

Energy strategies of China and their impacts on energy shipping import through the Straits of Malacca and Singapore

China's energy strategies and shipping import

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Abstract

Purpose – This study aims at investigating how energy strategies of China impact its energy shipping import through a strategic maritime link, the Straits of Malacca and Singapore (SOMS).

Design/methodology/approach – Vector error-correction modelling (VECM) is applied to examine the key energy strategies of China influencing crude oil and liquefied natural gas (LNG) shipping import via the SOMS. Strategies investigated include oil storage expansions, government-setting targets to motivate domestic gas production, pipeline projects to diversify natural gas import routes and commercial strategies to ensure oil and gas accessibility and cost-effectiveness.

Findings – For the crude oil sector, building up oil storage and diversifying oil import means, routes and sources were found effective to mitigate impacts of consumption surges and price shocks. For the LNG sector, domestic production expansion effectively reduces LNG import. However, pipeline gas import growth is inefficient to relieve LNG shipping import dependency. Furthermore, energy companies have limited flexibility to adjust LNG shipping import volumes via the SOMS even under increased import prices and transport costs.

Practical implications – As the natural gas demand of China continues expanding, utilisation rates of existing pipeline networks need to be enhanced. Besides, domestic production expansion and diversification of LNG import sources and means are crucial.

Originality/value – This study is among the first in the literature using a quantitative approach to investigate how energy strategies implemented in a nation impact its energy shipping volumes via the SOMS, which is one of the most important maritime links that support 40% of the global trades.

Keywords Energy strategy, Shipping, Vector error-correction modelling, The Straits of Malacca and Singapore (SOMS), Crude oil, Liquefied natural gas (LNG), China

Paper type Research paper

1. Introduction

As the main shipping channel connecting the Indian Ocean and the Pacific Ocean, the Straits of Malacca and Singapore (SOMS) is one of the most important maritime links. Nowadays, 40% of the global trades are transported through the SOMS. As such, SOMS is recognised as the lifeline of global economic growths (Chang and Khan, 2019). Particularly, China, as a rapidly developing economy with continually expanding energy demand, increasingly relies on this maritime link for crude oil and liquefied natural gas (LNG) imported from the Middle East, African and European countries (Zhang, 2011; Gholizadeh *et al.*, 2020). The vulnerability of SOMS to piracy, oil spills, other incidents and regional conflicts brings about maritime security concerns, especially for countries like China that heavily rely on the



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SOMS for energy shipping import. From 2008 to 2018, crude oil import to China via the SOMS increased by 110%, while LNG import to China via the SOMS increased by 1,600%. If SOMS is blocked, energy supplies of China will be disrupted, which will consequently hinder the economic development of the nation (Ramachandran, 2015).

The economic development and energy transition of China bring about growths in oil and gas demand (Figure 1), and derived shipping demand for crude oil and LNG import. On the one hand, the National Development and Reform Commission (NDRC) of China has set up long-term targets to motivate coal substitution with natural gas, which is one of the cleanest fossil fuels. On the other hand, crude oil also continues to grow in consumption volumes (NDRC, 2013; NDRC, 2017a) driven by an increasing demand for all refinery products. Due to slower growths in domestic crude oil and natural gas productions compared with consumption, crude oil and LNG import volumes increase over time. As various crude oil and LNG-exporting countries are in Middle East, Africa and Europe, over 60% of the crude oil import and over 30% of LNG import of China rely on shipping through the SOMS (Figure 2).

As energy demand of China continues to grow, various energy strategies have been deployed to relieve and cope with the excessive reliance on the SOMS. In terms of crude oil, on the one hand, Strategic Petroleum Reserve (SPR) and other storage expansion strategies have been established to provide a buffer for consumption surges. On the other hand, policy instruments have been adopted to facilitate diversification of crude oil import means and sources to dilute supply risks and reduce import costs. In terms of natural gas, firstly, the Chinese government has set targets for domestic gas production expansion to reduce import dependency (NDRC, 2017a). Secondly, natural gas pipeline projects help to increase import capacity. Thirdly, Chinese energy companies entered into purchase contracts with various foreign LNG suppliers for large volumes (i.e. above one million tons) and long periods (i.e. more than ten years) to secure steady supplies (Tsafos, 2019). Section 2 will explain the above-mentioned energy strategies in detail.

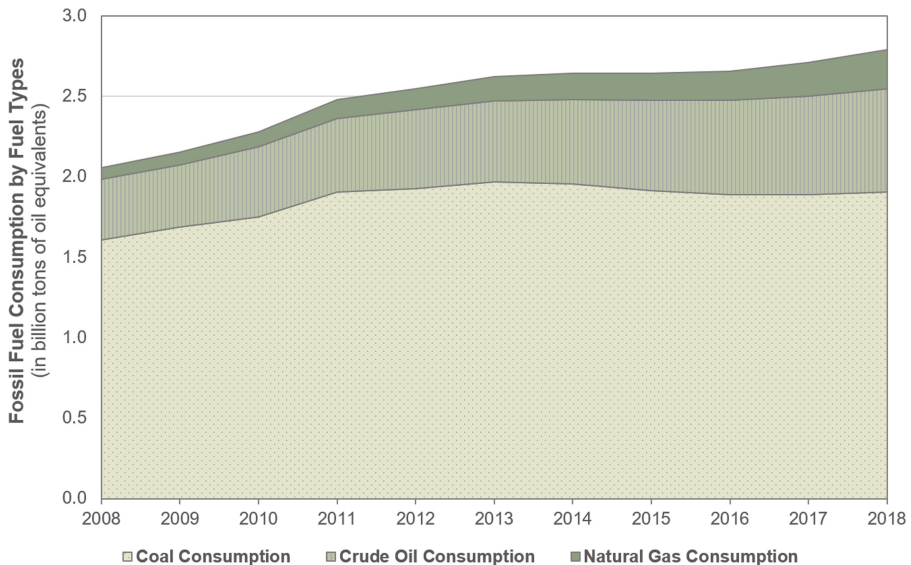
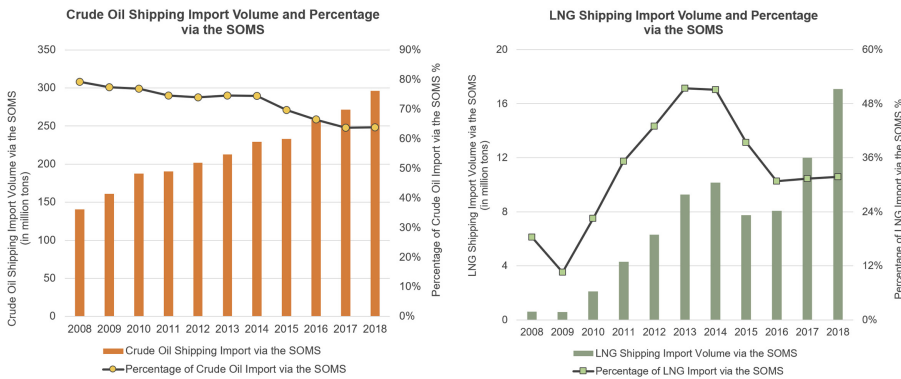


Figure 1.
Fossil fuel
consumption of China
by fuel types
(2008–2018)

Source(s): Drawn by authors based on Bloomberg statistics



Source(s): Drawn by authors based on Bloomberg statistics

Figure 2. Crude oil and LNG shipping import volumes and percentages via the SOMS

Despite the strategic importance of the SOMS in terms of facilitating trades at the global scale, in existing literature, no quantitative analysis has been found on how energy strategies implemented in a nation impact energy shipping import volumes via this maritime link. To fill the void, this study formulates a series of hypotheses to examine whether existing energy strategies of China effectively cope with the excessive reliance on the SOMS for crude oil and LNG import. A vector error correction modelling (VECM) approach is applied.

The rest of this study is organised as follows. Section 2 presents an overview of energy strategies implemented in present-day China to enhance oil and gas accessibility and energy security. Section 3 reviews existing studies to identify literature gaps and justify the selection of the research method. Section 4 introduces the hypothesis and research approach for this study. Section 5 presents the key results and implications, while Section 6 presents the conclusion.

2. Energy strategies in present-day China

In Section 2, the policy instruments and commercial strategies implemented to secure and expand crude oil and natural gas supplies of China are introduced. Notably, each energy strategy analysed in this study is selected based on the significance of its impacts on trade and shipping volumes in foreseeable future. For instance, the role of crude oil pipelines was not discussed, because there are no plans for new cross-country pipelines after 2018 (NDRC, 2017b). Besides, the role of natural gas and LNG storage is not considered, because the storage capacity of present-day China is limited due to infrastructure constraints (Bloomberg, 2018), which occupied 1–2% of supplies over the investigated period and have relatively insignificant impacts on LNG shipping import.

2.1 Crude oil strategies

2.1.1 Diversification of crude oil import sources and means. After entry into the World Trade Organisation in 2001, China has gradually liberalised its crude oil trades. Three state-owned enterprises (SOEs), including Sinopec, China National Petroleum Corporation and China National Offshore Oil Corporation, are entitled to import and export oil flexibly based on refinery capacities without quota control. Subsequently, from 2004, privately owned oil companies are also allowed to register trading licenses (Shanghai International Energy Exchange, 2018). Management Rules on Crude Market launched in 2007 highlighted diversity and marketisation as fundamental strategies, which motivate Chinese energy companies to

have flexible spot, futures and long-term contractual trades with a variety of exporting countries (Wang, 2019). Among the import means, futures play an increasingly important role in recent years, especially after China launching its own crude oil futures in 2018. Crude oil futures facilitate energy companies to trade flexibly as well as hedge risks of spot price shocks (Li *et al.*, 2021). Nowadays, 50% of crude oil import volumes are supplied by the top four origin markets, while 50% are from diverse import sources. Among the top four markets, 15% of crude oil import volumes are from Saudi Arabia, 15% from Russia, 10% from Angola and 10% from Iraq (Bloomberg, 2020a).

2.1.2 Oil storage expansions. China has a well-established crude oil storage system (Shanghai International Energy Exchange, 2018). Based on the latest available statistics in 2020, 30% of current crude oil storage is the SPR under government control, while 70% are commercial stocks owned by SOEs and private enterprises (Reuters, 2020a). These commercial stocks can be utilised to cope with consumption surges in the short term (Pan *et al.*, 2017).

Growths in crude oil storage capacities are driven by both port and independent crude storage operators. On the one hand, the Port Law of China launched in 2004 was regarded as an embodiment of the gradual shift from highly centralised port ownership and decision-making, to a port governance landscape that offers more room for private sector participation (Notteboom and Yang, 2017). Subsequently, the Ministry of Communications (2007) and the Ministry of Transport (2011) issued guidelines to enable commercial stakeholders to invest in building up oil storage capacities within terminals. On the other hand, the Ministry of Commerce (2015) allowed for granting crude oil import licenses to qualified private enterprises. After that, these enterprises (e.g. Hengli Petrochemical and Shandong Hongrun Group) are motivated to invest more and have become top independent crude storage operators. From 2014 to 2020, the crude oil storage capacity of China is estimated to increase by nearly 230% (Reuters, 2020a). Besides, by the end of 2022, the storage capacity is estimated to grow further by 14% supported by 18 commercial storage projects, among which 20% of the storage capacities are owned by ports, 33% are owned by SOEs, while 47% are owned by private enterprises (Reuters, 2020b).

2.2 Natural gas strategies

2.2.1 Government-setting targets for domestic production expansions. The Chinese government regards natural gas as one of the most efficient and cleanest fossil fuels with great potentials to be widely applied in foreseeable future (Ji *et al.*, 2018) and substitute coal to mitigate the negative environmental impacts. As such, NDRC of China set targets in the Five-Year Plans to motivate domestic natural gas production expansions, targeting to increase domestic gas production by 139% over 15 years (NDRC, 2017a). The Five-Year Plan is one of the most important energy policy instruments of China to facilitate energy transition (Yuan and Zuo, 2011). Driven by such targets, natural gas production of China grew by 99% from 2008 to 2018. However, as natural gas consumption increased by 246% over the same period, the domestic production growth could not catch up with demand expansions, which leads to intensified import dependency. Currently, 58% of natural gas supplies in China are met with domestic production, 28% are met with LNG shipping import and 14% are met with pipeline import (National Bureau of Statistics, 2020).

2.2.2 Long-term liquefied natural gas import contracts. Nowadays, over 30% of LNG shipping import volumes are shipped via the SOMS, mainly from Qatar (about 80%). Majorities of LNG import of China are under long-term contracts, which secures steady LNG import volumes to China over long terms. These contracts use linear pricing models equation (1) with coefficient α_1 for crude oil price indexes as the benchmark, and α_0 adjusted by inflations, transportation costs and other market factors (Wang *et al.*, 2020).

$$P_{LNG} = \alpha_1 \cdot P_{crude} + \alpha_0 \tag{1}$$

LNG import of China is from relatively fewer sources compared with crude oil import (in Section 2.1.1). Top four origin markets provided 81% LNG supplies, while the rest 19% are imported from other 11 countries. Among the top four markets, 44% of LNG import volumes are from Australia, 17% from Qatar, 11% from Malaysia and 9% from Indonesia (Bloomberg, 2020b). SOEs of China have entered into long-term LNG import contracts with suppliers in all the top origin markets. Despite the advantages of long-term contracts to ensure steady LNG supplies, it is also debated that this strategy compromises energy affordability. LNG import via long-term contracts is mainly on a take-or-pay basis (Hartley, 2015), which means importers need to pay for a minimum percentage of stipulated supply quantity. As such, even if LNG import prices under long-term contracts are much more expensive compared with spot market prices, SOEs in China cannot make flexible adjustments of the import volumes according to contract terms.

2.2.3 Natural gas pipeline projects. The Chinese government actively enhances bilateral relations with natural gas-exporting countries and signs agreements facilitating pipeline projects (Table 1). As more natural gas pipelines are implemented, pipeline import continuously increased by 69% from 2014 to 2018 (Bloomberg, 2020c). Nevertheless, current natural gas import volumes via all pipelines are significantly lower than design capacities, especially Myanmar and Russia lines, both only realise less than 30% of the respective capacities (Bloomberg, 2020c). As such, it remains questionable whether the pipeline projects effectively reduce excessive reliance on the SOMS for LNG shipping import.

Pipeline natural gas import prices were also based on long-term agreements but are significantly lower than LNG import prices. For instance, in 2018, natural gas pipeline import prices via the Central Asia lines were 36% lower than LNG import price from Australia and 44% lower than that from Qatar (Bloomberg, 2020b, c). These pipelines serve as an alternative mean for natural gas import to dilute foreign supply disruption risks and reduce natural gas import costs.

3. Current state of the art: energy strategies and impacts on maritime transportation

To analyse the current state of the art, two strands of literature related to this study are discussed: (1) impacts of energy strategies; (2) factors impacting maritime transportation volumes. Based on that, how energy strategies impact maritime transportation can be analysed.

As Section 1 discussed, the coal-to-gas transition driven by environmental concerns, and oil demand growth driven by economic development, both lead to growths in oil and gas consumption and thus intensifying import dependency. Energy strategies have been adopted

Pipeline projects	Time of operation	Annual design capacity (billion cubic meters)
Central Asia to China line AB	December 2009	30
Myanmar to China	July 2013	12
Central Asia to China line C	May 2014	25
Russia to China	December 2019	38
Central Asia to China line D	December 2022	30

Source(s): Compiled by authors based on CNPC (2015), CNPC (2018), Xinhua Net (2019a) and Xinhua Net (2019b)

Table 1. Natural gas pipeline projects of China

to cope with such demand growths, such as locking import supplies via long-term contracts (Hartley, 2015; Ji *et al.*, 2018), diversification of import routes and sources (Zhang, 2011; Guo and Hawkes, 2018; Chang and Khan, 2019; Gholizadeh *et al.*, 2020), government-setting targets, subsidies and other policy instruments to influence energy costs (Wang and Lin, 2014; Eric, 2015) and production/storage expansions (Maxwell and Zhu, 2011; Zhang, 2011; Pan *et al.*, 2017). Respectively, the impacts of these energy strategies include changing import/export trade volumes, growing domestic fuel production and storage capacities, and fluctuating commodity prices and shipping costs associated with supply and demand variations.

In previous studies, various factors have been identified to impact maritime transportation volumes. These factors are closely related to the impacts brought by energy strategies, as discussed above. Firstly, the import/export volumes of a nation directly impact the maritime transportation volumes (Zhang, 2011; Guo and Hawkes, 2018; Hou *et al.*, 2018; Gholizadeh *et al.*, 2020). Notably, Zhang (2011), based on statistics and facts, highlighted that growing oil and LNG import trades of China continually intensified its reliance on SOMS for shipping import.

Secondly, alternative supplies (i.e. domestic production, storage volumes, import/export via other transportation modes) also impact maritime transportation (Egging *et al.*, 2010; Maxwell and Zhu, 2011; Yang *et al.*, 2016; Pan *et al.*, 2017). Egging *et al.* (2010) built a mixed complementarity model of the global gas market, interpreting how constraints imposed by natural gas pipelines impact LNG trade flows. Pan *et al.* (2017) modelled how oil storage, domestic supplies, import volumes interacted and impacted transport volumes using system dynamics (SD).

Lastly, commodity prices and shipping costs significantly impact maritime transportation volumes (Maxwell and Zhu, 2011; Ji *et al.*, 2018; Bai and Lam, 2019; Braccaccio *et al.*, 2020; Yang *et al.*, 2020). Ji *et al.* (2018) developed a VECM study and found that high LNG import prices of China locked by long-term contracts hinder its coal-to-gas transition. Bai and Lam (2019) studied, in very large gas carrier (VLGC) market, how freight rates influence shipping demand using structural equation modelling. Yang *et al.* (2020) built a mixed complementarity-based equilibrium model, depicting interactions between iron ore shipping costs and trade volumes.

As discussed, existing studies proved that changes brought by energy strategies impact shipping volumes. However, no studies have been found on how key energy strategies of a nation impact its shipping import volumes via a specific shipping route. This study is among the first in the literature that develops a quantitative approach to investigate how energy strategies of China impact its energy shipping import volumes via SOMS, which is one of the most important maritime links that supports 40% of global trades.

Different models were deployed in previous studies. The research method of this study (VECM) is selected based on research objectives, data and market reality of present-day China. As Zhang (2011) has qualitatively analysed how China relies on SOMS for crude oil and LNG shipping, this study aims at quantifying whether existing energy strategies have effectively relieved such reliance on SOMS using historical time-series data. Hence, qualitative methods like strengths, weaknesses, opportunities and threats (SWOT) and political, economic, social and technological (PEST) analyses (Hou *et al.*, 2018), and structural equation modelling (Bai and Lam, 2019) that is usually for panel data or survey data are not considered.

Computable general equilibrium (CGE) methods are commonly used in literature to quantify how an economy reacts to different strategies based on actual data, including vector autoregression (VAR), VECM, SD and mixed complementarity-based equilibrium. VECM is opted for this study because of the relative limitations of other CGE methods concerning this research context. Due to the non-stationarity of research data, VAR (Maxwell and Zhu, 2011)

cannot be applied. Furthermore, the oil and gas industry in China follows an oligopolistic market structure dominated by state-owned energy companies (Wang and Li, 2014). The government plays an important role in providing guidelines, targets and financial incentives (Yuan and Zuo, 2011; Hou *et al.*, 2018). Hence, decision-making of energy companies can be complicated, which currently focused more on building up reliable and adequate supplies than profitability and diversification (Leung, 2011; Ji *et al.*, 2018). As such, it could be challenging to analyse oil and gas strategies of China based on subjective assumptions set by modellers in SD (Pan *et al.*, 2017) or mixed complementarity-based models (Egging *et al.*, 2010; Yang *et al.*, 2020) as defining scenarios and optimal solutions can be difficult. The two most recent and relevant studies on energy strategies of China both adopted VECM models (Wang and Lin, 2014; Ji *et al.*, 2018), which are stochastic process models that reflect linear interdependencies among non-stationary time-series variables, in which impulse-response patterns are assessed based on empirical patterns found in historical data (Granger and Newbold, 1974).

4. Research approach

4.1 Hypothesis formulation and variable selection

This study proposes an original research approach to evaluate whether and to which extent energy strategies of China (discussed in Section 2) influence the crude oil and LNG shipping import volumes through the SOMS.

Five hypotheses are developed for the five energy strategies analysed in Section 2:

- H1. Oil storage expansion helps to reduce the impacts of crude oil consumption surges on crude oil shipping import volumes via the SOMS.
- H2. Crude oil shipping import volumes via the SOMS decrease when import costs increase, which indicates that energy companies are flexible to adjust import volumes from different origin markets to reduce import costs.
- H3. Domestic natural gas production expansion effectively reduces LNG shipping import volumes via the SOMS.
- H4. Natural gas pipeline import expansion effectively reduces LNG shipping import volumes via the SOMS.
- H5. LNG shipping import volumes via the SOMS decrease when import costs (i.e. LNG prices and transport costs) increase, which indicates that energy companies are flexible to adjust import volumes from different origin markets to reduce import costs.

To examine the hypothesis, two groups of variables are selected based on the research context. Table 2 shows the variables included in the two VECM models. For Model 1, the crude oil shipping import volume via SOMS ($SOMS_{Crude}$) is selected as the response variable and three cointegrated variables are chosen: crude oil consumption (CSP_{Crude}), weighted average import prices from the Middle East, African and European origin markets that rely on the SOMS for crude oil shipping import (PC_{SOMS}) and weighted average import prices from other alternative origin markets (PC_{ALT}). To the best of our knowledge, oil storage data of China is unavailable in public databases. Reuters (2020a) estimated that the current crude oil storage of China is approximately equivalent to 105 days of its net import, which provides a substantial buffer in consumption surges. Zhang (2011) highlighted that building up oil storage helps to cope with consumption surges and thus reduce reliance on SOMS for shipping import, while Pan *et al.* (2017) used simulation data to justify the role of oil storage in coping with consumption surges and avoiding sharp import growths. Due to storage data

Table 2.
Variables included
in VECM

Model	Variable code	Description	Sampling period	Mean	SD
1	SOMS _{Crude}	Crude oil shipping import volumes via the SOMS ('000 metric tonnes)	2008-2018	18,050	4,075
	CSP _{Crude}	Crude oil consumption ('000 metric tonnes)		45,327	8,512
	PC _{SOMS}	Weighted average crude oil import prices in Middle East, African, European origin markets relying on the SOMS for shipping import to China (US\$ per tonne)		588	192
	PC _{ALT}	Weighted average crude oil import prices in other origin markets (US\$ per tonne)		552	176
2	SOMS _{LNG}	LNG import via the SOMS ('000 metric tonnes)	2014-2018	671	339
	PN _{SOMS}	Weighted average LNG import prices in the Middle East, African, European origin markets relying on the SOMS for shipping import to China (US\$ per tonne)		599	199
	PRD _{NG}	Natural gas production ('000 metric tonnes)		8,561	1,080
	PIP _{NG}	Pipeline natural gas import ('000 metric tonnes)		2,403	501
	FP _{SG}	Singapore heavy fuel oil (380cSt) price (US\$ per tonne)		368	128

unavailability and based on literature, the effectiveness of storage expansion was examined by analysing whether SOMS_{Crude} strongly responds to a positive shock in CSP_{Crude} that indicates consumption surges (H1). Besides, if energy companies of China can flexibly adjust import volumes, SOMS_{Crude} should decrease under increasing PC_{SOMS} or decreasing PC_{ALT} (H2) following conventional price–demand relations.

For Model 2, the LNG shipping import volume via the SOMS (SOMS_{Crude}) is selected as the response variable and four cointegrated variables are chosen: natural gas domestic production (PRD_{NG}), natural gas import volume via pipelines (PIP_{NG}), weighted average import prices from origin markets relying on SOMS for LNG shipping import to China (PN_{SOMS}) and bunker prices of Singapore (FP_{SG}). Bunker prices of Singapore are tested to be influential because bunkering costs occupy significant proportions in transportation costs, and Singapore is the most popular bunkering hub for crude oil and LNG tankers sailing through the SOMS to get refuelled during long-distance voyages due to its strategic location and competitive prices (Lam *et al.*, 2011). Domestic production expansion is effective if SOMS_{LNG} decreases under PRD_{NG} growth (H3). Similarly, natural gas pipeline expansion is effective if SOMS_{LNG} decreases under PIP_{NG} growth (H4). Securing LNG supplies via long-term contracts does not compromise cost-effectiveness if SOMS_{LNG} decreases under increasing PN_{SOMS} and FP_{SG} (H5), showing energy companies can flexibly adjust import volumes and reduce import costs.

All data are monthly and collected from Bloomberg. For monthly crude oil and natural gas supply or demand data (i.e. consumption, production, pipeline and shipping import), Census Method I seasonality decompositions are applied with units converted to metric tonnes (Dudley, 2019).

4.2 Model formulation and validation

The VECM method identifies interdependencies among time-series variables with statistically significant cointegrations. In a VECM model, historical values of all cointegrated variables have short- and long-term impacts on the response variable. As equation (2) shows, $\sum_{i=1}^n \partial_i \Delta x_{t-i}$ denotes that a shock in a variable x has a short-term impact on

y for n period, termed as lags (Granger and Newbold, 1974). More importantly, VECM identifies how a shock in x impacts the long-term equilibrium between x and y , which remains impactful after n lags. The key parameters in a VECM model are φ and γ_i . Equation (3). γ_i shows the increment in x that brings 1% reduction in y to maintain the equilibrium. φ is a coefficient for the error-correction term (ECT), indicating the percentage of deviations from the equilibrium that can be fixed in each period (Juselius, 1992). Assuming that a shock in x occurs at a time t , it has direct short-term impacts on y for n periods. However, as equation (2) shows ($\sum_{i=1}^n \beta_i \Delta y_{t-i}$), y_{t+1} is also impacted by historical changes in y_t brought by the shock.

Furthermore, this shock results in deviations from the equilibrium between x and y , causing dynamic changes over the long term. This study investigates the accumulated impacts of a shock over 24 months, which is commonly applied in various VAR and VECM studies (Maxwell and Zhu, 2011):

$$\Delta y_t = \beta_0 + \sum_{i=1}^n \beta_i \Delta y_{t-i} + \sum_{i=1}^n \delta_i \Delta x_{t-i} + \varphi z_{t-1} + \mu_t \quad (2)$$

$$z_{t-1} = \text{ECT}_{t-1} = y_{t-1} + \gamma_0 + \gamma_i x_{t-1} \quad (3)$$

A set of premises needs to be met for variables to be included in a VECM model. Firstly, the level data should be non-stationary, while the first-difference data should be stationary (Dickey and Fuller, 1979). Variables in this study meet this premise based on augmented Dickey–Fuller tests. Secondly, a cointegration relation among selected variables needs to be statistically significant based on the Johansen tests for cointegration (Juselius, 1992), including trace test and maximum eigenvalue test. The hypothesis for the trace test is that there are at most r cointegration vectors. The maximum eigenvalue test compares the hypothesis that there are $r+1$ cointegration vectors versus r cointegration vectors. If the null hypothesis that $r=0$ can be rejected based on both test statistics, at least one cointegrating relation (i.e. a long-term equilibrium) is statistically significant.

After justifying the premises, a VECM model can be formulated, while a series of tests should be performed for validation. Firstly, Jarque–Bera normality and Breusch–Godfrey Lagrange multiplier (LM) tests ensure that residuals are normally distributed and not autocorrelated. Secondly, the inverse characteristic polynomial root test is performed to check the stability of a VECM model. For a VECM system with n variables and k cointegration equations, $(n-k)$ roots have modulus equal to one, while other roots should all have modulus less than one (Madito and Khumalo, 2014). Finally, the Wald test checks if there exist short-term causalities among the cointegrated variables (Cheng *et al.*, 2019).

4.3 Hypotheses testing

After model formulation, the expected variable interrelations proposed in H1 to H5 are examined from two aspects: the signs of ECT coefficients and an impulse–response analysis (IRA) showing how response variables responding to a shock from each of the cointegrated variables (Maxwell and Zhu, 2011; Ji *et al.*, 2018). As equation (3) shows, negative γ_i imply resonant growths or reductions of two variables, while positive γ_i imply variables changing in converse directions.

IRA helps to assess accumulated short- and long-term changes in a response variable brought by a shock in each cointegrated variable (Johansen, 1995). Besides IRA, variance decomposition (VD) is performed to identify the relative importance of each cointegrated variable. VD reflects the contributions of each shock from each variable to the total variance (Maxwell and Zhu, 2011). Shocks are modelled with standard deviations of residuals.

Cholesky decomposition is applied to transform $\vec{\varepsilon}_t$ into uncorrelated unit variance innovations \vec{u}_t to ensure that shocks from different cointegrated variables are uncorrelated.

5. Result and discussion

According to the above-mentioned research approach, two VECM models are constructed. Both models pass all validation tests (Table 3).

5.1 Analysis of the crude oil shipping import (Model 1)

As the coefficients in Model 1 ECT indicate, the $SOMS_{Crude}$ growth was driven by the price reduction (PC_{SOMS}) in origin markets from which shipping import to China relies on SOMS and the price increase in alternative origin markets (PC_{ALT}) (Table 3). Such long-term cointegration relations justify H2: crude oil shipping import volumes via the SOMS decrease when respective import costs increase, which indicates that the current commercial strategies are cost-effective. By diversifying import sources (i.e. a variety of origin markets) and import means (long-term contracts, futures and spot trades), energy companies in China are flexible to adjust crude oil import volumes via SOMS to reduce import costs. IRA needs to be performed to further test how $SOMS_{Crude}$ respond to price shocks. Besides, the accumulated impacts of a positive consumption shock in CSP_{Crude} on $SOMS_{Crude}$ are also investigated using the IRA. This reflects whether oil storage effectively provides a buffer, so there will be no sharp responses in crude oil import via the SOMS in a consumption surge (H1).

The IRA results show that accumulated responses of $SOMS_{Crude}$ to shocks from PC_{SOMS} and PC_{ALT} are coherent with the long-term cointegration relation subject to short-run fluctuations in the first month. It justifies that the current commercial strategy targeting diversification and flexibility is effective to reduce crude oil import costs. VD analysis reveals that, at the end of 24 months, 23% of the total variance in $SOMS_{Crude}$ is explained by the shock in PC_{ALT} , 11% by PC_{SOMS} , and only 3% by the shock in CSP_{Crude} . It justifies H1: storage expansions help to mitigate the impacts of crude oil consumption surges. If such consumption shocks occur, the crude oil shipping import volumes via SOMS will not increase sharply (Figure 3).

Statistics	Model 1		Model 2	
ECT coefficient (φ)	-0.56 ^{***}		-0.73 ^{***}	
Coefficients for cointegrated variables in ECT (γ_i)	LOG(CSP_{Crude}) _{t-1}	-0.76 ^{***}	LOG(PN_{SOMS}) _{t-1}	2.34 ^{***}
	LOG(PC_{SOMS}) _{t-1}	2.01 ^{***}	LOG(PIP_{NG}) _{t-1}	-5.04 ^{***}
	LOG(PC_{ALT}) _{t-1}	-2.02 ^{***}	LOG(PRD_{NG}) _{t-1}	10.40 ^{***}
			LOG(FP_{SG}) _{t-1}	-2.54 ^{***}
Johansen trace statistic	60.39 ^{***}		121.88 ^{***}	
Johansen maximum eigenvalue statistic	29.43 ^{**}		63.54 ^{***}	
R^2	0.54		0.51	
Akaike information criterion	-1.91		1.33	
Optimal lag length	3		5	
Breusch–Godfrey LM statistics	9.62 ^{***}		24.82 ^{***}	
Jarque–Bera statistics	2.64 ^{***}		0.92 ^{***}	
Inverse characteristic polynomial roots = 1	3		4	
Wald test statistics	22.16 ^{***}		28.65 [*]	
Note(s):	***Denoting 0.01 significance level; ** denoting 0.05 significance level; * denoting 0.1 significance level			

Table 3. Vector error-correction model specifications and test statistics

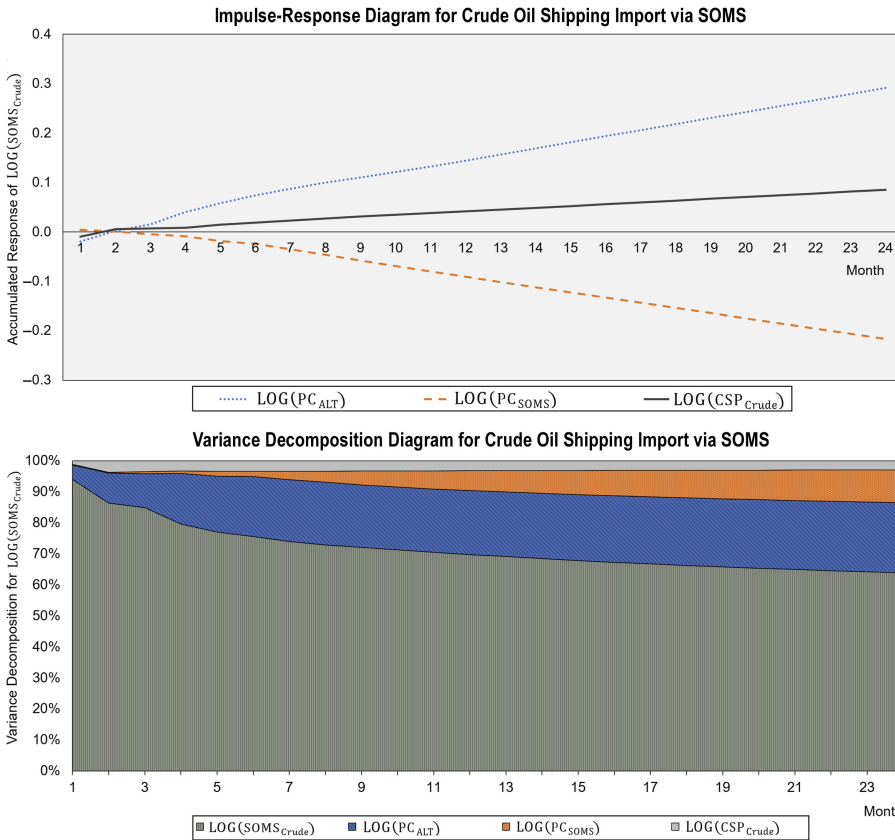


Figure 3. Impulse-response and VD diagrams for crude oil shipping import via SOMS (SOMS_{Crude})

5.2 Analysis of the liquefied natural gas shipping import (Model 2)

As the coefficient in Model 2 ECT indicate (Table 3), the SOMS_{LNG} reduction was driven by domestic production growth (PRD_{NG}), which justifies H3: domestic gas production expansions effectively reduce LNG shipping import volumes via the SOMS. Nevertheless, the coefficient of PIP_{NG} in ECT deviates from H4. Natural gas pipeline import, instead of substituting LNG shipping import, grows resonantly with SOMS_{LNG}. Besides, the coefficient of FP_{SG} also deviates from H5 as LNG shipping import volumes further increase under increasing import costs.

IRA shows similar evidence which justifies H3 while deviating from H4 and H5. The positive shock in PRD_{NG} representing production growth brings reductions in SOMS_{LNG}. However, SOMS_{LNG} increases despite pipeline import expansions or import cost increments. VD shows, at the end of 24 months, 66% of the total variance in SOMS_{LNG} are explained by FP_{SG}, PIP_{NG} and PRD_{NG}, each of which explains 20–30% variances. By contrast, only 2% of the variance are explained by PN_{SOMS}. The impacts of LNG import price shock on LNG shipping import volumes via the SOMS are less significant compared with other variables (Figure 4).

5.3 Research implications

Based on empirical evidence from historical data, the following implications are drawn. Firstly, energy companies in China have effectively deployed commercial strategies to

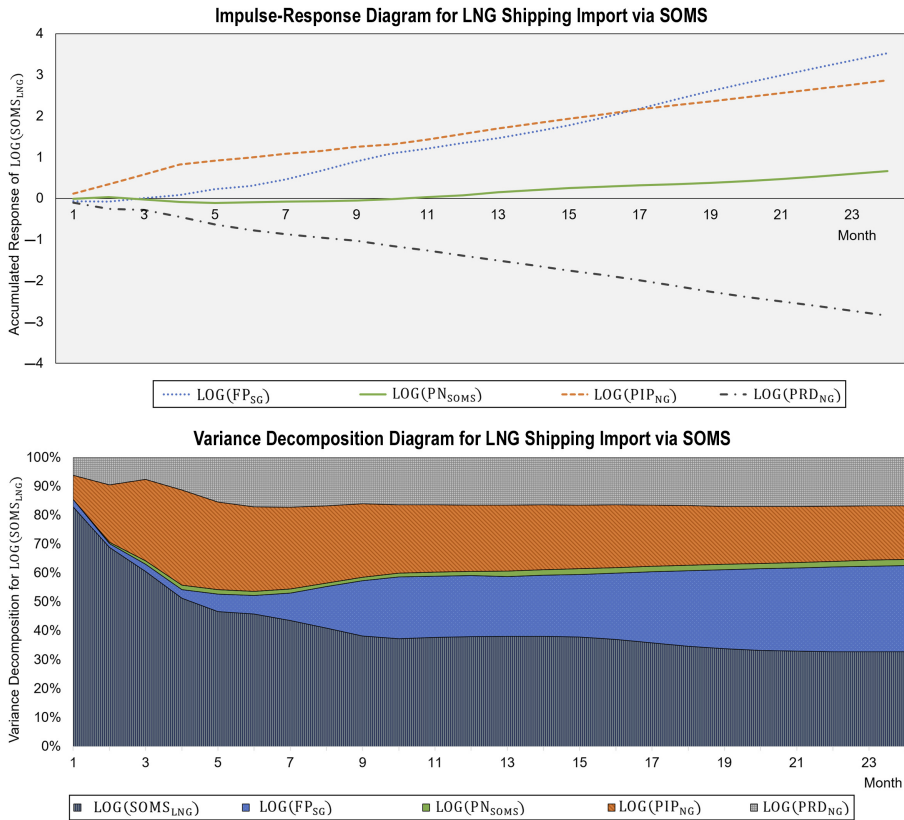


Figure 4. Impulse-response and variance decomposition diagrams for LNG shipping import via SOMS SOMS_{LNG}

diversify import sources and means to reduce import costs. Besides, the government and commercial stakeholders collectively facilitate oil storage expansions, which effectively provide a buffer in consumption surges and avoid sharp increases in crude oil shipping import volumes via the SOMS. Despite the high import dependency of crude oil, research evidence shows that the flexibility and affordability of crude oil import can be sustained in the foreseeable future.

Secondly, as Section 2 analysed, over 80% of LNG shipping import via the SOMS was from Qatar, which mainly locked by long-term contracts. LNG prices in long-term contracts are benchmarked against crude oil prices, while the import volumes are mainly on a take-or-pay basis (Hartley, 2015). As such, SOEs in China cannot make flexible adjustments for import volumes, which leads to cost-ineffectiveness in LNG shipping import. In future, as natural gas demand continues to expand, it is important for energy companies in China to diversify the sources and means of LNG import to achieve cost-effectiveness. For instance, entering LNG import contracts of shorter terms or increasing spot market trades with more LNG exporting countries can enhance flexibility and diversity of LNG import portfolio, which enhances cost-effectiveness and dilutes supply risks.

Thirdly, substitution effects between pipeline import and LNG shipping import were insignificant over the investigated period. Despite that China continually expanded its pipeline networks, the annual gas import volumes via existing pipelines remain less than

30% of the design capacities (Bloomberg, 2020c). Present-day China faces great challenges to achieve high pipeline utilisation rates. On the one hand, the unstable political situation of Myanmar possibly impacts the reliability of its natural gas supplies (Bloomberg, 2021). On the other hand, under COVID-19 impacts, it is likely for exporting countries to further cut gas supplies under global gas demand compression (S&P Global, 2020).

Finally, empirical evidence shows that domestic gas production expansions reduced LNG shipping import volumes over the investigated period. In future, to make this positive trend sustain, production expansion technologies such as shale gas development can be the ultimate solution for China to reduce import dependency, resolve the excessive reliance on the SOMS and reinforce energy security.

6. Conclusion

The paper provides an original contribution to investigate how energy strategies implemented in a nation impact its energy shipping import volumes through a strategic maritime link, the SOMS, which supports 40% of global trades. China is selected as a case study, because it is one of the largest economies with a rapid energy demand growth, a variety of policies and commercial strategies implemented and a heavy reliance on the SOMS for crude oil and LNG shipping import.

A VECM-based research approach is developed to investigate how energy strategies of China influence its reliance on the SOMS for crude oil and LNG shipping import. Five hypotheses are formulated with respect to existing energy strategies and tested based on cointegration relations and IRA. In terms of crude oil, firstly, the strategy of building up oil storage is found to be effective in terms of reducing impacts of consumption surges on growths of crude oil shipping import via the SOMS. Secondly, the strategy of diversifying crude oil import sources and means is also found to be effective. Empirical evidence shows that Chinese energy companies are flexible to adjust shipping import volumes via the SOMS from different origin markets to reduce import costs. In terms of LNG, firstly, the strategy of domestic natural gas production expansion has effectively reduced LNG shipping import volumes via the SOMS. Secondly, the current substitution effects between natural gas import via pipelines and LNG shipping import via the SOMS are found to be weak. Finally, empirical evidence shows that Chinese energy companies have limited flexibility to adjust LNG shipping import volumes via the SOMS under unfavourable market conditions (i.e. increased LNG import prices and transport costs), indicating the current commercial strategy of locking LNG supplies via long-term contracts compromised cost-effectiveness to ensure supply sustainability.

Implications are drawn based on the research findings. For the crude oil sector, despite high import dependency, research evidence justifies the effectiveness of existing energy strategies, showing that the flexibility and cost-effectiveness of crude oil import can be sustained in foreseeable future. For the LNG sector, driven by the coal-to-gas transition of China, natural gas demand is expected to continue growing in the future. However, natural gas import volumes via pipelines are still much below the design pipeline capacities and subject to disruption risks, given the unstable political environment in Myanmar and potential supply reductions considering the COVID-19 impacts on global gas demand. As such, diversification of LNG import sources and means is crucial for China to ensure cost-effectiveness and dilute supply disruption risks. Ultimately, developing technologies to expand domestic natural gas production (e.g. shale gas technologies) is the key to reduce import dependency.

If data of more variables and longer periods become available, it is recommended that more VECM models can be constructed in the future. For instance, freight rates for crude oil

and LNG tankers on various shipping routes can be investigated in terms of the respective impacts on the shipping import volumes via the SOMS.

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