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Bigerna, Simona and D'Errico, Maria Chiara and Polinori, Paolo and Simshauer, Paul

Department of Economics, University of Perugia, Department of Economics, University of Perugia, Department of Economics, University of Perugia, Centre for Applied Energy Economics Policy Research, Griffith University and Energy Policy Research Group, University of Cambridge

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S. Bigerna[1], M.C. D'Errico[1], P. Polinori[1] P. Simshauser[2,3]

Abstract
Over time, Gulf Cooperation Council (GCC) countries have accumulated large oil portfolio revenues. But the world economy is seeking to reduce greenhouse gas emissions and in turn, its reliance on fossil fuel resources through ongoing investments in renewable energy resources. In this article, we construct oil portfolios for four of the GCC countries (viz. Kuwait, Saudi Arabia, United Arab Emirates, Oman) and focus on their top five importing counterparties. Portfolio returns (quantity and price) have been derived between 2008-2018 with volatility spillovers computed via Diebold and Yilmaz's dynamic spillover index approach. The spillover analysis shows a consistent reallocation effect amongst spillover directions together with their generalized increases. The structural rigidity of oil demand was confirmed with 'quantity' Total Volatility Spillovers being lower than 'price' Total Volatility Spillovers. Analysis of net contributors for both kinds of volatility found China to be a "net transferer" in quantity spillovers, and India seemingly absorbing quantity and price shocks. We find economic policy uncertainty and rising renewable market shares significantly affects volatility spillovers in oil export portfolios. Although some degree of heterogeneity exists, greater deployment of renewables in importing nations reduces adverse impacts of oil market fluctuations. This result and broader 'net-zero' policy commitments means rising renewable market shares are predictable. For GCC countries, two consequential long run risks arise, viz. loss of revenues and stranded oil reserves, which has its own policy implications.

Key WORDS: *Gulf Cooperation Council countries; oil exports; total volatility spillovers; renewables; volatility determinants, energy security*

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[1] Università degli Studi di Perugia Department of Economics, Università degli Studi di Perugia
[2] Centre for Applied Energy Economics & Policy Research, Griffith University.
[3] Energy Policy Research Group, University of Cambridge.

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 (i.e. likelihood and consequences) 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 to reliability of supply and price stability. Viewed in this light, energy security policy can be seen as a form of applied risk management.[4]

One of the more prominent contemporary macroeconomic risks faced by both commodity-importing and exporting countries alike relates to uncertainty associated with global energy price fluctuations. Impacts are well known for importing countries vis-à-vis economic growth. For exporting countries, global energy price fluctuations may have the effect of threatening export earnings, driving the instability of fiscal accounts and balance of payments, and in turn, adversely impacting the smooth functioning of the domestic economy.

The *energy transition* and 'net zero' targets and policies will invariably increase uncertainty associated with the long run global oil demand. At the time of writing, 131 countries covering 85% of the world's population have committed to 'net zero' policies.[5]

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

[5] See Netzero Tracker at https://zerotracker.net

This necessarily exposes oil exporting countries to long-term challenges associated with a world economy less dependent on oil. It also gives rise to two primary risks, viz. i). loss of revenues, and ii). an inability to monetize oil reserves (i.e. stranded assets). Oil exporting nations should, and are, focusing on economic adaptation strategies (*viz.* fiscal diversification) in order to reduce risk by pooling uncorrelated income streams as Khan and Shaheen (2020) explain.[6]

In this article, we examine negative effects of uncertainty, renewable energy resources and adverse changes in global energy prices for four of the Gulf Cooperation Council (GCC) countries – Kuwait, Saudi Arabia, United Arab Emirates (UAE) and Oman. Specifically, we construct oil portfolios for the GCC countries and focus on their five primary counterparties (i.e. importing countries).

We approach the balance between oil export returns and oil price fluctuations using the modern portfolio theory where a risk averse investor chooses a combination (portfolio) which minimizes their variance for a given average return (Markowitz, 1952). In a similar way, risk averse countries can ideally allocate their resources to produce an export mix (amongst countries) according to the co-variability of prices on world markets (Brainard and Cooper, 1968). Portfolio returns have been derived from monthly oil export growth rates and prices between 2008-2018, with volatility spillovers analysed in a manner consistent with Diebold and Yilmaz's dynamic spillover index approach.

[6] 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 130 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.

Our substantive findings are as follows. Contemporary energy policy in oil importing countries will increasingly be designed to mitigate climate change, and by design reduce demand for fossil fuels. Our subsequent modelling finds that doing so reduces ‘quantity volatility spillover effects’ amongst GCC counterparty countries. Oil portfolio risk management will therefore become increasingly important for GCC countries. In the meantime, the structural rigidity of oil demand was confirmed with ‘quantity’ Total Volatility Spillovers being lower than ‘price’ Total Volatility Spillovers. Analysis of net contributors for both kinds of volatility (i.e. price and quantity) found that China is a “net transferer” in quantity spillovers, and India seems to absorb quantity and price shocks from oil markets more so than other importing nations. Rising renewable market share effects were largely predictable –a positive relationship was recorded in portfolios vis-à-vis quantity volatility spillovers, highlighting that expanding renewable market shares can be expected to reduce volatility spillovers coming from foreign markets, and in turn, positively affects the net spillovers. This was observed for all portfolios except UAE.

The article is structured as follows. Section 2 presents the review of the related literature. Section 3 provides summary statistics of the export portfolios. A description of methods is provided in Section 4, with results following in Section 5. Section 6 provides policy implicantions and concluding remarks follow. Appendix provides additional information.

2. Review of Literature

Our analysis has relevance to two related streams of the 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. However, due to the importance of energy security, many scholars and institutions have developed different interpretations of the concept as summarized in Ang et al. (2015) and Azzuni and Breyer (2018). In particular, a historical difference exists according to a countries' energy endowment given that 'security' originally received less attention in energy exporting countries. However, energy security is now gaining political importance for several countries with large energy endowments which highlight 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 by exporting countries. It is noteworthy that the United States does not have a formal definition of energy security. However, since the first oil crisis in 1973, the prevailing definition in informal documents relates to the concept of *energy independence* (see Metcalf, 2014). This customer-centered perspective was adopted and further developed globally by different international organizations and agencies.

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's high representatives (Barkindo, 2006), according to which security is part of a universal responsibility within the global community whereby guaranteeing supply and demand are complementary issues requiring balanced solutions. Given a position of net exporting countries, OPEC's conceptual framework of security also included an export-oriented perspective focusing on reliability and affordability of supply. More recently, increasing deployment of US shale gas shifted the United State from a net importer to the main exporter (of gas) to Europe. In this new energy scenario, Russia developed the concept of energy security from the perspective of an exporting country vis-à-vis highlighting supply diversification, decarbonization, economic sanctions and how such challenges are perceived from a supply-side (see Zhiznin, 2020). Furthermore, the Russian energy security doctrine[7] explicitly mentions execution of export contracts and international obligations as the primary policy means of preserving the economy and national security. As highlighted by Zhiznin (2020), this doctrine has been one of the first to provide practical instruments based on the security provisions of both importing and exporting countries. In this new perspective energy security first refers to adequate energy exports at reasonable prices, noting hydrocarbon exports generate a significant share of government revenues in those countries, which in turn directly affects the security of the state and its citizens.

2.2 Energy Security and Dynamic Spillover Effects

For 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

[7] The recent Ukraine-Russian war has stressed the importance of energy security. A war apparently unrelated to energy causes (yet causing acute energy market impacts) _ has had deep economic impacts worldwide, thus underlining important linkages among energy security definitions. Of course, one could argue the roots of the conflict relate to energy issues. The first signs were in March 2005 after the Orange Revolution with the win of Jušcenko/Tymoshenko when Moscow: i). increased gas prices; ii). made the first requests for payment of debt accumulated by the Ukrainian national gas company (Naftogaz), and iii). accused the company of illegally taking gas from quantities exported to European countries.

oil markets and stock markets have been extensively analyzed by Li et al. (2009), Khalfaoui et al. (2019), Sarwar et al. (2019) and others. From a macroeconomics perspective, Nasir et al. (2019) analyzed the impact of oil price shocks on the economies of oil exporting countries and how this may potentially feed back 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 take into account 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 both 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) finds in the BRIC countries, the mean spillover relationship between oil prices and economic policy uncertainty is weak in the short term but gradually 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) finds spillovers from exchange rates are stronger than those from oil prices. After the 2007 financial crisis, extreme risk dependence was found to be stronger than in other periods, 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 are explained by local and global factors (22.5% and 17.4%, respectively). Furthermore, they found the effects of political variables are comparably lower than the oil-specific shocks. Considering both export and import countries, He et al. (2021) finds volatility spillovers from oil-exporting countries' economic policy uncertainty is stronger than those of oil-importing countries with spillover asymmetry increasing with policy uncertainty, especially in a crisis period. Further, negative returns have a stronger impact than volatility driven by positive shocks to China's energy sector. 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) investigated the relationships 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 showed the influence of oil price shocks was more pronounced on oil exporting countries. They also found oil assets are a useful instrument to minimize portfolio risk. Furthermore, in order to form an optimal portfolio, investors could choose an equal ratio between stocks and oil assets for the oil exporting country, while more stocks than oil assets are required to form an optimal portfolio in the case of oil importing country. 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 increased connectedness during the 2008 global financial crisis as well as throughout the shale oil 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, a spillover volatility index is estimated. Then, the spillover volatility index is 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 macroeconomic contributors of detected net directional connectedness. Results show that economic policy uncertainty, implied volatility, 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 spillover channels by a linear panel regression. Bouri et al. (2021) investigated determinants of the volatility of 15 commodity futures, with their connectedness robust and mostly driven by macroeconomic variables and uncertainty, including the term spread of interest rates and real economic activity. 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) investigated whether economic policy uncertainty drives connectedness between the stock market returns of nine industrialized countries.

3. The selected GCC countries

Given the primary task of our analysis is to examine risk faced by four of the 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 renewables. We focus on the GCC countries because they have accumulated significant oil portfolio revenues that has enabled living standards to be raised materially (i.e. through fiscal revenues from oil and oil-related products). As shown in Table A.1, the selected GCC countries (Kuwait, Oman, Saudi Arabia and United Arab Emirates) record

26% of global oil trade. [8] Consequently, our analysis seeks to evaluate how rising renewables are impacting the 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 be adversely impacted by fluctuations in global demand. They lack a diversified industrial base and lag in technology. All things being equal, any fall in the 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 must ultimately increase uncertainty vis-à-vis 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 which will impact on GDP, and ii). stranded oil reserves.

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

Emerging countries such as India and China increase their shares in oil portfolios throughout the study period. Considering the oil portfolios that include these two emerging markets is particularly important when analyzing future developments of energy security due to rising renewable market shares. 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

[8] 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.

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.[9]

4. Methods

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

4.1 Volatility spillover effects

We use data of the efficient exports' portfolio of the four GCC countries derived from the standard risk portfolio optimization model introduced by Markowitz (1952). The portfolio of each GCC country $v_{m,t} = (s_{m,t,1}, \dots, s_{m,t,5})$ identifies the main five oil importing countries[10], where $s_{m,t,i}$ with $i=1,\dots,5$ are their import shares and *t* the month between 2008-2018. Returns $\theta_{m,t,i}$ are given by monthly export growth. Operationally, the four portfolios $v_{m,t}$ represent the export configurations that yield the lowest variance for a given level of expected earnings.

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[9] 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.

[10] 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).

Portfolio returns are the geometric mean of both export growth rates (quantities) and prices weighted by country shares. Portfolio risk is expressed by the standard deviation of export growth rates. Minimization yields the efficient portfolio such that $v_{m,t}^{*} = \left(s_{m,t,1}^{*}, \dots, s_{m,t,5}^{*}\right)$ with average return $\theta_{m,t}^{*} = E(\sum_{i=1}^{5} s_{m,t,i}^{*}\theta_{m,t,i})$ and minimum variance $\sigma_{m,t}^{*2}$, i.e., a frontier suitable for empirical estimation (Bigerna et al., 2021). Next, for each GCC country a VAR structure is set to estimate the dynamic response of returns to shocks of main suppliers. The VAR specification for each country *m* considers the oil import growth (and price benefit) for the main five purchasers:

$$\boldsymbol{\theta}_{m,t} = \sum_{p=1}^{P} \phi_{m,p}\boldsymbol{\theta}_{m,t-p} + \varepsilon_{m,t} \qquad (1)$$

where $\boldsymbol{\theta}_{m,t} = [\theta_{m,1,t}, \dots, \theta_{m,5,t}]$ is the vector that includes the growth rate of oil exports or the average price $\theta_{m,i,t}$ of the importing country *i=1, ...,5*, at time *t* for each GCC exporting country *m*. $\varepsilon_t \sim N(0, \Sigma)$ 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 variance decomposition. It allows for an assessment of the contributions of shocks to forecast error variances of both respective and other variables of the model.

Using rolling-window estimation, the evolution of spillover effects can be traced over time and illustrated by spillover plots. The method uses a generalized vector autoregressive framework in which forecast-error variance decompositions are invariant to variable ordering, and explicitly include directional volatility spillovers. Starting from the VAR representation in eq. (2), the corresponding moving average $MA(\infty)$ representation is the following (Diebold and Yilmaz, 2012):

$$\boldsymbol{\theta}_{m,t} = \sum_{i=0}^{\infty} \boldsymbol{A}_{m,i}\varepsilon_{m,i} \qquad (2)$$

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} + - \cdots + \phi_{m,p}\boldsymbol{A}_{m,i-p}$ with $\boldsymbol{A}_{m,0} = \boldsymbol{I}_N$ and $\boldsymbol{A}_{m,i} = \boldsymbol{0}$ for *i<0*. Values in $\boldsymbol{A}_{m,i}$ are the impulse response coefficients, which are usually graphed on figures in the empirical analysis.

VAR shocks ε_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 analyze and decompose the forecast error variances of each variable according to various system shocks. Indeed, it allow 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: $\varepsilon_{m,t+H} = \boldsymbol{\theta}_{m,t+H} - E(\boldsymbol{\theta}_{m,t+H})$ and then the mean squared error for the variance is calculated for every element in $\varepsilon_{m,t+H}$ as $E(\boldsymbol{\theta}_{m,t+H} - E(\boldsymbol{\theta}_{m,t+H}))^2$. Then, each variance is decomposed to shares of every variable in the VAR model, $\phi_{i,j}(H)$,[11] due to shocks in individual variables as follows:

$$\phi_{i,j}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma\, e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_j' A_h \Sigma A_h' e_i\right)} \tag{3}$$

where Σ is the variance matrix for the error vector ε_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 $\phi_{i,j}(H)$ 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

[11] For simplicity and clarity, we omit the apex *m* referring to the exporter GCC country.

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 $\phi = [\phi_{i,j}(H)]_{i,j=1,\ldots,N}$ 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: $\sum_{j=1}^{N} \phi_{i,j}(H) \neq 1$. In order to use the variance decomposition matrix in the calculation of the spillover index, each entry $\phi_{i,j}(H)$ is normalized by the row sum as follows:

$$\widetilde{\phi_{i,j}}(H) = \frac{\phi_{i,j}(H)}{\sum_{i,j=1}^{N} \phi_{i,j}(H)} \tag{4}$$

Using the volatility contributions from eq. (4), the total volatility spillover index (TSI) is:

$$TSI(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\phi_{i,j}}(H)}{\sum_{i,j=1}^{N} \widetilde{\phi_{i,j}}(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\phi_{i,j}}(H)}{N} \cdot 100 \tag{5}$$

The TSI measures the contribution of spillovers of volatility shocks across the N variables to the total forecast error variance. Since the generalized VAR allows the generalized variance decomposition being invariant to the ordering of variables, it allows directional volatility spillovers to be computed using the elements in eq.(4). The directional volatility spillovers from variable i to all other variables j can be expressed as:

$$DS_{i\rightarrow}(H) = \frac{\sum_{j=1; j \neq i}^{N} \widetilde{\phi_{i,j}}(H)}{\sum_{i,j=1}^{N} \widetilde{\phi_{i,j}}(H)} \cdot 100 = \frac{\sum_{j=1;\, j \neq i}^{N} \widetilde{\phi_{i,j}}(H)}{N} \cdot 100 \tag{6}$$

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

$$DS_{\rightarrow i}(H) = \frac{\sum_{j=1; j \neq i}^{N} \widetilde{\phi_{j,i}}(H)}{\sum_{i,j=1}^{N} \widetilde{\phi_{j,i}}(H)} \cdot 100 = \frac{\sum_{j=1;\, j \neq i}^{N} \widetilde{\phi_{j,i}}(H)}{N} \cdot 100 \tag{7}$$

To summarise, the set of directional spillovers provides a decomposition of TSI into those coming from eq.(6) or eq.(7) to a particular variable *i.* Finally, subtracting eq.(7) from eq.(6), the net spillovers from variable *i* to all other variables *j* can be obtained as:

$$NS_i(H) = DS_{\rightarrow i}(H) - DS_{i\rightarrow}(H) \quad (8)$$

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

4.2 Econometric approach for the determinants of outward spillovers

To assess the determinants of volatility spillovers in the four GCC export portfolios, we employ linear panel models where spillovers are functions of four potential channels which reflects the theoretical background of the spillover explanation. Namely climate change policy uncertainty, the rate of renewable energy resources deployed in power generation, industrial growth and exchange rates. These channels are selected according to Alkathery and Chaudhuri (2021), Hamed et al. (2021), Hu et al. (2020), and finally, Karali and Ramirez (2014) and Nguyen and Walther (2020). for renewable energy resources, exchange rate, energy policy uncertainty and industrial production growth, respectively.

In order to identify contributing factors of dynamic volatility spillover, a panel structure of data is required where spillovers of importing markets composing GCC country portfolios are the panels *i* and *t* corresponding to years 2008-2018[12]. As explained by Gorodnichenko and Lee (2019), forecast error variance decomposition (FEVD) may led to biased estimates in small

[12] We have focused on this period for two reasons. First, using data after 2008 we take into account that during the 2007–2008 crisis oil prices were a driver of what would become the Global Financial Crisis. The exceptional oil price volatility during 2007 affected many other economic variables and related markets. Conditions in 2008 vis-à-vis energy and economics variables created an important structural break in the main economic fundamentals. Second, we face data limitations in periods prior to 2008.

samples. They propose a bootstrap procedure to correct for possible biases in the FEVD estimates by local projections. Alternatively, Choi and Shin (2020) propose a bootstrap procedure for volatility spillover indexes focusing on standard errors and confidence intervals.[13] Bootstrap methods are an attractive approach because finite sample performances are frequently reported in the literature to be better than methods based on central limit theorems. In this article, we apply the bootstrap procedure in Choi and Shin (2020) aiming to derive consistent and statistically significant directional volatility spillover indexes. We use the Word Uncertainty Index (explained below) to depict the energy policy channel through which shocks spread to the export portfolios (Ahir et al., 2022). Crude oil, as one of the most important global commodities, is significantly impacted by economic policy uncertainty. 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 geopolitical risks (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* 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. We use the annual average of quarterly indices and higher values for the index state for higher economic and policy uncertainty. EIU reports discuss major political and economic developments in each country, along with analysis and forecasts of

[13] 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).

political, policy and economic conditions. To make the uncertainty index comparable across countries, raw counts have been scaled by the total number of words in each report.[14] We control for renewable energy resource (*RES*) market shares in domestic energy production. *RES* are being integrated into power systems at a fast rate to achieve energy security goals and net zero commitments. 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) and defuse the impacts of price volatility which characterizes global energy markets (Gouveia et al., 2014; Rentizelas et al., 2012). At the same time, RES substantially differ from conventional generation units. 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, viz. industrial and financial channels. The industrial dimension is expressed by the industrial productivity index (*IP*), that is, changes in output (physical quantity) produced by manufacturing, mining, gas and electricity sectors. The exchange rate (*EXC*) represents the financial dimension and is expressed by the annual average exchange rate for each importer country. Table 1 shows the main summary statistics for the variables used in the econometric specification.

The econometric specification is as follows:

$$NS_{i,t} = \beta_1 WUI_{i,t} + \beta_2 RES_{i,t} + \beta_3 IPI_{i,t} + \beta_4 EXC_{i,t} + \varepsilon_{i,t} \tag{9}$$

[14] 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.

[15] Low-carbon energy is defined as the sum of nuclear and renewable sources. Traditional biofuels are not included.

where, $NS_{i,t}$ is the annualized net spillover index from importer country i and t the year *2008-2018.*

Table 1: Importer country variables used in the econometric specification by GCC country portfolios.

Kuwait portfolio - Importer countries: China, India, South Korea, Japan, Taiwan						
Variable		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 = 11
	within		8.611	-0.755	36.830	T = 5
RES	overall	10.103	3.063	6.019	18.238	N = 55
	between		0.802	8.989	11.248	n = 11
	within		2.964	5.518	17.093	T = 5
IPI	overall	109.402	21.692	81.563	184.219	N = 55
	between		11.430	90.561	126.601	n = 11
	within		18.697	84.492	167.019	T = 5
EXR	overall	264.972	438.805	6.143	1277.246	N = 55
	between		11.566	251.251	291.815	n = 11
	within		438.664	-20.011	1250.403	T = 5
Oman portfolio - Importer countries: China, India, South Korea, Japan, Taiwan						
Variable		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 = 11
	within		8.611	-0.755	36.830	T = 5
RES	overall	10.103	3.063	6.019	18.238	N = 55
	between		0.802	8.989	11.248	n = 11
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	between		11.566	251.251	291.815	n = 11
	within		438.664	-20.011	1250.403	T = 5
Saudi Arabia portfolio - Importer countries: China, India, South Korea, Japan, USA						
Variable		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 = 11
	within		8.078	-2.500	31.175	T = 5
RES	overall	11.324	3.555	6.019	18.238	N = 55
	between		0.791	9.981	12.224	n = 11
	within		3.472	5.917	17.448	T = 5
IPI	overall	110.493	21.523	81.563	184.219	N = 55
	between		12.117	89.923	128.845	n = 11
	within		18.091	83.340	165.867	T = 5
EXR	overall	259.000	442.202	1.000	1277.246	N = 55
	between		11.373	245.392	285.411	n = 11
	within		442.067	-25.411	1250.835	T = 5
United Arab Emirates portfolio - Importer countries: China, India, Japan, Singapore, Thailand						
Variable		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 = 11
	within		7.587	-1.353	29.960	T = 5

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

To check the robustness of our empirical estimates, we conduct three different linear econometric regressions: heteroskedastic generalized least square (H-GLS) linear model, heteroskedastic GLS with cross-sectional correlation (HC-GLS) and heteroskedastic GLS with first order autocorrelation among panels (H-GLS(AR1)).

5. Results

5.1 The volatility spillover indexes

We start by computing the volatility spillover index for the overall sample. The adequate lag length for VAR models is checked by calculating the Akaike Information Criteria (AIC)[16]. Optimal lag lengths are shown in Table 2. Thus, the rest of the VAR analysis is continued with lag lengths from Table 2.

Table 2: VAR (p) model details, by exporting country' portfolio, quantity 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

[16] 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.

Table 3 refers to volatility spillover amongst Kuwait's main importing countries. Panel A refers to oil quantity and Panel B refers to price. First, total spillovers from India to other countries ("Spillover to O.") accounts for 3.326%. Meanwhile, total spillovers to India ("Spillover from O.") is 7.818%. The same relative pattern arises in South Korea and Japan. An opposite relation is found in China and Taiwan that contribute to the rest of countries for 8.274% and 12.812%, respectively, while they receive from others the 5.768% and 8.832%. This suggests potential shocks triggered in China could spill to other importing countries.

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

Kuwait						
Panel A	**Quantity**					
	South Korea	China	Japan	India	Taiwan	Spill. from O.
South Korea	10.772	3.966	1.490	0.559	3.212	9.228
China	3.124	14.232	0.750	1.074	0.819	5.768
Japan	1.637	0.836	11.168	0.640	5.719	8.832
India	1.817	1.406	1.533	12.182	3.061	7.818
Taiwan	2.028	2.065	3.175	1.053	11.679	8.321
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	100.000
Panel B	**Price**					
	South Korea	China	Japan	India	Taiwan	Spill. from O.
South Korea	10.768	0.946	1.145	3.269	3.872	9.232
China	7.934	7.360	0.407	1.555	2.743	12.640
Japan	6.644	0.219	5.565	3.402	4.169	14.435
India	6.004	0.483	2.046	8.465	3.002	11.535
Taiwan	7.469	0.368	2.079	3.155	6.928	13.072
Spill. to O.	28.052	2.016	5.677	11.381	13.786	60.913
Spill. to O. including own	38.820	9.376	11.243	19.846	20.715	100.000

Moving to the price returns portfolio, the decomposition of volatility spillovers provides a different input-output scenario. Asymmetry between contributions to- and from- are highest 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 is 9.232%. Japan and China are markets which receive the largest contribution from others, at 14.435% and 12.640%, respectively. Japan and China affect the overall variance by 5.677% and the 2.016%.

The remaining countries are characterized by a comparable magnitude of spillovers to- and from-

Oman (Table 4) is characterized by a different structure of volatility across its main oil buyers (in spite of the same mix as Kuwait). Focusing on Panel A quantities, asymmetry arises in India and Taiwan, while other importers show a symmetric structure in terms of directional spillovers. India contributes to other oil-importing countries by 1.723%, while other importers spill to India for 13.866%.

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

OMAN						
Panel A	**Quantity**					
	South Korea	China	Japan	India	Taiwan	Spill. from O.
South Korea	17.639	0.455	1.026	0.066	0.815	2.361
China	0.712	16.235	0.740	0.406	1.907	3.765
Japan	0.769	1.750	11.536	1.146	4.798	8.464
India	0.718	0.886	1.258	6.134	11.003	13.866
Taiwan	0.763	1.135	0.520	0.106	17.477	2.523
Spill. to O.	2.962	4.226	3.544	1.723	18.524	30.979
Spill. to O. including own	20.601	20.461	15.080	7.857	36.001	100.00
Panel b	**Price**					
	South Korea	China	Japan	India	Taiwan	Spill. from O.
South Korea	13.981	1.150	2.812	1.206	0.852	6.019
China	1.372	8.187	4.084	2.588	3.768	11.813
Japan	4.126	1.073	11.693	1.529	1.579	8.307
India	1.325	1.816	2.003	13.874	0.982	6.126
Taiwan	0.542	2.063	2.772	1.364	13.260	6.740
Spill. to O.	7.365	6.102	11.670	6.687	7.180	39.005
Spill. to O. including own	21.346	14.289	23.363	20.562	20.440	100.000

Conversely, Taiwan spills to other importers by 18.524% and is spilled by others for 2.523%. Price spillovers exhibit a different structure. Amongst Oman's importers, China and Japan show an imbalance between from- and to- spillovers, viz. China spilled from (11.813%) and to (6.102%) whereas Japan spills more to (11.670%) than from (8.307%).

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) portfolios. Comparing the quantity and price portfolios, the structures of directional spillovers are however substantially different. In Panel A, all importers (except USA) show asymmetric behavior. China and Japan spill to other importers (11.612 and 13.525%, respectively) more than they are affected by shocks from others (9.075%

and 7.889% respectively). South Korea and India exhibit an opposite imbalance, contributing to others (7.912 and 1.715%, respectively) less than they are spilled by others (10.914 and 5.095% respectively). In Table 5 Panel B, unbalanced behavior is recorded for all importers with the exception of China. Japan and South Korea are markets which contribute to portfolio variances at 26.753% and 22.933%, respectively, with spillover from other importers of 12.032% and 13.190%, respectively.

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

Saudi Arabia						
Panel A	**Quantity**					
	China	Japan	USA	South Kores	India	Spill. from O.
China	11.271	3.790	1.760	2.721	0.458	8.729
Japan	3.948	10.925	1.955	2.696	0.475	9.075
USA	2.568	3.139	12.111	1.768	0.414	7.889
South Korea	3.192	4.962	2.392	9.086	0.368	10.914
India	1.905	1.634	0.829	0.727	14.905	5.095
Spill. to O.	11.612	13.525	6.937	7.912	1.715	41.701
Spill. to O. including own	22.883	24.450	19.048	16.999	16.620	100.000
Panel B			**Price**			
	China	Japan	USA	South Kores	India	Spill. from O.
China	4.978	6.377	0.394	6.417	1.834	15.022
Japan	3.604	7.968	0.864	6.237	1.326	12.032
USA	3.054	7.474	3.919	4.714	0.838	16.081
South Korea	3.657	7.189	0.863	6.810	1.480	13.190
India	4.062	5.713	0.430	5.565	4.229	15.771
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	100.000

These asymmetries suggest any potential shock could trigger Japan and South Korea spilling over to the rest of the oil-importing countries. Volatility spillovers amongst the importing countries of UEA (Table 6) show that Japan is the main contributor – spilling to others for 11.053% in terms of quantity volatility and for 26.738% in terms of price volatility. Focusing on Panel A, Thailand and China are the other net contributors, spilling to other markets by 9.416% and 5.796%, respectively, while receiving 8.385% and 4.932% from others. Conversely, India and Singapore receive from other markets more than they spill: 7.883 and 6.042% against the

5.134 and the 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). Contrariwise, India, China and Singapore spill from others roughly four times (between 12.318% and 15.133%) than they spill to others (between 2.304% and 4.636%). To summarise the findings, *gross* directional volatility Spillovers To Others (Spillover To O.) for each GCC country portfolio is quite different. Similarly, differences were found vis-à-vis gross Spillover From O. columns. Finally, Total Volatility Spillovers of the exports' quantity portfolios are lower than those of price portfolios, confirming the structural rigidity of oil demand.

Table 6: Directional spillover index for United Emirates of Arabia's export portfolio, quantity and price

UAE						
Panel A	**Quantity**					
	Japan	India	Thailand	China	Singapore	Spill. from O.
Japan	12.986	1.190	5.122	0.528	0.173	7.014
India	3.625	12.167	2.447	1.415	0.346	7.833
Thailand	4.853	1.577	11.615	0.881	1.074	8.385
China	1.070	1.617	1.033	15.068	1.213	4.932
Singapore	1.505	0.750	0.814	2.973	13.958	6.042
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	100.000
Panel B	**Price**					
	Japan	India	Thailand	China	Singapore	Spill. from O.
Japan	11.031	0.806	6.921	0.969	0.272	8.969
India	7.954	4.867	6.329	0.558	0.292	15.133
Thailand	7.730	0.880	10.523	0.603	0.263	9.477
China	5.103	1.603	4.134	7.682	1.477	12.318
Singapore	5.951	1.074	4.636	0.962	7.378	12.622
Spill. to O.	26.738	4.363	22.021	3.092	2.304	58.519
Spill. to O. including own	37.770	9.230	32.544	10.774	9.682	100.000

Tables 3-6 focused on gross directional volatility spillovers while Tables 7-8 examine net contributors for quantity and price volatility. For Table 7, China, Japan and India are importers of quantity spillover effects in all four portfolios and China exhibits a "net transfer" of quantity spillover in all portfolios.

Table 7: Net volatility spillovers index by GCC country export portfolio -quantity-

Exporter	Importing countries	To	From	Net	Net transfer
Kuwait	South Korea	8.605	9.228	-0.622	No
	China	8.274	5.768	2.506	Yes

	Japan	6.949	8.832	-1.883	No
	India	3.326	7.818	-4.492	No
	Taiwan	12.812	8.321	4.491	Yes
Oman	South Korea	2.962	2.361	0.601	Yes
	China	4.226	3.765	0.461	Yes
	Japan	3.544	8.464	-4.919	No
	India	1.723	13.866	-12.143	No
	Taiwan	18.524	2.523	16.001	Yes
Saudi Arabia	China	11.612	8.729	2.883	Yes
	Japan	13.525	9.075	4.450	Yes
	USA	6.937	7.889	-0.952	No
	South Korea	7.912	10.914	-3.001	No
	India	1.715	5.095	-3.380	No
UAE	Japan	11.053	7.014	4.039	Yes
	India	5.134	7.833	-2.699	No
	Thailand	9.416	8.385	1.031	Yes
	China	5.796	4.932	0.864	Yes
	Singapore	2.806	6.042	-3.236	No

Japan is a net transferer for Saudi and UAE, while India never acts as a net transferer. South Korea imports oil from three of the four GCC countries and plays the role of “net transferer” only in Oman. Taiwan acts as a “net transferer” both in the Kuwait and Oman portfolios. Singapore, Thailand and USA are included in just one of the four exports portfolios and only Thailand is a “net transferer” vis-à-vis UAE. In Oman’s portfolio, we find the greatest magnitudes associated to net transferers and receivers, via Taiwan and India, respectively.

Looking at price volatility (Table 8), the number of net transfers is similar. Nevertheless, behaviors change substantially amongst importers. For example, China never acts as a net transmitter, India acts as a net transferer in Oman, and Japan impacts Oman, Saudi Arabia and UEA as a net transmitter. South Korea is still an important net transmitter in Kuwait, Oman and Saudi Arabia. The higher magnitude in “net transfers” refers to South Korea for Kuwait, and Japan for Saudi Arabia and UEA at 18.8%, 14,7% and 17.8% respectively. The most important net receivers are USA (-13.5%) in Saudi Arabia’s portfolio and India (-10.8% in the UAE and -10.3% in Saudi Arabia) and China (-10.95%) in Kuwait’s portfolio.

Beyond the technical results reported, it emerges that the same countries in different portfolios may show different behaviors (net- transferer or receiver). These mixed results deepen the requirement to further analyse other macro-determinants.[17]

Table 8: Net volatility spillovers index by GCC country export portfolio -price-

Exporter	Importing countries	To	From	Net	Net transfer
Kuwait	South Korea	28.052	9.232	18.820	Yes
	China	2.016	12.640	-10.624	No
	Japan	5.677	14.435	-8.757	No
	India	11.381	11.535	-0.154	No
	Taiwan	13.786	13.072	0.715	Yes
Oman	South Korea	7.365	6.019	1.346	Yes
	China	6.102	11.813	-5.711	No
	Japan	11.670	8.307	3.363	Yes
	India	6.687	6.126	0.562	Yes
	Taiwan	7.180	6.740	0.440	Yes
Saudi Arabia	China	14.377	15.022	-0.645	No
	Japan	26.753	12.032	14.721	Yes
	USA	2.552	16.081	-13.529	No
	South Korea	22.933	13.190	9.744	Yes
	India	5.479	15.771	-10.292	No
UAE	Japan	26.738	8.969	17.770	Yes
	India	4.363	15.133	-10.770	No
	Thailand	22.021	9.477	12.544	Yes
	China	3.092	12.318	-9.226	No
	Singapore	2.304	12.622	-10.318	No

5.2 Macro-determinants of net spillover indexes

In this section, we investigate an interesting and under-researched topic, namely the effects of the different channels through which net spillovers spread to the markets of the four portfolios. More specifically, we examine the role of economic policy uncertainty (i.e. World Uncertainty Index or WUI) and rising renewable market shares (RES) in driving net spillovers within oil portfolios, along with industrial production (IPI) and exchange rates (EX). Heteroskedastic GLS models (H-GLS), accounting also for cross-sectional correlation (HC-GLS) and autocorrelation among

[17] 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).

panels (H-GLS(AR1)) were performed. Estimates are reported in Table 9. We first compute the annual net spillover indices using a bootstrap procedure. The results are based on a *VAR(p)* fitting and 10-step-ahead volatility forecast error variance decomposition. As in the previous step, the order *p* is chosen according to the AIC criterion. Volatility spillovers are estimated by mean bootstrapping with B=1000 iterations.

Table 9 shows results for the three regression models applied to the four portfolios, quantity and price volatility net spillovers (Panel A and Panel B, respectively). The significance and signs of the *WUI*'s coefficients are mixed. In both panels, coefficients are mainly negative (ranging between -0.299 and -0.023). But a positive sign emerges for quantity net spillovers of UEA's portfolio. 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). Energy policy tensions create severe financial repercussions in terms of spillover reactions to regional and international markets, leading to huge losses of financial assets and the distortion of their pricing dynamics. The effects of *RES* market share are also mixed. In Panel A, a positive effect on quantity volatility spillover prevails and ranges from 0.074 - 0.621. Only UEA's portfolio shows a negative effect (-0.531 to -0.340) which may be related to variations in LNG exports to Japan (coinciding with fuel switching in that country following the Fukushima nuclear incident in March 2011).[18] Fuel switching to domestic RES has mitigated the effects of fossil fuel scarcity in importing countries – which is an important finding. It has positively impacted energy security and demonstrated an ability to reduce quantity volatility spillovers coming from foreign markets.

[18] UAE has been exporting LNG to Japan under long term agreements since 1977. Following more recent structural changes within its own energy mix, UAE also now imports LNG. See IRENA (2015).

Table 9: Panel estimation of the effects of policy and economic variables on net spillover indexes of export portfolios -Saudi Arabia, Kuwait, UEA, Oman (Quantity and price)

Panel A						**QUANTITY**						
		Saudi Arabia			Kuwait		UEA				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)
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
WUI	0.044	0.049	-0.113	-0.081	-0.068	-0.299*	0.125	0.091	0.124***	-0.028**	-0.023*	-0.008
	0.104	0.097	0.118	0.07	0.069	0.2	0.115	0.112	0.038	0.016	0.016	0.009
RES.	0.316	0.32	0.577***	0.621***	0.569**	0.561***	-0.486**	-0.531***	-0.340***	0.08	0.101*	0.074*
	0.261	0.242	0.223	0.314	0.298	0.244	0.286	0.248	0.08	0.067	0.065	0.049
IPI	-0.02	-0.022	-0.044***	-0.044**	-0.040**	-0.01	-0.016	-0.013	-0.010***	0.018***	0.015***	0.013***
	0.026	0.023	0.016	0.026	0.024	0.038	0.026	0.024	0.005	0.006	0.006	0.007
EX	-0.001	-0.001	-0.001	0.004**	0.004**	0.006**	0.084***	0.088***	0.051***	0.002***	0.002***	0.002***
	0.002	0.002	0.001	0.002	0.002	0.003	0.028	0.026	0.007	0	0	0.001
N	55	55	55	55	55	55	55	55	55	55	55	55

Panel B						**PRICE**						
		Saudi Arabia			Kuwait		UEA				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)
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
WUI	0.023	0.095	-0.066	-0.139	-0.138*	-0.009	0.029	0.075	-0.001	-0.175**	-0.162**	-0.089***
	0.193	0.177	0.127	0.099	0.093	0.049	0.128	0.116	0.099	0.091	0.09	0.03
RES.	0.03	-0.085	0.003	-0.224	-0.252	-0.144	-0.098	-0.239	0.158	-0.988***	-0.960***	-0.580***
	0.475	0.452	0.241	0.385	0.344	0.136	0.257	0.207	0.158	0.325	0.315	0.247
IPI	-0.04	-0.035	-0.013***	-0.001	-0.001	-0.001	0.001	0.003	-0.019	0.084***	0.077***	0.027
	0.046	0.042	0.006	0.033	0.028	0.009	0.022	0.018	0.014	0.031	0.03	0.025
EX	0.006*	0.007**	0.006***	0.001	0.002	0.003***	0.034	0.027	0.027	0.011***	0.010***	0.008***
	0.004	0.004	0.001	0.003	0.003	0.001	0.027	0.024	0.023	0.002	0.002	0.003
N	55	55	55	55	55	55	55	55	55	55	55	55

Therefore, positive coefficients could be explained by the lower impact that RES has on Spillover from O. that, in turn, positively affects aggregated effects expressed by net spillovers. Looking at Panel B for price volatility spillovers, coefficients are not statistically significant, except for Oman's portfolio where they are negative in all three regression models (ranging from -0.988 to -0.580). This means an increase in *RES* reduces net spillovers, consistent with the findings in Rentschler (2013) who concludes expanding renewable energy reduces an economy's vulnerability to oil price volatility.

Estimated coefficients of industrial production (*IPI*) are negative and significant for all portfolios except for Oman, where the coefficient in both panels is significant and positive. Negative impacts confirm an inverse relationship between economic growth and price fluctuations in international markets for crude oil (see also Van Eyden et al., 2019 and Gong et al., 2020). Conversely, the positive sign recorded for Oman's portfolio volatility spillovers indicates some degree of heterogeneity exists amongst GCC countries.

The exchange rate (EX) is also a significant determinant of net spillovers in most of the portfolios except for Saudi Arabia. Overall though, the effects are positive and more pronounced for UEA's portfolio and confirms results in Akram (2009) and Gruber and Vigfusson (2018), that shocks to exchange rates account for a substantial share of fluctuations in commodity prices.

6. Conclusion and Policy Implications

6.1 Policy Implications

Using the results of a consolidated application of financial portfolio theory to the energy security domain and the efficient frontiers of oil export quantities and prices for four GCC energy exporters, we estimated a new measure of risk volatility and associated spillover effects. The estimated efficient frontiers provided a measure of risk associated with portfolio composition – for a given level of total oil export quantities and average oil export prices.

The reason why this analysis is important is axiomatic. New energy policies aim to mitigate climate change, and by design are intended to reduce global demand for fossil fuels[19]. GCC countries have a heavy reliance on international oil markets as a primary source of income. Oil portfolio risk management will become increasingly important for GCC countries given the longer run consequential implications of a world economy less dependent on oil. Understanding how existing oil portfolios behave vis-à-vis quantity and price volatility spillovers is therefore an important first step in managing risk in the transitional period. Once these spillovers and their relationships are understood, oil export portfolios can be re-balanced by targeting a re-weighting of specific country export allocations. This may have the effect of reducing portfolio returns risk, which in turn may provide a more stable fiscal platform (viz. *in relative terms*) for a GCC country to focus on necessary and longer-run domestic economic restructuring.

Our analysis found spillover increases over the period considered were driven by economic policy uncertainty and rising levels of RES markets shares. Furthermore, the spillover analysis exhibited a consistent reallocation effect amongst spillover directions. Most significantly, for importing countries rising RES reduced adverse impacts of oil market fluctuations. We also found an inverse relationship between economic growth and price fluctuations in the international crude oil markets was confirmed. Some degree of heterogeneity existed among GCC countries, implying linkages between industrial production index and oil market fluctuations are not univocal.

The structural rigidity of oil demand was confirmed by the fact that quantity Total Volatility Spillovers were, on average, lower than price. The inelastic demand of major consumers, jointly with China's and India's additional oil demand, is likely to raise oil price volatility and can be expected to have the effect of inducing *insecurity* during supply disturbances. This also has a predictable and circular reasoning vis-a-vis rising market shares of RES.

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

The analysis of net contributors for both kinds of volatility also provides useful information. Among the countries belonging to all portfolios, only China is always a "net transferer" in quantity spillovers, confirming its importance vis-à-vis energy security. Also of note is that India's Spillover to Others is lower than their Spillover from Others - underlining the fact that India never acts as "net transferer". A possible interpretation is India is not actively influencing the market, but rather absorbs shocks from the market. This being the case, one logical implication of this finding would be for any GCC country experiencing volatile fiscal conditions within their own economy to rebalance their oil export portfolio more heavily to India over the short and medium term – whilst simultaneously driving broader economic restructuring within their own domestic economy.

When considering all portfolios, we find Total Spillovers are higher in price returns than in quantity returns and on average is 15% - 25% lower than values typically reported for financial markets. These results suggest that a significant proportion of volatility is due to intrinsic factors and shocks that are specific to individual countries in spite of the fact that 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 gives rise to portfolio risk exposures to manufacturing business cycles, i.e. both up- and downward cycle risks.

To assess the effects of energy policy trends and climate change mitigation policies, we have used panel econometric models where importer net spillovers are functions of their specific indices – measuring degrees of economic policy uncertainty and the market share of RES within energy production. Results showed economic policy uncertainty has mixed effects on the magnitude of net spillovers, highlighting that portfolio-heterogeneity needs to be considered in the analysis. The positive effect recorded for UEA's portfolios testifies that political tensions can increase oil market fluctuations.

Rising RES market share effects generally pointed to reducing quantity spillovers, as expected. Positive relationships were recorded for all portfolios except UAE. Positive effects recorded for quantity volatility spillovers highlights that expanding renewable market shares can be expected to reduce volatility spillovers coming from foreign markets, and in turn, positively affects the net spillovers. Consequently, importing countries can be expected to continue to pursue growth in RES, not only to meet net zero obligations, but to reduce quantity volatility spillovers. And for GCC countries, this will necessitate broader microeconomic adjustments to their respective macroeconomies over time.

For RES price volatility spillovers, a significant and negative relation was found for Oman. The negative effect recorded for price volatility spillover testifies the role of rising RES market shares in reducing exporters' vulnerability to oil price volatility.

6.2 Conclusion

In this article, concepts of energy security and climate change mitigation policy have been investigated for GCC countries, and specifically, the inherent risk within their oil export portfolios. 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 prominent group of importing countries. In this view, we reconstructed the portfolio of counterparties and assessed impacts of potential vulnerabilities. Financial portfolio theory was applied to energy security which in turn allowed us to estimate a new measure of risk volatility and associated spillover effects. This in turn provided a measure of risk levels associated with portfolio composition. Furthermore, we provided a measure of risk volatility for the composition of export portfolios and a measure of directional spillover that sheds light on the cross-volatility transmission of different importing markets within a given portfolio. Net-spillovers were computed in order to investigate the behaviors of different importers and the main determinants of net effects.

The spillover analysis showed a consistent reallocation effect amongst spillover directions together with their generalized increase. This confirms deep shocks can modify the quality composition of the variance along with its level. Rising renewable market shares in importing countries had mixed effects on GCC portfolios, but overall dampened quantity spillovers and moderated price impacts in oil importing nations – confirming dual objectives of climate change (i.e. net zero) policies and the reduction in exposure to adverse oil market fluctuations. This has consequential implications for the GCC countries.

Industrial production reduces both quantity and price volatility spillovers, suggesting the economic growth of importing countries helps mitigate fuel market fluctuations faced by GCC countries. A certain degree of portfolio-heterogeneity remains across indices since the effect on the Oman's portfolio was opposite and positive.

The last macroeconomic channel examined was exchange rates, and was revealed to be a significant determinant of net spillovers, positively contributing to quantity and price portfolio fluctuations. 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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Appendix

Table A.1: Portfolio structure

Countries*	2008	2013	2018	Portfolio
Kuwait: C5**	73.2%	78.9%	74.3%	
Japan	*19.2%*	*13.4%*	*11.6%*	*yes*
South Korea	*17.0%*	*20.0%*	*21.3%*	*yes*
India	*15.0%*	*20.2%*	*10.6%*	*yes*
USA	*11.5%*	*16.1%*		*no*
Taiwan	*10.5%*	*9.2%*	*8.8%*	*yes*
China			*22.0%*	*yes*
Oman: C5	89.5%	90.4%	98.6%	

China	*49.5%*	*60.5%*	*77.3%*	*yes*
Japan	*15.2%*	*9.3%*	*6.1%*	*yes*
Thailand	*11.4%*	*6.0%*		*no*
South Korea	*8.8%*			*yes*
Taiwan	*4.6%*	*9.9%*	*7.2%*	*yes*
Singapore		*4.8%*		*no*
India			*7.3%*	*yes*
Malaysia			*0.6%*	*no*
Saudi Arabia: C5	65.3%	68.6%	67.5%	
USA	*21.5%*	*17.2%*	*11.5%*	*yes*
Japan	*17.6%*	*15.5%*	*16.5%*	*yes*
South Korea	*11.2%*	*11.1%*	*12.4%*	*yes*
China	*10.1%*	*14.2%*	*15.7%*	*yes*
Singapore	*4.9%*			*no*
India		*10.6%*	*11.4%*	*yes*
UEA: C5	84.0%	79.7%	75.7%	
Japan	*41.8%*	*31.7%*	*31.4%*	*yes*
South Korea	*16.1%*	*12.2%*		*no*
Thailand	*10.3%*	*15.0%*	*12.8%*	*yes*
India	*8.7%*	*10.3%*	*12.4%*	*yes*
Taiwan	*7.2%*			*no*
Singapore		*10.5%*	*8.9%*	*yes*
China			*10.2%*	*yes*
Total***	26.5%	29.5%	26.5%	

* In italic importing countries.
** C5 is the concentration index of the five main importing countries.
*** Share of the worldwide oil export of four selected GCC countries.
Number of the portfolios in which each country is included
2008: Japan, South Korea (4), Taiwan (3), China, India, Thailand, USA (2), Singapore (1)
2013: Japan (4), India, South Korea (3), China, Singapore, Taiwan, Thailand, USA (2)
2018: China, India, Japan (4), South Korea, Taiwan (2), Singapore, Malaysia, Thailand, USA (1)