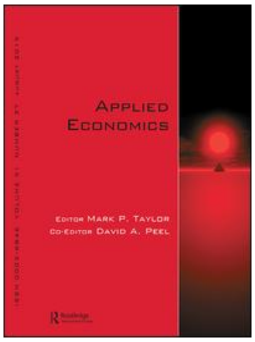

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Balancing energy security priorities: portfolio optimization approach to oil imports

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ABSTRACT

The notion of energy security in most interpretations includes the physical supply and price affordability components, making financial risks a crucial part of energy security strategies. Mainstream analysis has focussed on the notion of the physical supply. This paper introduces a novel approach, considering simultaneously the quantity of oil imports and the risk associated with this quantity. This approach applies the financial portfolio theory to explore these issues from the perspective of four major Asian energy importers: China, Japan, Korea and Taiwan, by estimating efficient frontiers for corresponding oil import portfolios. Results show that the composition of oil import portfolios determines varying risk levels for given oil import growth rates and average import prices. Scenario analysis suggests that increasing the Saudi Arabia share of oil imports improves the portfolio performance of China and that the impact of the Iranian oil export embargo would increase portfolio risk of the economies in focus within a 3–15% range.

KEYWORDS

Energy security; portfolio optimization; efficient portfolio frontier; oil imports; risk diversification

JEL CLASSIFICATION

G11; Q41

I. Introduction

The notion of energy security emerged in the 1970s following a wave of energy crises. It has evolved from the initial paradigm 'assuring sufficient energy supplies' to a more complex multi-pillar concept, shifting from physical supply concerns to the price and affordability considerations; also given the rapid deployment of renewables presumably reduce the pressure to secure physical fuels supplies and facilitate reliance on market mechanisms (Kovacic and Felice 2019; (Brown et al. 2014). However, these developments could be offset by escalating global financial, economic and geopolitical risks (Munoz, García-Verdugo, and San-Martín 2015).

The new approaches have focussed on the financial structure of contractual agreements, taking in consideration primarily the price volatility issue to define a measure of the risk assessment (e.g. Gholz, Awan, and Ronn 2017) or the degree of diversification, with descriptive methods such as the Herfindahl index, not considering the correlation of oil markets with other economic variables (Ge and Fan 2013).

Surprisingly, there is a certain gap in the relevant literature and methodological approaches to energy security when it comes to an integrated analysis framework of the physical security and the price affordability. This paper intends to fill this gap, applying optimal portfolio theory to evaluate the physical supply and price components of energy security.

This study contributes to the literature in two ways. First, based on microeconomic theory foundations we consider that oil imports are a crucial requirement in the production function of the country. The optimization of the production function yields conceptually the factor demand for oil. Consequently, we assume that oil import portfolios are characterized by a positive return, represented by the growth rate of oil imports (which is derived from the desired optimal factor demand) and by its associated risks, represented by the portfolio variance, and portfolio composition. In this context, conceptually the duality theory allows to obtain from cost optimization the derived factor requirements. Consequently, we consider the average import price as a measure

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of the return of the oil import portfolio, with its associated risks, represented by the import prices variance. Both of these elements are based on historical shipment and price data. We derive efficient portfolio frontiers and construct the oil import growth and oil import price portfolios for the four major Asian oil importers – China, Japan, Korea and Taiwan. This method captures the trade-offs between high growth/best price terms and the concentration of suppliers, and portfolio diversification to lower the associated risks.

Second, we propose a novel methodology to identify the energy security priorities of individual economies, comparing the efficient portfolio frontiers for import volumes and average import prices. The model allows for both positive and negative effects of an increase in imports shares from a particular supplier (even the one deemed most reliable and offering beneficial price terms), in terms of changes in the volatilities for both the growth rate of oil import volumes and the average import price, depending on the portfolio composition.

The rest of the paper is organized as follows: Section 2 reviews the relevant literature on energy security. Section 3 discusses the theoretical background, data and methodology. Section 4 summarizes the empirical results and Section 5 delivers the conclusions.

II. Literature review

The subject of energy security, spurred by the energy crises of 1970s, as the concept of 'assuring sufficient energy supplies' was introduced by Willrich (1976). In this period, energy security was primarily viewed as supply availability from the perspective of fuel-importing countries. The Gulf war and subsequent oil price fluctuations in the beginning of 1990s induced the inclusion of an economic perspective, in particular, the affordability of energy and its impact on national welfare.

Recent studies suggest that the energy security concept should comprise an extensive list of issues including infrastructure (Scheepers et al. 2007), environmental impact (Greenleaf et al. 2009), societal effects (Kemmler and Spreng 2007), energy efficiency (Hughes 2009) and governance (Yergin 2006) among others. In this context, the major international organizations define energy security as:

- 'Uninterrupted availability of energy sources at an affordable price' (IEA 2018);
- 'The continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices' (UNDP 2000);
- Assurance of uninterrupted physical availability of energy products on the market, at an affordable price, while looking towards sustainable development" (European Commission 2000).

Evidently, security of physical supply and price affordability remain the principal components of the energy security paradigm of Governments' strategies. Taking the major Asian countries' perspective, energy outward foreign direct investments (ODI) for such fuel import-dependent economies as China and Korea have been declining both in absolute and in relative (compared to total ODI) terms (see Figure A1 in Appendix for details). On the other hand, the same economies are aggressively building strategic petroleum reserve (SPR) capacities, which are currently reaching 500 million barrels in China and 146 million barrels in Korea (Oil Price 2017).

The trends in market concentration of international fuel trade measured by the Herfindahl-Hirschman Index (HHI) vary by fuel type and by importer. A general increase in HHI for coal (see Figure A2, Appendix) implies that economies are less focused on diversification and may reflect their declining concerns about supply security. The HHI of oil imports has been relatively steady over the last decade with the notable exception of vastly diversified Chinese imports portfolio, while global gas imports became much more diversified due to proliferation of LNG trade.

However, the supply security component continues to be one of the major priorities. Besides intensive development of SPR, which should be able to cover 90 days of oil demand by 2020, Chinese Five Year Plan for the Development of Foreign Trade states the goals of 'sustained and steady growth of energy resources and commodity trade, and ensure the supply of domestic markets' and 'supporting powerful companies to "go global", develop overseas resources, energy, and processing and production' (MOFCOM 2017). Korea's Energy Master Plan also emphasizes diversification of existing energy routes and expanding domestic stockpiling capacity (MOTIE 2014).

Measuring energy security can be quite challenging given its complex multidimensional structure and a loosely defined scope. For instance, the Global Energy Institute (2020) issues the index of US energy security risk, while Sovacool (2011) proposes 200 indicators grouped into 20 dimensions for the analysis of energy security in the Asia Pacific region. Zhang et al. (2017) developed a model to optimize China's LNG imports based on importing costs, exporting county and shipping route risks and applied it to simulate the effects of changes in input factors and extreme events.

More comprehensive models, which are usually derived from energy system models, e.g. Rioux, Galkin, and Kang (2019), EIA (2017), can provide a broader perspective on the energy imports security and its interactions with domestic energy systems and global fuel markets. Finally, political science provides another perspective on energy security (Garrison 2010; Hughes and Lipscy 2013) covering the elements of bargaining process, distribution of power and interdependence between actors.

The overview of traditional methodologies applied in the energy security domain reveals that none of these 'classic' approaches on its own represents a clear evaluation mechanism of the trade-off between the price and physical supply security components, motivating our proposed method, developed based on financial analysis.

III. Theoretical analysis, data and estimation

The concept of minimizing portfolio risk, which is represented by the portfolio variance (or standard deviation), for any given level of expected return was first introduced by Markowitz (1952). Since then, this theory has been extensively applied both within and outside of the traditional financial portfolio domain.

Energy crises and increased price volatility of internationally traded fuels in the 1970s prompted the application of portfolio theory in the field of energy. Bar-Lev and Katz (1976) applied it to explore the efficiency of fossil fuels procurement by the US utility industry. Since then, the portfolio theory has been utilized to assess energy projects and investment decisions (Westner and Madlener 2010), maximize yields in power generation subsectors (Medimorec and Tomsic 2015), optimize the power generation industry as a whole (Awerbuch and Berger 2003) and rationalize national energy consumption mix (Humphreys and McClain 1998). Tissaoui and Azibi (2019) analyze the return volatility of the Saudi financial portfolios and the implications for the oil markets. Shahzad et al. (2018) and Lang and Auer (2019) and Ajmi et al. (2014) investigate the relationship between financial portfolio diversification volatility and oil prices. Yin and Xiyuan (2020) analyze the correlation of stock markets and oil price volatility. Chan and Woo (2016) explore the nexus between international and Chinese oil prices. Zhu et al. (2019) analyze the relation between international oil prices and Chinese commodity futures markets, using quantile regression.

Energy security risk is defined based on a variance in imports cost (Wu et al. 2007) or suppliers' economic and political environment (Ge and Fan 2013; Wabiri and Amusa 2010).

To our knowledge, no studies have yet derived an energy import efficiency frontier, where importers could assess the trade-offs between cheaper or more abundant supply sources and associated risks. We address these gaps by applying the optimal portfolio theory approach to the problem of evaluating both physical supply and price security components of energy imports to derive corresponding efficient import frontiers.

Operationally, we look into two aspects of oil imports: the physical imported volumes and the unit dollar import cost. In the first case, we consider that a derived demand for energy from the optimization of the production function has to be satisfied with an import portfolio, and therefore, the return is the overall import growth rate, computed as the monthly growth rate in oil import volumes and the uncertainty is the variability of the import growth rate across suppliers.

Formally, we have a two-stage cost function C for a country, where Y is GDP, Q is the total quantity of energy, w_i are the factor prices, one of which is energy price p_e to produce GDP, q_i are the individual imported quantities in the import portfolio, with associated p_i prices:

$$C_y = C_y(w_1, w_2, pe, \dots w_n, Y) \quad (1)$$

$$C_E = C_E(p_1, p_2, \dots p_n, E) \quad (2)$$

The sequential minimization to derive, via the duality approach of the Shephard's Lemma, the optimal energy input E demand in GDP production and the optimal energy input demand functions into the import portfolio, yields:

$$E = \partial C_y/\partial p_e = E(w_1, w_2, pe, \dots w_n, Y) \quad (3)$$

$$q_i = \partial C_E/\partial p_i = q_i(p_1, p_2, p_n, E) \quad (4)$$

The vector $(q_1, q_2, \dots, q_n)$ is treated as a portfolio with desired return g^*, which is the growth rate of E^*, i.e the growth rate of the desired optimal total quantity, as derived from the desired optimal growth rate of GDP) and a risk variance, due to uncertainty, which is measured by the standard deviation of the import portfolio.

The standard deviation of the return to be minimized can be expressed as the weighted average of covariance matrix of the individual inputs: s'Vs, where V is the square root of the return's covariance matrix and s is an import shares vector. The total return rate of the portfolio g^* can be viewed as the sum of the returns weighted by each supplier's relative importance:

$$g^* = \Sigma_j \, s_j \, g_j \quad (5)$$

Standard optimization, which is formally given by: min s'Vs, given the constraint: $\Sigma_j \, s_j \, g_j = g^*$ (g^* is the optimal return), yields the relation between the minimum variance and its return for different values of g^*. This yields the efficient frontier for empirical estimation, as a relation of the standard deviation with the return and return squared, expressed as follows:

$$SD_{gt} = a + b_1 g_t + b_2 {g_t}^2 + e_t \quad (6)$$

where SD_{gt} is the standard deviation of the t-th oil import flows growth s, a is the fixed effect, g_t is the annual growth rate of the total flow and e_t captures the residual error.

In the second case, we consider that minimizing the cost of the import portfolio yields a return, which is the price benefit associated with the oil imports, computed as 1000 USD/ton of imported oil minus the actual import price ($/ton) paid at the border and the uncertainty is the variability of the price benefit across suppliers. In other words, the lower the specific import price, the higher the benefit.

Formally, in analogy with Equations (5) and (6) we have:

$$p^* = \Sigma_j \, s_j \, p_j \quad (7)$$

$$SD_{pt} = a + b_1 p_t + b_2 {p_t}^2 + e_t \quad (8)$$

where SD_{pt} is the standard deviation of the t-th price benefit, a is the fixed effect, p_t is the annual average profitability index and e_t captures the residual error.

We consider crude oil imports and prices of major East Asian economies: China, Japan, Korea and Taiwan. For similar approaches applied in other domains, see Chandra (2003), Bigerna 2013) and Almusehel and Alfawzan (2017).

In the mean-standard deviation space, Equations (6) and (8) define a parabolic function of efficient portfolios, which represents the frontier of portfolios with minimum variance (see Figure 1).

In the first case, the return variable defined by the oil import growth rate of an economy and the variance defined by the structural composition or diversification of its imports represent a trade-off between high growth and concentration or diversification of the supply structure. An importer which prefers a narrow range of high growth suppliers faces a higher risk of downturn in case of exogenous disruptions.

Similarly, the second case represents a trade-off between focusing on most profitable suppliers and diversification to reduce supplier-specific risks. Hence, this approach covers the physical supply security and price affordability components of energy security.

A frontier can shift to the left, implying more diversification (lower uncertainty) and up, representing a more efficient and diversified portfolio (Figure 2).

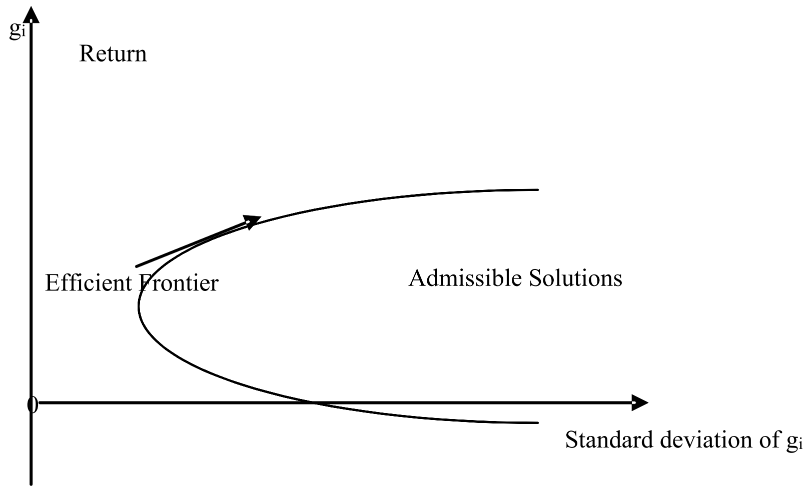

Figure 1. The standard efficient portfolio frontier.

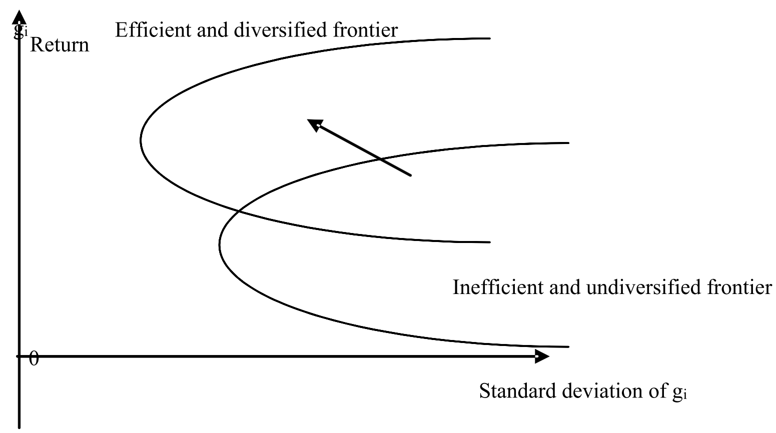

Figure 2. An efficient and diversified portfolio.

A frontier can also move to towards the lower left or towards the upper right (Figure 3), showing an increase of aggressiveness towards higher return and higher risk.

Our analysis of these trade-offs is focused on major oil importers in the East Asia region: China, Japan, Korea and Taiwan. In order to construct the efficient portfolio frontiers, we use the oil import data of these economies disaggregated by suppliers. Oil imports are recorded at the monthly frequency in physical terms (tons) and value terms ($ on the CIF basis). We derive the monthly average unit price as the ratio of associated imported values to quantities. For each importing economy in focus data are aggregated for a specified period T and a specified number of suppliers M.[1]

For the variable of flows in physical terms, we compute monthly growth rates and associated standard deviations for each supplier. For the variable of flows in dollar terms, we compute a measure of price benefit, defined as 1000 USD minus the unit price, associated with each supply source.[2]

The theoretical model of the efficient portfolio determination relies on a set of assumptions, such as the normal distribution of the assert returns, rationality of agents with risk averse preferences, price-taking behaviour and absence of borrowing

[1]The structure of the monthly data set is different for each country. Specifically: the end period is December 2017 for all countries, but the initial period is January 2005 for China; January 2002 for Japan; January 2002 for Korea; January 2006 for Taiwan. The number of partner countries is: $M_{China} = 76$; $M_{Japan} = 51$; $M_{Korea} = 23$; $M_{Taiwan} = 39$.

[2]We first test for the cointegrating properties of the series applying the Dicky-Fuller and the Engle-Granger tests as shown in Table A1 in the Appendix. The cointegration tests that we apply to avoid the risk of spurious correlation in running the regression, show that the growth variables are generally stationary and that cointegration relations exist.

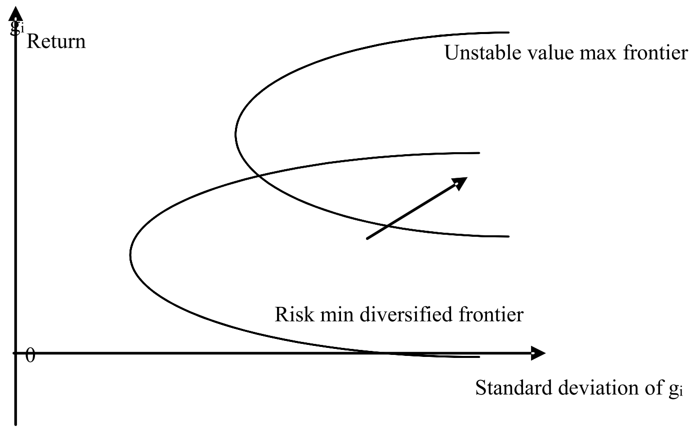

Figure 3. Value maximization and risk minimization strategies.

constraints, which we assume valid to characterize oil-importing country's rational strategies. In addition, price-taking is a reasonable assumption for buyers in the international oil market.

Normality of the returns is confirmed by Jarque-Bera tests (a joint Lagrange Multiplier test of the residuals' skewness and kurtosis) on growth returns and price benefit for the four economies and we find no serious indication of non-normality (not reported, available upon request).

The empirical results confirm the assumption of convexity of the portfolio frontiers (Table A2 in the Appendix): the first coefficient (b_1) is negative and the second (b_2) is positive. The Durbin-Watson test results are acceptable. The significance value of the coefficient b_2 is important to assess the pattern of diversification. If the coefficient value is significantly greater than unity, this shows an increasing degree of importer's diversification. The empirical results show increasing diversification only for Korea oil quantity growth rate.

IV. Results and discussion

The empirical estimation corroborates the finding that China has managed to comprise a vastly diversified portfolio of oil imports. China exhibits a lower level of risk than that of its regional peers, and the shape of her efficient frontier curve suggests that potential further increase in imported volumes can be achieved without a significant spike in volatility. Korea and Taiwan, on the other hand, seem to prioritize economic benefits, composing their oil imports portfolios based on the best possible price terms. Japan's import growth frontier is similar to those of Korea and Taiwan, but its price benefit curve lags behind in the price/ risk balance – suggesting that the portfolio structure could be improved.

Efficient frontiers for imported oil volumes derived for China, Japan, Korea and Taiwan are shown in Figure 4(a), showing a trade-off between the monthly growth rate of imports (vertical axis) and associated risks represented by its standard deviation (horizontal axis). The average monthly growth rates over the last 12 months, which are used as a basis for our Baseline 2017 scenario, in the cases of China, Japan and Korea reside within a narrow range of 1.0122, 1.0117 and 1.0026, respectively. Taiwan stands out compared to its peers with a 1.0437 or 4.37% average monthly growth.

Due to the differences in the composition of oil imports portfolios, similar average monthly import growth rates result in varying risk levels. The corresponding standard deviations of imported oil volumes estimated for the Baseline 2017 scenario are: 0.055 for China, 0.67 for Japan, 0.53 for Korea and 0.798 for Taiwan.

Among the four oil importers, China clearly stands out as the one with the lowest-risk import portfolio. The standard deviation of its portfolio observed in 2017 is by a magnitude lower compared to peers. The steep frontier curve also implies that China can substantially increase its monthly oil imports without major negative implications for the overall portfolio risks.

The shape and position of China's efficient frontier curve mirrors the economy's considerable

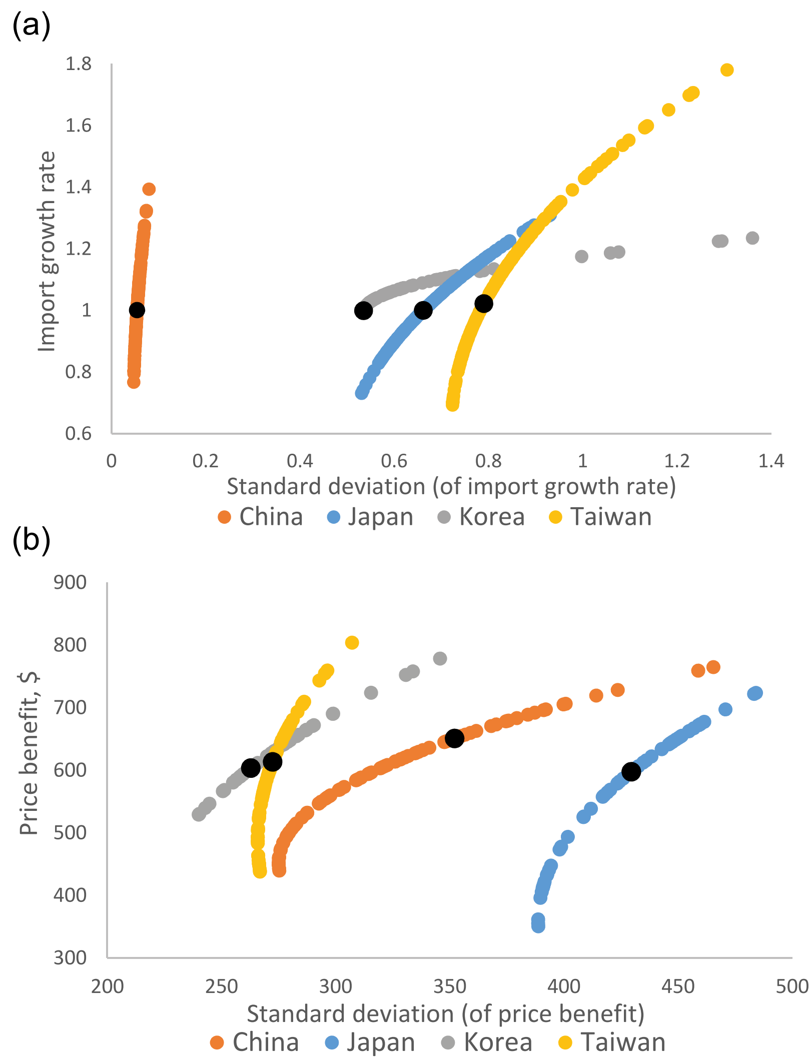

Figure 4. (a) Efficient oil import frontiers: import growth rate. (b) Efficient oil import frontiers: import price benefit.

efforts to ensure the security of supply. Given China's current significant level of oil import dependence at about 70% of domestic consumption (CEIC 2018) and strong demand projections for the coming decade – a 2.1% growth rate until 2030 according to the EIIJ 2019 Outlook (EIIJ 2018), – such extensive focus is not surprising. Although, it can be debated whether the costs associated with securing and diversifying oil imports can be optimized and whether the current portfolio risk is already lower than the sufficiently tolerable level.

Far behind China's benchmark, Korea has the lowest portfolio risk among the remaining three importers under the Baseline 2017 scenario. However, the shape of its frontier curve suggests that Korea would not be able to easily accommodate for a sharp increase in monthly imported volumes, which may occur due to supply disruptions or other unforeseen events. In this case, its oil imports portfolio risk would increase exponentially and, starting from certain import growth levels, Korea's portfolio can become the riskiest of the four importers.

Such shape of the efficient frontier curve may represent a worrisome symptom given Korea's resent steady growth in oil imports around 3–4% per annum and projected, albeit moderate (0.2% growth rate), increase in oil demand until 2030 (IEEJ 2018). This may also signal a lack of focus on oil imports in the overall national energy policy and energy security agenda.

Japan and Taiwan demonstrate similarly shaped efficient frontier curves. Both economies have not had a substantial oil import growth in recent years (a decrease in Japan and a plateau in Taiwan) and are expected to demonstrate a decrease in consumption in the coming decade. In 2017, Japan is somewhat better positioned in terms of its oil import portfolio risk due to relatively higher diversification of suppliers. Conversely, in the case of Taiwan, Saudi Arabia and Kuwait together account for over 50% of imported oil volumes.

Efficient frontiers for the price-risk measure of oil import security for the four East Asian importers are shown in Figure 4(b). The vertical axis represents the price benefit measure – the difference between 1000 USD/ton and the actual import price of imported oil paid at the border – calculated on a monthly average basis. The horizontal axis represents associated price volatility expressed as a standard deviation.

The price benefits estimated for the Baseline 2017 scenario for Japan, Korea and Taiwan fall within a narrow range at 597.6 $/t, 603.3 $/t and 610.2 $/t, respectively. China managed to secure more favourable imports price terms at 650.8 $/t due to the significant imported volumes and long-term pipeline delivery contracts.

Assuming that the price of oil imports is primarily defined by the global market rather than by bilateral contract terms (especially in the case of tanker imports), the portfolio composition remains one of the most essential tools that oil importers can use for the cost and risk management. Similar price benefit levels can yield significantly different risks, as evident in the case of Japan compared to Korea/Taiwan, see Figure 4(b).

Korea and Taiwan composed the most efficient price risk-balanced import portfolios according to the Baseline 2017 conditions. Although Taiwan's current position is slightly more risky (as represented by higher standard deviation on the chart) than that of Korea, the shape of Taiwan's efficient frontier curve suggests that it would be able to attain higher price benefits at lower risk compared to Korea starting from about 635 USD/t. China, on the other hand, has an efficient frontier curve that exponentially increases the risk level starting from the price benefit measure of 580 USD/t and higher.

In contrast to the oil imports volumes frontier curves, the price benefit curves seem to be only partially affected by the import's diversification levels. The HHI index for China's 2017 oil imports is 794, much lower (meaning a much more diversified portfolio) than those of Korea (1495) and Taiwan (1690). Yet, the latter economies managed to obtain more efficient import price frontiers.

Conventional criteria of energy/import security, such as those applied in the Energy Security Risk Index (Global Energy Institute 2020), position China above its regional peers. Japan and South Korea, on the other hand, rank in the lower tier among the OECD countries, with Japan having better scores than South Korea in the 'Import Expenditures per GDP' category. These results partially match with the performance of energy importers discussed above: China can be deemed to have an overall more efficient oil import portfolio. However, South Korea is not the riskiest oil importing economy in the region from the portfolio optimization perspective, especially on the import price side. Its focus on the price optimization, in turn, can be explained by a significant share of energy import expenditures as highlighted in the Risk Index. Japan's oil import portfolio, on the other hand, could be further optimized in terms of import prices and associated risks.

Thus, our method allows to assess energy security and its associated risks, as well as to identify the opportunities for increasing energy security performance of importers.

Based on the estimated parameters, we computed for each importer the point where the frontier slope equals to zero, which represents the optimal return values at the minimum risk level. The results are shown in Table 1; the corresponding frontier slopes and their sensitivity analysis are presented in Tables 2 and 3.

The estimated import growth rate values for China, Japan and Korea are higher than those observed in 2017. This implies that these economies experienced a sub-optimal level of oil imports growth demonstrating an overcautious approach to managing their oil imports portfolios. Taiwan,

Table 1. Estimates of import growth and price benefit under the uncertainty minimization condition.

Importer	Oil Import Growth Rate, %	Price Benefit, $/t
China	1.43%	452
Japan	2.01%	335
Korea	1.00%	359
Taiwan	1.59%	390

Table 2. Estimates of uncertainty-minimizing growth rate of oil imports.

Importer	Oil Imports Growth Rate	Frontier Slope	Frontier Slope for Different Values of Growth		
			g = 1%	g = 2%	g = 3%
China	1.43%	0.151 g-0.106	0.045	0.121	0.196
Japan	2.01%	1.323 g-0.659	0.664	1.326	1.987
Korea	1.00%	0.291 g-0.289	0.001	0.146	0.291
Taiwan	1.59%	0.880 g-0.552	0.328	0.767	1.207

Note: coefficient values taken from Table A2 in Appendix; g represents the growth rate of oil imports

Table 3. Estimates of uncertainty-minimizing oil imports price benefit.

Importer	Price Benefit, $/t	Frontier Slope	Frontier Slope for Different Values of Price Benefit		
			p = 500	p = 600	p = 700
China	452	0.00389p-1.756	0.19	0.58	0.96
Korea	335	0.00133p-0.445	0.22	0.35	0.49
Japan	359	0.00144p-0.516	0.20	0.35	0.49
Taiwan	390	0.00082p-0.402	0.01	0.09	0.18

Note: coefficient values taken from Table A2 in Appendix; p represents the price benefit associated with oil imports

conversely, significantly exceeded its risk-minimizing import growth threshold in 2017 signalling a more aggressive approach to managing its oil imports. The price benefit levels that minimize portfolio uncertainty are significantly lower than actually observed in 2017 for all economies in focus. However, China has a notably higher risk minimizing price benefit level compared to peers, mirroring its comparatively more beneficial price terms of the 2017 oil imports.

Comparison of the efficient frontier curves of oil import volumes, Figure 4(a) and oil import prices, Figure 4(b) can provide insights into trade-offs between supply security and associated costs and reveal the importers' priorities among these energy security dimensions. China, for instance, clearly emphasizes physical supply security and is willing to take higher risks on the price side of its extremely diversified oil imports portfolio. Taiwan, on the other hand, has structured its oil imports in a way that minimizes price risks but can lead to significant fluctuations in imported volumes. Japan, while demonstrating comparable results in its import volumes/risks efficiency, lags behind the other East Asian importers in the price/risk efficiency of its oil imports, which implies that its overall oil imports portfolio performance could be improved.

From the theoretical perspective, the observed differences in the efficient frontiers of the four oil importers demonstrate the applicability of individual economy-based approach to the portfolio strategies in the global oil market. Varying shapes and positioning of the curves suggest that factors affecting such divergence extend beyond the differences in the transportation costs and that there is no universal efficient portfolio frontier for oil importers even within the same geographic region.

We develop several scenarios to assess potential impacts on the importers' portfolios resulting from the changes in portfolio structure, geopolitical events, disruptions and re-evaluation of risk premiums associated with particular supply routes.

We establish a Baseline scenario to place the oil importing economies on their respective efficient frontier curves using the average monthly oil imports data observed in 2017. In Scenario 1, we estimate the consequences of portfolio restructuring by increasing the share of oil imports from Saudi Arabia. In Scenario 2, we assess the potential immediate and ensuing impacts of Iranian sanctions on the volatility of oil import portfolios. In Scenario 3, we evaluate how the risk premium associated with passing the Malacca straits affects the price levels and price volatility of oil import portfolios. Table 4 summarizes the attributes of scenarios applied in this study.

In Scenario 1, the share of Saudi Arabia in each of the four importers' portfolios is risen by 10% compared to the Baseline 2017 – amounting to approximately additional 1.5 million tons per month for the four importers (Table 5).

We fix the average import growth rates according to the Baseline 2017 scenario values by

Table 4. Description of energy security scenarios for oil importers.

Scenario	Description
Baseline 2017	For the four oil importing economies (China, Japan, Korea and Taiwan), we estimate the points on the efficient frontier curves that most closely corresponds to the recently observed average monthly oil import volumes growth rates and oil import price benefit for a particular economy.
Increased KSA Imports	We increase the share of oil imports from Saudi Arabia by 10% for each economy. Imports from other suppliers are proportionally reduced, so that the total import volumes remain the same.
Iranian Embargo	We simulate the short-run impact of Iranian oil export embargo. Importing economies stop oil imports from Iran and these volumes are not substituted by other suppliers.
Iranian Replacement	Oil imports from Iran are proportionally substituted by existing suppliers.
Malacca Straits Risk Premium	We add a 10% risk premium to the price of oil imports that pass through the Malacca straits.

Table 5. Effects of increased oil imports from Saudi Arabia.

		Baseline 2017	Increased KSA imports	
Importer	Parameter	Values	Values	% Change
China (volume)	Growth rate	1.22	1.22	
	St. dev.	0.055	0.0667	21.3%
China (price)	Price benefit	650.8	657.5	1.0%
	St. dev.	352.0	342.1	−2.8%
Japan (volume)	Growth rate	1.17	1.17	
	St. dev.	0.67	0.797	19.0%
Japan (price)	Price benefit	597.6	597.5	0.0%
	St. dev.	429.8	511.6	19.0%
Korea (volume)	Growth rate	0.26	0.26	
	St. dev.	0.53	0.647	22.1%
Korea (price)	Price benefit	603.3	607.5	0.7%
	St. dev.	262.9	324.2	23.3%
Taiwan (volume)	Growth rate	4.37	4.37	
	St. dev.	0.798	1.397	75.1%
Taiwan (price)	Price benefit	610.2	606.4	−0.6%
	St. dev.	272.1	367.4	35.0%

proportionally decreasing oil imports from other suppliers. In this simulation, we assess the impact of such portfolio restructuring on the risk component associated with imported volumes, the price benefit and its standard deviation. From the perspective of imported oil volumes portfolio, the scenario output indicates that increasing oil imports from Saudi Arabia at the expense of other suppliers would increase the volatility of imports portfolios by around 20% for China, Japan and Korea, and by 75% in the case of Taiwan. It should be noted that with the exception of China, which has vastly diversified its oil imports, Saudi Arabia already dominated the oil imports market share of most Asian economies in 2017: it accounted for 40.2% of oil imports of Japan, 29.0% – of Korea and 31.4 – of Taiwan. Thus, further enhancing the share of a major supplier magnifies the market concentration levels and induces higher volatility.

The negative impact on the supply security component, i.e. higher volatility, under this scenario is offset by the positive price effect for some importers. The price benefit levels increase for China (1.0%) and Korea (0.7%). In the case of China, increasing oil imports from the KSA also leads to reduction in price volatility of its composite portfolio. Other importers would see their price volatility increase from 19.0% for Japan up to 35% for Taiwan. Taiwan would also be the only importer incurring negative effect on its' portfolio price benefit.

These results suggest that changing a share of a particular supplier in the oil import mix would yield significantly different outcomes for each importer. Depending on the individual portfolio composition and bilateral contract terms, increasing the market share of even those suppliers that are deemed most stable and reliable, such as Saudi Arabia (Downes 2011; Yicai Global 2017), can have both beneficial and detrimental impact.

In Scenario 2, we study how various external disruptions impact the performance of oil imports portfolios, simulating the potential consequences of Iranian oil embargo (Table 6).

First, we assume that all imports from Iran are reduced to zero and there is no redistribution of blocked imported volumes among other exporters – the Iranian Embargo scenario. In the second scenario, the Iranian oil imports remain withdrawn, but the associated volumes are proportionally reallocated among existing suppliers – the Iranian Replacement scenario. Under both scenarios we estimate the impact on the imported oil volumes portfolios. We do not assess the effect on the price benefit and its volatility, as an event like this would have a significant impact on the global oil price, representing a systematic non-diversifiable risk, assessment of which lies outside of the scope of this study rendering the diversifiable price risk peripheral.

Table 6. Immediate and ensuing impacts of Iranian oil exports Embargo.

		Baseline 2017	Iranian embargo		Iranian replacement	
Importer	Parameter	Values	Values	% Change	Values	% Change
China (volume)	Growth rate	1.22	1.24	1.6%	1.22	
	St. dev.	0.055	0.0594	8.0%	0.0587	6.7%
Japan (volume)	Growth rate	1.17	1.17	0.0%	1.17	
	St. dev.	0.67	0.73	9.0%	0.603	−10.0%
Korea (volume)	Growth rate	0.26	0.26	0.0%	0.26	
	St. dev.	0.53	0.61	15.1%	0.594	12.1%
Taiwan (volume)	Growth rate	4.37	4.37	0.0%	4.37	
	St. dev.	0.798	0.822	3.0%	0.694	−13.0%

An interruption of oil shipments from Iran would have a varied impact on the Asian importers. The volatility of Taiwan's imports portfolio would increase by only 3.0%. China and Japan would see their portfolio risk rising by 8.0 and 9.0%, respectively. Korea would be impacted the most with the oil imports portfolio volatility rising by 15.1%. These results to a certain extent correspond to the shares of Iran in the total imports of the four economies in 2017: 3.1% for Taiwan, 7.2 – for China, 5.5 – for Japan and the largest share of 12.2% in Korean oil imports. However, they also depend on the specific terms of Iranian shipments, i.e., price, regularity, etc., and how they fit within the import portfolios of these four importers.

Over time, however, when the volumes shipped from Iran are redistributed among remaining suppliers, for some of the economies in focus the effect on the oil import portfolio becomes reversed. The risk profiles of Japanese and Taiwanese portfolios actually improve under this scenario with the volatility reduced by 10.0 and 13.0% respectively. The negative impact on Chinese imports portfolio is somewhat alleviated: the volatility is up by 6.7% compared to 8.0% in the previous scenario. In the case of Korea, however, under the current portfolio structure, the substitution of Iranian imports would still substantially increase the portfolio volatility. Thus, it is not surprising that out of the economies in focus it was Korea that strived to attain the maximum flexibility on the waiver from the US sanctions on Iran (Reuters 2018).

Several studies have looked into the potential impact of Iranian sanctions on Asian oil importing economies. They primarily measure the sensitivity of Asian oil importers to Iranian sanctions in terms of their imported volumes (total and relative to other suppliers) and potential disruption of their energy investment projects, e.g. Jalilvand (2019). However, the impacts of such disruptions extend beyond these criteria and, as shown in Table 6, may lead to varying outcomes for the risk performance of import portfolios. The qualitative analyses discuss the balance between energy security and foreign policy considerations (Hong 2013) and explore potential response measures, such as increasing diversification of suppliers and shipping options (Babri-Gonbad 2013). In this regard, the portfolio approach can help evaluate both the potential impacts of supply disruption scenarios and the efficiency of proposed prevention and mitigation strategies.

Finally, in Scenario 3, we estimate the effects of adding the risk premium to the price of oil imports that pass through the Malacca straits (Table 7). This is a crucial and sensitive issue for the Chinese energy security, because despite the import diversification from Middle-East and Africa, the Malacca Strait is the most important single chokepoint for Chinese oil imports (Zhang, 2011).

In the Malacca Risk Premium scenario, we increase the price of relevant oil imports by 10% keeping all other inputs constant as per the Baseline 2017 scenario. We assess the impact on

Table 7. Price effects of malacca risk premium.

		Baseline 2017	Malacca risk premium	
Importer	Parameter	Values	Values	% Change
China (price)	Price benefit	650.8	633.6	−2.6%
	St. dev.	352.0	448.8	27.5%
Japan (price)	Price benefit	597.6	562.7	−5.8%
	St. dev.	429.8	339.7	−21.0%
Korea (price)	Price benefit	603.3	571.7	−5.2%
	St. dev.	262.9	245.3	−6.7%
Taiwan (price)	Price benefit	610.2	576.3	−5.6%
	St. dev.	272.1	255.4	−6.1%

the price parameters of the oil imports portfolio: the price benefit measure and corresponding standard deviation.

Most of the Asian oil importers in focus would see their price benefit reduced within a 5.2 (Korea) – 5.8 (Japan) range. Such price increase, on the other hand, would marginally reduce the standard deviation of their portfolios. China, which seems to be the most concerned about the risks associated with Malacca straits[3]and best positioned to develop alternative import routes, would suffer comparatively less than other importers in the region in terms of the reduced price benefit – a 2.6% decrease. Due to its geographic location and extensive diversification efforts, China is relatively less dependent on the Malacca straits. Significant oil import volumes from Russia, the U.S., Kazakhstan and Vietnam among others bypass this route. However, extensive oil import portfolio diversification would not mitigate a substantial – by 27.5% – associated increase in the portfolio volatility.

Despite being relatively less affected by the disruption of the Malacca strait passage in our simulation, China has been in the spotlight of research and analysis on this subject. One strain of research has been focussed on integrating the risks associated with the Malacca strait into a comprehensive trade route risk and energy security analysis framework. Wu et al. (2007) simulate the impact of different import routes and strategies on Chinese oil imports. Zhang, Qiang, and Fan (2013) find that the trade route risks for China are less significant than those associated with import dependence and global market volatility. Collins (2018) focuses on the direct impact of imposed Malacca strait blockade on Chinese energy security using the changes to oil stocks as a primary indicator.

The financial impacts of the Malacca strait blockade have been primarily assessed from the macroeconomic, rather than energy security perspective. Qu and Meng (2012) estimate the costs associated with the disruption of Malacca strait passage for carriers and industries globally. Kato et al. (2013) apply the GTAP model to assess the increase in the cost of container imports for specific countries, finding that Japan would be, on average, the most affected, followed by China and South Korea.

Thus, the portfolio optimization approach fills the gap in the economic assessment of the Malacca strait blockade (and other potential supply route disruptions) within the energy security paradigm. This method can also be replicated for all potentially affected economies, allowing the comparison of their exposure to the risks associated with supply chain disruptions.

V. Conclusions

Despite the recent expansion trend associated with the scope of the energy security concept, security of physical supply and price affordability remain its major pillars, as evident from the energy security definitions adopted by international organizations and relevant policies of energy importing economies. Rapidly shifting energy markets as well as changing global economic and geopolitical trends call for a methodology capable of evaluating the trade-offs between the economic and supply security considerations, accounting for the perspective of particular importers and their bilateral relationships with suppliers and assessing the impacts of potential vulnerabilities via scenario analysis.

This study demonstrates the benefits of applying the financial portfolio theory to the energy security domain, estimating the efficient frontiers of oil imports and their prices for the major Asian energy importers, China, Japan, Korea and Taiwan. We assess the risk levels associated with particular import growth levels and average import prices. Comparison of the price benefit and import growth frontiers also provides insights into economies' current energy security priorities and potential trade-offs they would face should they decide to amend their energy security strategy.

The energy security evaluation framework presented in this study has certain limitations. It deals only with diversifiable risks, not accounting for the systemic or systematic (impacting the whole market) ones, and its scope is limited to the short-term horizon. Potential areas for further research may include incorporating systemic and systematic

[3]Already in 2003, then president Hu Jintao emphasized the need to address what he call the 'Malacca dilemma' (Lanteigne 2008)

risks, as well as integrating a risk assessment framework for events not observed in the past. Its application can also be extended to the long-term range based on the appropriate data and to assess the energy security dilemma from the energy exporter's perspective.

In conclusion, our scenario analysis highlights the necessity of assessing energy security from the perspective of an individual importer taking into account the structure of its imports portfolio, rather than analyzing the abstract uniform risks associated with suppliers, import routes or potential disruptions. Our simulations have shown that increasing the share of oil imports even from the most reliable and stable suppliers could be detrimental to the overall imports portfolio. Depending on its structure, such an increase can result in amplified volatility (represented by variance or standard deviation) of the import flows. Ensuing gains in average imports price could also come with associated rise in volatility.

Potential disruptions associated with particular suppliers or import routes also demonstrate significantly varying impacts on energy importing economies. In the case of a fully enforced Iranian oil exports embargo scenario, the short-run portfolio risk increases across the board, albeit at different rates: from 3% for Taiwan to 15% for Korea. However, over time when Iranian imports are substituted by other suppliers, some importers, including Japan and Taiwan, would see an improvement in the risk profile of their portfolios. Accounting for the 10% risk premium associated with shipments passing through Malacca straits would have a relatively moderate impact on China's oil imports price levels in comparison to its regional peers, but would significantly increase the price volatility of its portfolio.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

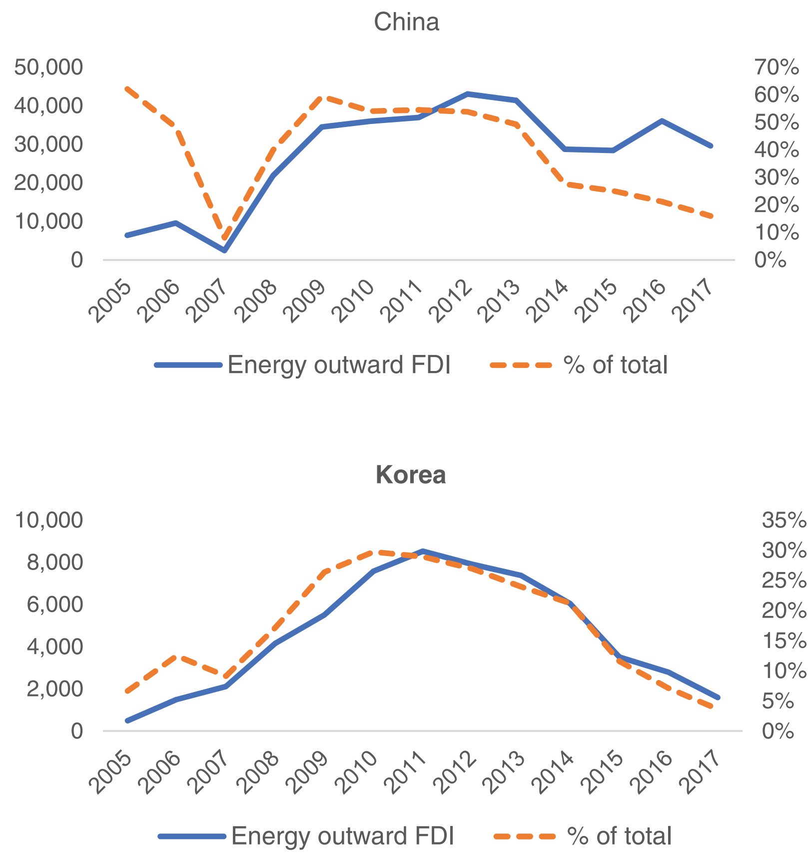

Figure A1. Energy outward FDI flows – China and Korea. Mil USD. Sources: CEIC (2018); American Enterprise Institute (2018)

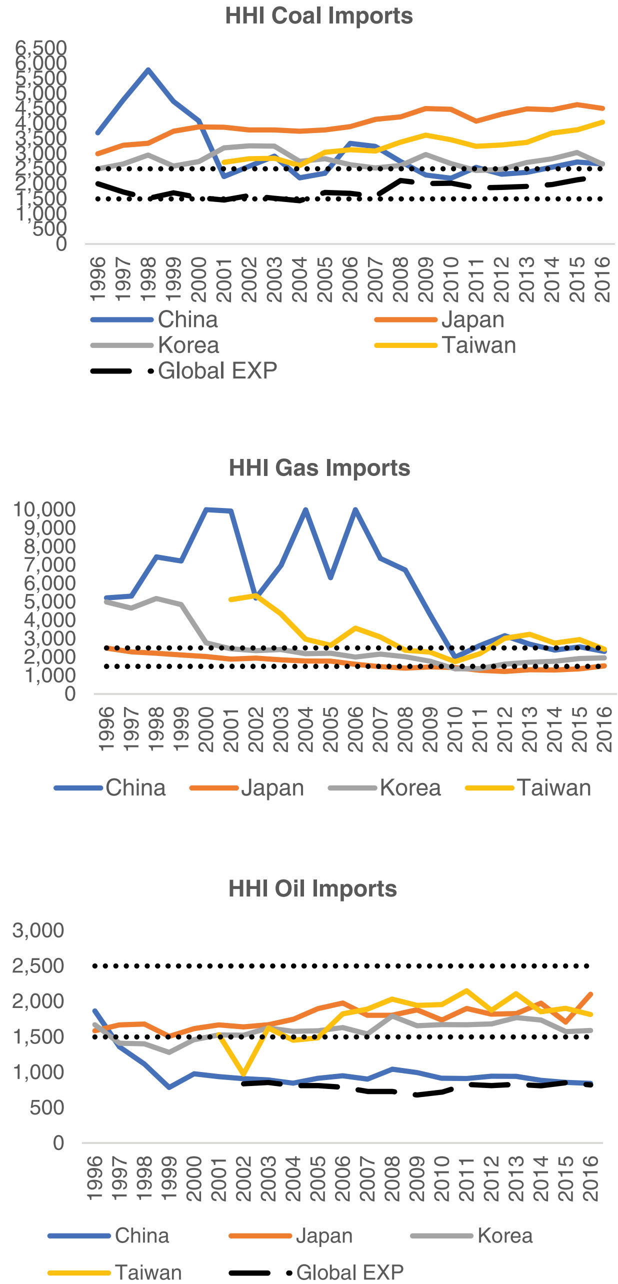

Figure A2. Herfindahl-Hirschman Index of East-Asian Economies' Fuel Imports. Source: JODI (2018)

Table A1. Cointegration analysis.

				China				
	Oil import growth rate					Oil price benefit		
test	SDEV	SG	SGSQ		test	SDEV	SG	SGSQ
Wtd.Sym.	−4.57299	−4.63067	−6.29985		Wtd.Sym.	−6.61586	−3.32025	−3.73141
Dickey-F	−4.42484	−5.74684	−7.50091		Dickey-F	−6.44679	−3.18084	−3.64723
P-values					P-values			
Wtd.Sym.	0.0008	0.0007	0.0000		Wtd.Sym.	0.0000	0.0344	0.0103
Dickey-F	0.0020	0.0000	0.0000		Dickey-F	0.0000	0.0883	0.0261
Num.lags					Num.lags			
Wtd.Sym.	5	8	3		Wtd.Sym.	2	3	3
Dickey-F	5	8	4		Dickey-F	2	3	3
Engle-Granger					Engle-Granger			
TestStat	P-value	Num.lags			TestStat	P-value	Num.lags	
−4.49307	0.0172	5			−6.49644	0.0000	2	
				Korea				
Oil import growth rate						**Oil price benefit**		
test	SDEV	SG	SGSQ		test	SDEV	SG	SGSQ
Wtd.Sym.	−5.88235	−6.6993	−6.50378		Wtd.Sym.	−5.88235	−6.6993	−6.50378
Dickey-F	−5.72407	−6.73635	−6.36048		Dickey-F	−5.72407	−6.73635	−6.36048
P-values					P-values			
Wtd.Sym.	0.0000	0.0000	0.0000		Wtd.Sym.	0.0000	0.0000	0.0000
Dicky-F	0.0000	0.0000	0.0000		Dickey-F	0.0000	0.0000	0.0000
Num.lags					Num.lags			
Wtd.Sym.	2	5	4		Wtd.Sym.	2	5	4
Dickey-F	2	5	5		Dickey-F	2	5	5
Engle-Granger					Engle-Granger			
TestStat	P-value	Num.lags			TestStat	P-value	Num.lags	
−5.78186	0.0001	2			−5.78186	0.0001	2	
				Japan				
Oil import growth rate						**Oil price benefit**		
test	SDEV	SG	SGSQ		test	SDEV	SG	SGSQ
Wtd.Sym.	−5.9152	−5.85848	−5.03217		Wtd.Sym.	−1.87872	−2.03346	−1.61885
Dickey-F	−5.76384	−5.76453	−4.92098		Dickey-F	−1.71236	−1.5368	−1.53231
P-values					P-values			
Wtd.Sym.	0.0000	0.0000	0.0002		Wtd.Sym.	0.7261	0.6254	0.8521
Dicky-F	0.0000	0.0000	0.0002		Dicky-F	0.7454	0.8162	0.8178
Num.lags					Num.lags			
Wtd.Sym.	5	12	12		Wtd.Sym.	6	5	8
Dickey-F	15	12	12		Dickey-F	6	8	8
Engle-Granger					Engle-Granger			
TestStat	P-value	Num.lags			TestStat	P-value	Num.lags	
−5.98774	0.0001	5			−5.45109	0.0005	4	
				Taiwan				
Oil import growth rate						**Oil price benefit**		
test	SDEV	SG	SGSQ		test	SDEV	SG	SGSQ
Wtd.Sym.	−6.82379	−8.38558	−8.36571		Wtd.Sym.	−4.71745	−3.17694	−3.79913
Dicky-F	−5.42525	−8.30428	−8.2467		Dickey-F	−4.65543	−3.03879	−3.68666
P-values					P-values			
Wtd.Sym.	0.0000	0.0000	0.0002		Wtd.Sym.	0.0005	0.0519	0.0085
Dickey-F	0.0000	0.0000	0.0002		Dickey-F	0.0008	0.1216	0.0233

(*Continued*)

Table A1. (Continued).

	China							
	Oil import growth rate				Oil price benefit			
Num.lags				Num.lags				
Wtd.Sym.	2	4	3	Wtd.Sym.	2	4	3	
Dickey-F	3	4	3	Dickey-F	2	4	3	
Engle-Granger					Engle-Granger			
TestStat	P-value	Num.lags		TestStat	P-value	Num.lags		
−6.49044	0.0001	2		−6.39239	0.0001	2		

SDEV – standard deviation
SG – return
SGSQ – return square
Wtd.Sym. – weighted symmetric test
Dickey-F – Dickey-Fuller test
Engle-Granger – Engle-Grange test
Num.lags – number of lags

Table A2. Estimation results.

China
Oil imports growth rate
Number of observations: 154
LM het. test = 4.42708 [.035]
Durbin-Watson = 1.93455 [<.672]
R-squared =.037179 Schwarz B.I.C. = −83.7440
Log likelihood = 108.929
Variable Coefficient Std.Error t-statistic P-value
B1 −.106115.086362 − 1.22873 [.221]
B2 .075642 .015987 4.73155 [.000]
Oil price benefit
Number of observations: 154
LM het. test = 5.66136 [.017]
Durbin-Watson = 2.13967 [<.936]
R-squared =.048857 Schwarz B.I.C. = 1181.58
Log likelihood = −1161.43
Variable Coefficient Std.Error t-statistic P-value
C 671.819 239.335 2.80702 [.006]
B1 − 1.75641 1.21823 − 1.44177 [.152]
B2 .194376E-02.140912E-02 1.37942 [.170]
Korea
Oil import growth rate
Number of observations: 119
LM het. test = 13.6191 [.000]
Durbin-Watson = 1.67730 [<.087]
R-squared =.112209 Schwarz B.I.C. = 214.175
Log likelihood = −202.227
Variable Coefficient Std.Error t-statistic P-value
C 14.9663 11.0752 1.35134 [.179]
B1 − 28.9548 22.0840 − 1.31112 [.192]
B2 14.5236 10.9516 1.32616 [.187]
Oil price benefit
Number of observations: 119
LM het. test =.432472 [.511]
Durbin-Watson = 1.71630 [<.069]
R-squared =.985338 Schwarz B.I.C. = 460.820
Log likelihood = −456.032
Variable Coefficient Std.Error t-statistic P-value
C 289.813 152.668 1.89832 [.066]
B1 −.445969 .474438 −.939994 [.354]
B2 .665103E-03 .366426E-03 1.81511 [.079]
Japan
Oil import growth rate
Number of observations: 198
LM het. test = 3.74006 [.053]
Durbin-Watson = 2.03477 [<.715]
R-squared =.125371 Schwarz B.I.C. = 73.6509
Log likelihood = −60.4303
Variable Coefficient Std.Error t-statistic P-value
B1 −.658568 .212517 − 3.09889 [.002]
B2 .661404 .025644 25.7915 [.000]
Oil price benefit
Number of observations: 108
LM het. test =.377540 [.539]
Durbin-Watson = 2.02497 [<.707]
R-squared =.966365 Schwarz B.I.C. = 480.565
Log likelihood = −468.859
Variable Coefficient Std.Error t-statistic P-value
C 481.326 8.71664 55.2192 [.000]
B1 −.515816 .055616 − 9.27463 [.000]
B2.718015E-04 .724519E-04.991023 [.324]
Taiwan
Oil import growth rate
Number of observations: 192
LM het. test = 1.09557 [.295]
Durbin-Watson = 1.73390 [<.107]
R-squared =.217978 Schwarz B.I.C. = 119.353
Log likelihood = −98.3228
Variable Coefficient Std.Error t-statistic P-value
C .342693.206697 1.65794 [.099]
B1 −.552038 .467155 − 1.18170 [.239]
B2.439809 .191908 2.29177 [.023]
Oil price benefit
Number of observations: 96

Table A2. (Continued).

LM het. test = 7.38212 [.007]
Durbin-Watson = 1.82639 [<.429]
R-squared =.307558 Schwarz B.I.C. = 582.156
Log likelihood = −566.180
Variable Coefficient Std.Error t-statistic P-value
C 363.836 40.2776 9.03321 [.000]
B1 −.401999 .202373 − 1.98642 [.049]
B2 .515470E-04 .532341E-04 .968859 [.125]