predictable and circular reasoning regarding the rise in RES market shares.

The analysis of net contributors for both kinds of volatility also provided useful information. Among the countries belonging to all portfolios, only China was a consistent net transmitter in quantity spillovers. This result highlighted the pivotal role held by China in driving the dynamics of global oil demand and energy security. Conversely, it is worth noting that India's spillovers to other countries were lower than its spillovers from them, implying that India is a net receiver. This finding is significant, emphasizing that India is not actively influencing the market but rather absorbing shocks from it. This being the case, one logical implication would be for any GCC country experiencing volatile fiscal conditions within their own economy might seek to rebalance their oil portfolio more heavily to India whilst simultaneously driving broader economic restructuring within their own domestic economy.

When considering all portfolios, we found total spillovers are lower than values typically reported in financial markets. These results suggest that a significant proportion of volatility is due to intrinsic factors and shocks that are specific to individual countries, although oil markets are a global market. Numerical results confirm net spillover effects exhibit heterogeneity in different markets. In Saudi Arabia's portfolio, the net index is higher in Japan and Korea, which can be interpreted as a closer interconnection of Saudi Arabia with manufacturers of Asia. For Saudi Arabia, such linkages give rise to portfolio risk exposures to manufacturing business cycles, i.e. both up- and downward cycle risks.

25. See for example IRENA (2019), OSCE-PA (2022) and Resources for the Future (2022).

26. It is beyond the scope of our research to offer the micro-level policy adjustments—but it should be obvious that stabilizing portfolio revenues at country-level will provide a materially better base for doing so.

To assess the effects of energy policy trends and climate change mitigation policies, we have used panel econometric models where spillovers, to and from, are functions of two specific indices—measuring the degree of economic policy uncertainty (*WUI*) and the market share of *RES* within importing country's energy production mix.

Our analysis revealed that spillovers are significantly driven by these determinants.Economic policy uncertainty increases spillovers in both directions (to and from), testifying that political tensions increase oil market fluctuations. Therefore, rising economic policy uncertainty in import markets will increase oil export portfolio volatility, and in turn, GCC country risks with respect to their primary source of income.

Rising RES market shares affect importer economies with spillovers (to and from) flowing in opposite directions, as expected. Increasing RES market shares in importers' energy production mix amplifies the volatility of oil export portfolios, threatening the reliance and stability of oil export revenues. Conversely, fuel switching to domestic RES demonstrates an ability to reduce volatility spillovers coming from foreign markets. This, in turn, mitigates effects of fossil fuel scarcity in importing countries, thereby enhancing their energy security.

The opposite effects of climate change mitigation policies on volatility spillovers suggest an outcome that can be traced back to the "Beggar Thy Neighbour" policy, since environmental policies aiming at shifting domestic energy demand from oil imports to domestic RES can potentially worsen the economic conditions of other GCC counterparties. Consequently, importing countries can be expected to continue to pursue growth in RES, not only to meet net zero obligations, but to reduce volatility spillovers. As for GCC countries, this will necessitate broader microeconomic adjustments to their respective macroeconomies over time.

Fuel-switching towards a sustainable development has become unavoidable. During the transitional period, GCC countries can assume a strategic role and take actively part in transition.

As highlighted by the IEA (2020), two trends are emerging in the oil demand sector. Societies are simultaneously demanding energy services and reductions in emissions. However, the unstable availability of renewable energy sources warns that renewable technologies still need a hybrid system (integrated with traditional energy sources) to fulfil the increasing energy demand. In particular, the increased demand and the COVID-19 pandemic have exposed weak links in the global supply chain, which has already been struggling under an interconnected web of risks. Many raw materials supporting the renewable energy supply chain are in short supply, especially those related to solar energy: polysilicon, metallurgical-grade silicon, silicon wafers, and ingots. Unprecedented events such as the Suez Canal blockage, clogged ports worldwide, a global shortage of drivers, and shipping containers have caused transportation slowdowns that are difficult to resolve in a few years. All these factors menace to disrupt the global supply chain.

Within these opposing trends, GCC countries are finding their place and facing the strategic challenge of balancing short-term returns with their long-term license to operate. GCC countries are unavoidably reacting to the changing energy dynamics by developing new models of resource consistent with decarbonization and economic diversification. They are providing resources and increasing investment to help capital-intensive clean energy technologies reach maturity. These investments would lead to several social impacts, such as improving health, reducing gender inequality, and alleviating poverty by providing job opportunities in rural areas. An annual increase in electricity generation by 1 gigawatt-hour (GWh) from renewable energy sources could offer 3.5 jobs (Arvanitopoulos and Agnolucci, 2020).

Globally, renewable energy sources are considered the most effective solution to minimize the social and environmental problems associated with non-renewable energy sources. The GCC countries have embraced this challenge and begun to play a central role in addressing emissions reduction from some of the hardest-to-abate sectors.

7. CONCLUSIONS

In this article, the concept of energy security has been investigated from an exporter perspective, and specifically, the inherent risk within oil export portfolios of four GCC countries. We developed a joint measure of the risk-return trade-off, viewed from the perspective of a single oil exporter, which encompasses bilateral relationships with a group of prominent importing nations. In this view, we reconstructed the portfolios of counterparties and assessed impacts of potential shocks and vulnerabilities. Financial portfolio theory was applied to energy security allowing us to estimate a new measure of portfolio risk volatility and the associated spillover effects, shedding light on the cross-volatility transmission of different importing markets within a given portfolio. Directional spillovers (to and from others) were computed in order to investigate the behaviours of different importers and the main determinants of their directional effects.

As expected, rising economic policy uncertainty amongst importers, and expectations of declining financial markets, aggravate in both directions, volatility spillovers among export portfolios. Rising renewable market shares in importing countries has the opposite effect on GCC portfolios, depending on the direction of spillovers. Spillovers to others are spurred by deepened RES market shares, increasing the overall volatility of portfolios. Conversely, rising renewable market shares dampen quantity and price spillovers from, helping importers to react and absorb foreign market shocks. This "Beggar Thy Neighbour" outcome confirms the dual objectives of climate change policies, i.e., net zero emissions and the reduction in exposure to adverse oil market fluctuations. This has meaningful implications for the GCC countries. Understanding how existing oil portfolios behave with respect to quantity and price volatility spillovers is therefore a first step in managing risk in a transitional period, by re-balancing their export allocations.

Using econometric techniques typical of financial analysis, our analysis showed the need to jointly address climate change, global trade and energy security in a concerted strategy involving both importer and exporter oil countries.

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