Energy 259 (2022) 125013

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Time-varying determinants of China's liquefied natural gas import price: A dynamic model averaging approach

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ARTICLE INFO

Keywords:
Natural gas
China LNG import
Dynamic model averaging
Energy security

ABSTRACT

We adopt a dynamic model averaging (DMA) approach to study the time-varying impacts of several domestic and international factors on the volatility and premium of China's liquefied natural gas (LNG) import price from January 2008 to December 2020. China's LNG import price tends to be more affected by domestic market information than by international crude oil prices. The demand side factors in the domestic market, including gas consumption, weather conditions and industrial growth, are shown to be the major drivers of the dynamics of China's LNG import price. Relative to the influences of the US or European gas markets, China's LNG import price is more sensitive to the impacts of its Japanese counterpart, which could be attributed to their similar pricing mechanisms. The high premium of China's LNG import price is also largely caused by increasing domestic energy demands. Our results further provide evidence of the benefits of marketizing the natural gas pricing in China. While trying to secure natural gas supply, more efforts should be made to keep promoting the liberalisation and marketisation of the domestic natural gas market.

1. Introduction

During the global green transition and on-going joint efforts to tackle climate change, natural gas is shown to have played a positive role as a "bridge fuel" in reducing short-term emissions at lower cost and on a larger scale relative to zero-carbon sources, and thus offers substantial benefits to the low-carbon transition at least in the short-to-medium term until lower-carbon alternatives become sufficiently cost-competitive and reliable [1]. The utilization of natural gas and gas market risks are especially relevant in the context of China, given the country's so-called Dual Carbon goals to peak carbon emissions by 2030 and to reach carbon neutrality by 2060. China has been striving for accelerating energy transition, optimizing energy consumption structure and eventually building a low-carbon economy system. During this process, natural gas has been playing a significant role in fueling the fast-developing economy and bridging the country towards a lower-emission future. Being a major fossil fuel, China's natural gas consumption exceeded 320.7 billion cubic metres in 2020, with its gas import dependence around 41%. Relevant forecasts indicate that China's natural gas demand will maintain rapid growth in the future, and that the gap between natural gas supply and demand will continue to expand [2–4,60].

Liquefied natural gas (LNG) is an increasingly important source of natural gas consumption in China, based on its efficient and low-cost transportation mode. Its price directly affects China's natural gas import costs. The imported volume of liquefied natural gas (LNG) amounted to 67.4 million tonnes, accounting for 66% of China's total gas import in 2020. The import price of LNG in China, however, has been higher than those of the US and Europe, respectively since 2010 and 2014 (shown in Fig. 1). China and Japan, which represent the level of natural gas price in Asia, have been long featured by having higher LNG import prices than those of Europe and the US, known as the "Asian gas premium". China's GDP loss caused by this gas price premium during 2010 and 2016 achieved approximately 330 billion yuan [5].

Several studies document that the oil-indexation pricing mechanism is a main reason of the Asian natural gas premium [6,7]. Natural gas

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https://doi.org/10.1016/j.energy.2022.125013
Received 15 December 2021; Received in revised form 30 June 2022; Accepted 30 July 2022
Available online 8 August 2022

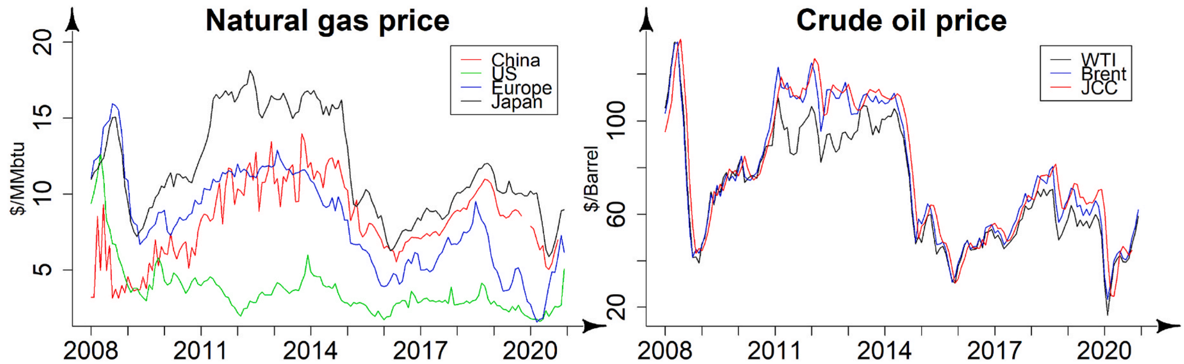


Fig. 1. Natural gas and crude oil prices over time. Note: In this figure, *China* represents China's average LNG import price; *US* represents US's Henry hub natural gas price; *Europe* represents Europe's average natural gas price; *Japan* represents Japan's LNG import price; *WTI* represents the West Texas Intermediate crude oil price; *Brent* is the Brent crude oil price; *JCC* represents the average price of customs-cleared crude oil imports into Japan.

prices in Asia, usually represented by Japan, are mostly linked to Japan Customs Cleared (JCC) crude oil price. The Wholesale Gas Price Survey data of 2020 show that about 65% gas trade in Asia is based on the oil-indexation pricing mechanism, principally being domestic production, pipeline, and LNG imports in China. The oil-indexation pricing mechanism, however, is set from a seller's perspective and cannot effectively reflect supply and demand information in the natural gas trading market [6]. Shown in Fig. 1, the natural gas prices in Asia (represented by China and Japan) and Europe tend to fluctuate with the international crude oil price, implying the close linkage between these two types of energy prices.

By contrast, the natural gas price in the US adopts a hub pricing mechanism, therefore exhibiting very different characteristics. For example, the reactions of various markets to the recent plummet of the international crude oil price in the first quarter of 2020 were distinct. The oil price drop was immediately followed by remarkable decreases of Europe's natural gas price and Japan's LNG import price. Both then rebounded along with the increase of the oil price. Compared to these markets, China's LNG imports were directly interrupted in January and February, and the prices dropped in March and April. The US Henry Hub's natural gas price has also declined since January 2020, but this is largely caused by the changes in gas demand and storage [8]. These differed behaviours show that natural gas price under a hub-pricing mechanism tends to be more sensitive to market information relative to the fluctuation of crude oil prices [9,10].

In Asia, Japan is the earliest LNG importer. It also used to be the largest LNG importer in the world before 2020. Most existing studies adopt Japan's LNG import price to represent the Asian LNG market when analysing the Asian natural gas premium [11,12], comparing various pricing mechanisms (for example [9,13]), or measuring the degree of integration of the global natural gas market [14]. In 2021, however, China's LNG imports surpassed Japan to become the world's largest LNG importer [15]. This recently emerged trend implies a rising role of China's natural gas market in the international market. China's LNG import price has non-negligible potential to affect the Asian natural gas market and the broader global market. Nevertheless, China's LNG import price or its determinants is rarely discussed in the literature.

To fill this gap, we focus on the Chinese market and adopt the dynamic model averaging (DMA) theory to explore the impacts of several factors on China's LNG import price. The demand for natural gas in China is expected to keep rising during the progress of achieving the country's goal of peak carbon emissions and carbon neutrality. Investigating the time-varying determinants of China's LNG import price and premium is therefore conducive to making the best of the bridge role of natural gas and identifying a sustainable path of China's low-carbon economic transition.

To incorporate a diversity of factors in a quantitative model, we benefit substantially from the application of the DMA theory that allows time variations in both the regression coefficients and their weights, thus enabling us to discover the time-varying impacts of several potential determinants on China's LNG import price as well as the import price premium. Based on the DMA method, this paper seeks to answer the following questions: Is China's LNG import price closely connected with the international natural gas market? Why is China's LNG import price more expensive than the international natural gas trading price? Can market information be better reflected by the LNG import price following the pricing mechanism marketisation reform? By answering these questions, policymakers could further explore an optimal mode for promoting natural gas pricing marketisation and enhancing China's natural gas import security.

Among the diverse potential driving factors of the LNG import price in China, we first consider the influences of both international crude oil prices and domestic coal prices, the two major substitutes of natural gas, motivated by the existing evidence of the links and gradual integration through spillovers among the coal, crude oil and natural gas markets (For example, [16–19]). The determinants of natural gas prices are closely related to its pricing mechanism. We introduce the international crude oil prices to consider whether the marketisation of natural gas pricing will lead to the decoupling of oil and gas prices [9,20] and promote the integration of the global natural gas markets [14]. China has implemented a series of reforms to promote a more market-oriented mechanism of natural gas pricing. The ex-factory price of natural gas in China has not been controlled by the government since September 2014. China also established the Shanghai Petroleum and Gas Centre (SHPGX), the Chongqing Petroleum and Gas Exchange Centre, and the Shenzhen Natural Gas Trading Centre in 2015, 2017 and 2020, respectively. The LNG indices of SHPGX have played a role in the market [21]. Compared with the international market, however, China's natural gas price is still expensive and lacks elasticity. There has been significant price distortion in the Chinese natural gas market [22]. Considering these unique characteristics of the Chinese market, we investigate the influence of the pricing mechanism marketisation reform on the LNG import price.

As mentioned before, we also consider the risk spillover from the domestic coal market on the LNG price. While coal consumption has accounted for a highest proportion of primary energy consumption in China, this proportion is expected to decline continuously during the process of achieving China's "Dual Carbon" goal, for which coal phase-out is considered a critical step. The coal price in China has been determined by market competition. With the progress of China's natural gas marketisation, the prices of China's coal and natural gas, both being market-oriented, are expected to become more tightly linked. On the other hand, the contradiction between the green transition and China's resource characteristics (rich in coal but poor in oil and gas) can easily trigger frictions and uncertainty and lead to huge fluctuations in the coal price. The risks in the coal market have the potential to transmit to the natural gas market and affect gas market risks and the LNG import price.

Analysing the impact of coal prices on the LNG market is helpful to deal with the natural gas price risk caused by energy transition.

We then consider the potential influences of international natural gas prices on China's LNG import price. The global natural gas trade can be roughly divided into three regions: North America, Europe and Asia. The gradual maturity of LNG transportation technologies may lead to more integrated global gas markets, and the establishment of a natural gas trading hub will effectively promote the integration of the natural gas market. As the pricing mechanism reform in China's natural gas market is progressing, China's natural gas price is expected to be more closely connected to the international prices. We compare the impacts of natural gas prices under different market conditions on China's LNG import prices, by incorporating the US Henry Hub's natural gas price, the average natural gas price in Europe and the LNG import price in Japan. We also calculate the premium level of China's LNG import price relative to the fully marketized natural gas price and explore the reasons for China's LNG import premium.

To address the potential impacts of various market fundamental factors, we analyse the roles of the volumes of domestic natural gas production and consumption, the volume of LNG import, the industrial growth rate and climate conditions. With the further marketisation of the gas market pricing, all these fundamental factors have potentials to drive China's natural gas prices. While previous studies focus on some single factor, we consider the potential impacts of a multiple of fundamentals.

As a result of the energy transition and marketisation, the driving factors of China's LNG import price tend to be increasingly diversified. Our empirical analysis finds the time-varying contributions made by each factor to the volatility and high premium of China's LNG import price and provides the following evidence to the literature. The results show that the probabilities of China's coal price being a significant explanatory variable for China's LNG import price are higher than those of international crude oil prices. The energy transition under the dual carbon targets is thus expected to promote the price linkage between China's natural gas and coal markets. Comparing the influences of three international natural gas markets, we find that China's LNG import price is more influenced by Japan's LNG import price than by Europe's natural gas price, and the impact of the US gas price is the weakest. Specifically, the probability of Japan's LNG import price being included in the optimal prediction model is significantly higher than the other two, and the probability of Japan's LNG import price being in the prediction model fluctuates in a similar fashion to that of the crude oil prices. As the oil-indexation pricing mechanism dominates both the natural gas markets in China and Japan, it implies that the level of integration of China's natural gas market with the international natural gas markets depends mainly on the degree of similarity between the pricing mechanisms rather than market trades.

We find that the pricing mechanism marketisation reform has made the gas price increasingly responsive to market fundamental information and has promoted the integration of the Chinese gas market into the global market. Comparing the time-varying impacts of the fundamental factors and the substitute energy prices, China's LNG import price tends to be driven increasingly more by domestic demand-side factors (total natural gas consumption and weather conditions) than by the international crude oil price. The high premium of China's LNG import price is also mainly driven by demand-side factors including domestic natural gas consumption and economic development. These findings jointly suggest a weakening role of the oil-indexation pricing mechanism in the Chinese gas market.

The remainder of this paper is organised as follows. Section 2 reviews the relevant literature on the driving factors of natural gas price. Section 3 briefly introduces the methodology. Section 4 describes the data. Section 5 reports and discusses the empirical results. Section 6 concludes the article.

2. Review of the literature

2.1. The oil–gas price relationship

The determinants of natural gas prices are closely related to its pricing mechanism. For example, natural gas prices in Europe and Asia maintain a stable link with international crude oil prices due to oil-indexation pricing [23]. In the US natural gas market with competitive pricing, the oil–gas price relationship has decoupled after the shale gas revolution [16,17,24,25]. Some studies analyse the oil–gas price relationship and gas pricing mechanisms in different regions including North America, Europe and Asia [7,9,18,20,26]. Chiappini et al. [27] adopt Japan's LNG import price as the representative price of the Asian natural gas market. The authors point out that international crude oil price is an important factor affecting the price of natural gas in Asia, though not the only decisive factor.

China has surpassed Japan as the world's largest natural gas importer (including LNG and pipeline natural gas). The oil–gas price relationship and their cointegration in the Chinese market have not drawn sufficient attention in the literature [28], nor has the gas price distortion in the China market [22]. Focusing on the influence of marketisation, Wang et al. [28] point out that the impact of international crude oil prices on China's natural gas import price (whether LNG or pipeline natural gas) has decreased since China's natural gas pricing mechanism reform. Chai et al. [22] discuss the rationality of natural gas prices in China and compare natural gas to other alternative energy sources (crude oil and coal), documenting significant price distortions of natural gas in industrial, residential, and commercial sectors. Motivated by these studies, we introduce the international crude oil prices to consider whether the deepening marketisation of natural gas pricing tends to accelerate the decoupling of China's gas prices and the international oil prices.

2.2. The coal–gas price relationship

As an alternative energy commodity to natural gas, the coal market dynamics appear to be an important factor affecting the price fluctuation of natural gas. Based on the structural vector autoregressive (SVAR) model, Nick and Thoenes [29] explore the determinants of gas prices in the German market and find that the natural gas price in Germany is closely related to coal prices in northern and western Europe in the long run. Li et al. [19] study the coal–gas price relationship in the US, Europe, and Japan, and find evidence of mutual impacts between natural gas and coal prices in Europe and Japan markets. In the highly market-oriented US market, the impact of coal price changes on natural gas prices is found to be relatively weak but has gradually strengthened [19,30].

In the Chinese market, the "coal to gas" policy implemented by the government in recent years has not only effectively improved the air quality of the Beijing, Tianjin, and Hebei areas [31], but also has gradually changed China's energy consumption structure. In 2018, the proportion of coal in China's primary energy consumption was less than 60% for the first time. On the contrary, the proportion of natural gas consumption in primary energy consumption has increased steadily. The coal price in China is determined by market competition, while the market-oriented reform of the natural gas pricing mechanism is under way. It is expected to see clear correlations between these two energy prices when market-oriented pricing of the natural gas price is realised in China [19]. In addition, the progress towards peaking the carbon emissions and achieving carbon neutrality will lead to a continuously declining proportion of coal consumption in China, though China's resource endowment is characterized by "rich in coal but poor in oil and gas". Such a green transition will inevitably cause huge fluctuations in coal prices and lead to risk transmissions to other energy markets, especially the natural gas market. Analysing the impact of domestic coal prices on the LNG market therefore addresses the potential coal-to-gas risk spillovers arising from energy transition.

2.3. Integration of the international natural gas market

In the past, the high cost of natural gas transportation hindered natural gas trading, which endowed the natural gas trade with regional characteristics. With the gradual maturity of LNG transportation technologies, such as maritime, oil tanker and low-temperature railway transportations, the number of LNG trading countries and natural gas short-term spot trading volumes are increasing [32]. The increase in liquidity in the spot market helps the gas market gradually shift from long-term, oil-linked contract pricing to shorter-term, spot-based transactions, which may lead to more integrated global gas markets [22, 33]. The establishment of a natural gas trading hub will effectively promote the integration of the natural gas market [34]. The integrated LNG trading market is expected to help gas importers reduce their total procurement costs [10].

Using an error correction model (ECM), Chiappini et al. [27] show that natural gas markets in the US, Europe, and Asia have gradually integrated in recent years, and there is an asymmetric long-term correlation between the US natural gas price and the Japanese and Korean market prices. Li et al. [35] find convergence evidence of natural gas prices in Japan, South Korea, Taiwan, and the UK through the Philips Sul test and Kalman filtering, while natural gas prices in North America show different behaviours from this group. Some scholars find a stable long-term relationship between the state natural gas prices in the US [36]. A similar trend of natural gas price changes in Asia and Europe has been suggested to lie in the pricing mechanism linked to oil prices rather than a result of market supply and demand interactions [35].

Wang et al. [28] find that the Henry Hub natural gas price in the US has a significant short-term impact on China's LNG import price. Ma and Zhao [6] suggest the Asia Pacific natural gas price to be simultaneously linked with the JCC crude oil price and the Henry Hub natural gas price. The LNG price under the double-linked natural gas pricing mechanism can reduce the LNG import price in the Asia-Pacific region and effectively solve the Asia LNG premium problem. As the pricing mechanism reform in China's natural gas market is progressing, China's natural gas price is expected to be more closely connected to the international prices. To address the information and risk spillovers form the international gas markets, we incorporate and compare the impacts of international natural gas prices under different marketisation levels on China's LNG import prices. We further calculate the premium level of China's LNG import price relative to the fully marketized natural gas price and explore the underlying drivers of such premium.

2.4. Fundamental factors and natural gas prices

The close relationship between oil and gas prices is based on the influence of temperature, seasonal change, storage capacity, and supply environment [37]. The early study of Hartley and Medlock [38] shows that climate conditions, storage capacity, and sudden supply interruption are the main factors that cause short-term natural gas prices to deviate from its long-term equilibrium state. Subsequent studies have taken these factors as indispensable determinants of natural gas prices in the US [24,30,39]. Apart from the US market, natural gas prices in many developed European markets [29,40] are also shown to be affected by negative climate, storage and supply factors.

As China fully liberalised its unconventional gas market pricing in 2014, all these fundamental factors have the potential to become determinants of Chinese natural gas price [22,28]. Based on a Bayesian structural equation model, Chai et al. [22] find that economic activities and demand are the two major determinants of natural gas price in China, followed by supply and alternative fuel prices. Using a vector error correction model, Wang et al. [28] provide evidence that China's import gas prices are increasingly affected by market fundamentals, such as economic growth, climate factors and policy changes. With the process of marketisation of the pricing mechanism, China's LNG import price is expected to be increasingly affected by multiple factors from both domestic and overseas sources. Previous studies on the determinants of China's LNG import price mainly focus on some single factor, and rarely pay attention to the time-varying influences of the selected factor. To fill this gap, we consider the potential contributions of multiple factors in a dynamic setting to identify the most important determinants of China's LNG import price since January 2008.

Based on the above-mentioned literature and evidence, with the ongoing marketisation of the pricing mechanism, China's LNG import price is expected to be increasingly affected by multiple factors from both domestic and overseas sources. Previous studies on the determinants of China's LNG import price mainly focus on a single factor and rarely heed the time-varying influences of the selected factor. To fill this gap, we consider the potential contributions of multiple factors in a dynamic setting to identify the most important determinants of China's LNG import price since January 2008. Through these analyses, we can identify the risk sources of China's LNG import price and premium, which is highly conducive to maintaining China's energy safety.

3. Methodology

3.1. The dynamic model averaging method

The dynamic model averaging (DMA) method adopted in this study is first proposed by Raftery et al. [41] and then promoted by Koop and Korobilis [42]. In this framework of Raftery et al. [41]; a state space model for the parameters of each model is combined with a Markov chain model for the correct model. They applied the method to several simulations and found that it well recovered both constant and time-varying regression parameters and model specifications. Koop and Korobilis [42] then conducted an empirical study involving forecasting output growth and inflation using 139 time series variables of the UK at the monthly frequency. The authors showed that the DMA method can greatly improve forecast performance relative to traditional forecasting methods.

The most notable advance of the DMA method is its flexibility, that model construction and parameters are allowed to vary over time. This enables more precise prediction of asset prices. Its capability of predicting asset prices is then extended to forecasting energy commodity prices and confirmed by, for example, Naser [43]; Drachal [44] and Wang et al. [30]. The DMA approach is shown to outperform many other competitive models adopted in forecasting practice and has the ability to provide explanations of energy price changes [45]. Such an approach allows both the regression coefficients and their weights to vary in time. Drawn on this advantage, we are enabled to detect the time-varying impacts of several potential determinants on China's LNG import price.

In this study, we introduce 11 variables ($K = 11$) as potential driving factors of China's LNG import price. A linear combination regression of 11 variables equals 2048 (2 ^ 11). The adoption of the DMA method enables us to use these K models to forecast China's LNG import price at each point of time.

We set the China's LNG import price at time t as Y_t. $X_t^{(k)}$ is the explanatory variable in the k_{th} model at time t. $\theta_t^{(k)}$ is the parameter of the k_{th} model at time t. The basic model in the DMA framework is expressed as:

$$Y_t^{(k)} = X_t^{(k)}\theta_t^{(k)} + \varepsilon_t^{(k)},\ \varepsilon_t^{(k)} \sim i.i.d.N\left(0, H_t^{(k)}\right) \tag{1}$$

$$\theta_t^{(k)} = \theta_{t-1}^{(k)} + \tau_t^{(k)},\ \tau_t^{(k)} \sim i.i.d.N\left(0,\ Q_t^{(k)}\right) \tag{2}$$

where $Y^t = \{y_1, y_2, \cdots, y_t\}$ is a series of observations from time 1 to time t. The probability that model k (M_k) is used at time t ($L_t = M_k$) can be set as $P[L_t = M_k | Y^{t-1}]$. The probability distribution of the corresponding parameter set $\Theta_t = \{\theta_1^{(1)}, \theta_2^{(2)}, \cdots, \theta_t^{(k)}\}$ is then expressed as:

$$p(\Theta_t, L_t) = \sum_{k=1}^{K} \left[p\left(\theta_t^{(k)} \middle| L_t = M_k\right) p(L_t = M_k) \right] \quad (3)$$

The conditional probability distribution of the parameters at time *t*-1 is:

$$\mathrm{p}\left(\Theta_{t-1}, \mathrm{L}_{t-1} \middle| \mathrm{Y}^{t-1}\right) = \sum_{k=1}^{K} \left[\mathrm{p}\left(\theta_{t-1}^{(k)} \middle| \mathrm{L}_{t-1} = \mathrm{M}_k, \mathrm{Y}^{t-1}\right) \mathrm{p}\left(\mathrm{L}_{t-1} = \mathrm{M}_k, \mathrm{Y}^{t-1}\right) \right] \quad (4)$$

The conditional distribution of $\theta_{t-1}^{(k)}$ is approximated by a normal distribution, thus,

$$\theta_{t-1}^{(k)} \middle| L_{t-1} = M_k, Y_{t-1} \sim N\left(\hat{\theta}_{t-1}^{(k)}, \sum\nolimits_{t-1}^{(k)}\right) \quad (5)$$

Following Raftery et al. [41]; we set the form of H_t, Q_t and $\sum_t$ as:

$$H_t^{\wedge} = \begin{cases} \left(\frac{t-1}{t}\right) H_{t-1}^{\wedge} + \frac{1}{t}\left(e_t^2 - x_t' Q_t x_t\right), \; if\ H_t^{\wedge} > 0, \; or \\ H_{t-1}^{\wedge} \end{cases} \quad (6)$$

$$Q_t = \left(1 - \lambda^{-1}\right) \sum_{t-1|t-1}, \; 0 < \lambda \le 1 \quad (7)$$

$$\sum_t = \left(\theta_t - \hat{\theta}_t\right)\left(\theta_t - \hat{\theta}_t\right)' \quad (8)$$

$\hat{\theta}_t$ is Kalman filter estimate of θ_t. λ is a forgetting factor to measure the weight of previous models in the current model estimation. The higher value of λ, the greater the impact of previous observations on the current. If $\lambda = 1$, it implies that the parameters remain constant. When $\lambda \rightarrow 0$, only the last observation is used for forecasting [43].

$\pi_{t|t-1,k} = \mathrm{P}(\mathrm{L}_t = \mathrm{M}_k | \mathrm{Y}^{t-1})$ is the probability that M_k is adopted under $\mathrm{Y}^{t-1} = \{y_1, y_2, \cdots, y_{t-1}\}$. The probability distribution matrix can be set as:

$$\Pi_{K \times T} = \begin{bmatrix} \pi_{1|0,1} & \pi_{2|1,1} & \cdots & \pi_{T|T-1,1} \\ \pi_{1|0,2} & \pi_{2|1,2} & \cdots & \pi_{T|T-1,1} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{1|0,K} & \pi_{2|1,K} & \cdots & \pi_{T|T-1,K} \end{bmatrix}_{K \times T} \quad (9)$$

The Markov switching process cannot solve such a large amount of calculation. Raftery et al. [41] thus introduce a second forgetting factor α ($0 < \alpha \le 1$), so that:

$$\Pi_{t|t-1,k} = P\left(L_t = M_k \middle| Y^{t-1}\right) = \frac{\pi^{\alpha}{}_{t-1|t-1,k}}{\sum_{l=1}^{K} \pi^{\alpha}{}_{t-1|t-1,l}} \quad (10)$$

The DMA estimation of the y_t can be expressed as:

$$\hat{y}_t^{DMA} = \sum_{k=1}^{K} \pi_{t|t-1,k} \hat{y}_t^{(k)} = \sum_{k=1}^{K} \pi_{t|t-1,k} \left(x_t^{(k)}\right)' \hat{\theta}_{t-1}^{(k)} \quad (11)$$

The estimated value is the weighted average of the estimated results of all possible models, where the weight is the probability of each model being selected. On this basis, we can calculate the contribution of each explanatory variable to the LNG price prediction at each point of time. For a given explanatory variable V_n, it is represented by 1 if selected in M_k, or otherwise 0. A matrix $M_{N \times K}$ is then formed where all elements are either 0 or 1. The k_{th} column of the matrix represents the k_{th} linear model M_k. $M_{(n,\,k)} = 1$ indicates that the n_{th} variable (V_n) exists in model M_k.

The importance of each explanatory variable at each time point can be calculated by:

$$V_{N \times T} = M_{N \times K} \times \Pi_{K \times T} = \begin{bmatrix} v_{1,1} & v_{1,2} & \cdots & v_{1,T} \\ v_{2,1} & v_{2,2} & \cdots & v_{2,T} \\ \vdots & \vdots & \ddots & \vdots \\ v_{N,1} & v_{N,2} & \cdots & v_{N|T} \end{bmatrix}_{N \times T} \quad (12)$$

Each element in $V_{N \times T}$ represents the probability that variable *n* is selected to predict China's LNG import price at time *t*. When the probability of the explanatory variable being in the prediction model exceeds 1/2, we consider that the effect of the explanatory variable at this point is significant [46]. During the initial period, the DMA model provides little useful information, and there are certain disturbances that interfere with the prediction process. Notwithstanding, the prediction power based on the DMA model, even during the initial unstable period, is still more accurate than that of the single model [41,44].

3.2. Selection of explanatory variables

We first consider the influences from the international oil markets and incorporated WTI, Brent, and JCC crude oil prices into the model to analyse their impacts on China's LNG import price. This study focuses on the influences of the global and Asian oil markets, which we believe are currently the major and most direct forces from the oil-side that affect the energy market risks in China. To represent the global oil market, WTI and Brent are two most widely used common benchmarks. These two, however, are not always fully integrated [47]. Drawn on this fact, we analyse the impacts of both prices to ensure the robustness of the major empirical results. On the other hand, natural gas prices in Asia are mostly linked to Japan Customs Cleared (JCC) crude oil prices. We therefore further analyse the impact of the JCC price. On the other hand, to represent the domestic coal price in China, Qin Huang Dao (QHD) is the largest coal shipment port in China, the volume of which accounts for more than 30% of China's total [48]. We therefore adopt the spot price of China power coal (QHD 5500) to study the coal–gas price relationship.

According to the marketisation of natural gas pricing, the global natural gas trade can be roughly divided into three regions: North America (hub-pricing), Europe (coexistence of hub-pricing and oil-indexation pricing) and Asia (mostly oil-indexation pricing). Considering the gradual integration of the global natural gas market [27], we incorporate the US Henry Hub natural gas price, Europe's average natural gas price, and Japan's LNG import price to analyse the relationship between the dynamics of the international natural gas market and China's LNG import price. The introduction of above three markets' natural gas prices enables us to compare the impact of natural gas prices under these different market conditions on China's LNG import prices. It should be explained that our sample of monthly natural gas consumption data starts in January 2008 and ends in December 2020. As the COVID-19 epidemic severely hit the global economy in 2020, China's LNG imports were interrupted in January and February of that year. These months are therefore not included in our sample period.

In terms of fundamental factors, we analyse the roles of several macroeconomic and gas market fundamental variables in directing the dynamics of China's natural gas market. We first consider how economic fundamentals may affect the LNG import price, based on the well acknowledged argument that economic growth is often accompanied by increased consumption of energy. Relevant studies document a positive correlation between China's energy demand and economic growth [49]. When the economy is on the rise, natural gas consumption tends to increase as a result of growing demands for goods and services in the commercial and industrial sectors. With the acceleration of China's economic growth, marginal utility of natural gas for China's economic development is also expected to gradually increase [50]. In this study, we adopt China's industrial economic growth rate to represent China's economic development level to further analyse how economic growth tends to navigate the LNG import price of China. The selection of industrial economic growth rate as the economic growth proxy is based on that argument that the increase in energy consumption associated with economic growth is particularly pronounced in the industrial sector [32].

To account for the supply and demand fundamentals in the natural gas market, we incorporate natural gas production and consumption

Table 1
Variables and data sources.

	Variable	Definition	Data source and Unit	Reference
Dependent Variable	China	China LNG import price	Wind (Dollar/ MMbtu)	[28]
	China-US	China's LNG import premium	Dollar/ MMbtu	[5]
Alternative energy price	WTI	West Texas Intermediate crude oil price	EIA (Dollar/ Barrel)	[16,20,26,37,38]
	Brent	Brent crude oil price	EIA (Dollar/ Barrel)	[28]
	JCC	Japan Customs cleared crude oil price	Wind (Dollar/ Barrel)	[6]
	COAL	Qinhuangdao (Datong 5500) power coal price	Wind (Yuan/Ton)	[19,22,29,30]
Climate conditions	HDD	Heating degree days	Bloomberg	[24,28,30,37]
	CDD	Cooling degree days	Bloomberg	[24,28,30,37]
China's fundamental factors	Production	Natural gas production volume	Wind (MMcf)	[28,30]
	Consumption	Natural gas consumption volume	Wind (MMcf)	[53,54]
	LNG import	LNG import volume	Wind (Tone)	[28]
	IGR	Industrial growth rate	Wind (%)	[22,28]
International natural gas price	US	Henry Hub natural gas price	World Bank (Dollar/ MMbtu)	[27,28]
	Europe	Europe average natural gas price	World Bank (Dollar/ MMbtu)	[9]
	Japan	Japanese LNG import price	World Bank (Dollar/ MMbtu)	[27,35]

volumes as well as the LNG import volume into the model. Alongside gas consumption per se, we also take into account climate-induced changes of gas consumption. Easing seasonal pressure on China's natural gas consumption has been one of the government's major efforts in recent years. We include two climate factors proxied by heating degree days (HDD) and cooling degree days (CDD)[1] in the empirical analysis as potential determinants of China's LNG import price, based on the conjecture that both tend to affect natural gas demand through different mechanisms. On the one hand, colder weather directly leads to a surge of energy consumption for space heating, where natural gas has been one of the major heating fuels in China. Historic data show that China's LNG import price usually peaks during cold winters. There is also evidence of a significant positive correlation between natural gas demand and HDD in the Chinese context [51]. On the other hand, CDD can indirectly affect the demand of natural gas in China, through its direct and positive impacts on electricity consumption during hotter days, mainly due to increased use of air conditioning powered by electricity. About 70% of China's electricity demand is met by thermal power generation. While coal power still dominates the Chinese electricity market (with a 42% share), natural gas is an indispensable transitional energy for the transition of the power structure [52] and tends to be affected by the fundamental factors in the electricity market. We therefore include also the CDD to address the indirect impact of domestic power demand during hotter days on the LNG price. By including both HDD and CDD in the analysis, more information can be shown concerning the impacts of climate change on the LNG import price through different mechanisms.

Among the above factors, the industrial economic growth rate and climate factors are usually considered as important drivers of gas demand, while the LNG import volume can reflect the level of LNG shortage in China. A summary of the explanatory variables selected in this study and the data sources are shown in Table 1.

3.3. *Identifying determinants of China's LNG import price*

We then empirically test whether China's LNG import price tends to be more affected by domestic market information than by the oil-indexation pricing mechanism. Six models are constructed to analyse the determinants of China's LNG import price. The explanatory variables included in Models 1 to 6 are shown in Table 3, where Models 4 to 6 can be regarded as robustness tests of Models 1 to 3. In Model 7, the dependent variable is set to be China's LNG import price premium to detect how each factor tends to affect China's LNG premium. Following Liu et al. [5]; China's LNG import premium is calculated as the difference between China's LNG import price and Henry Hub's natural gas price. The level of China's LNG import premium was not much pronounced before February 2010. The sample period for Model 7 is accordingly set between February 2010 and December 2020.

The forgetting factors λ and α determine the weights of different stage models in the subsequent model estimation [41]. We compared the root mean square error (RMSE) and mean absolute error (MAE) of each model estimation under 121 different combinations of the forgetting factors. The forgetting factor combination with the minimum RMSE and MAE values is then selected for further analysis.

4. Data and descriptive statistics

Table 2 reports the summary statistics of variables or their transformed forms. Panel A reports the summary statistics of the gas and oil prices based on the original data. The ADF test statistics show that all oil and gas price series have unit roots and are non-stationary, except for the Henry Hub natural gas price. We therefore transform all the series into their first-order logarithmic differences, which represent the percentage changes of each variable and are then used in the following model analysis. The logarithm transformation is applied to all series except for IGR which already represents the growth rate of China's economy. Panel B reports that summary statistics of the transformed variables, which are all stationary evidenced by the ADF test statistics. The Jarque-Bera test statistics reject the null hypothesis of normal distribution for all series at the 1% significance level.

The mean values shown in Table 2 indicate that the growth rate of China's LNG import price (ΔLN_China) is on average positive over the full sample. This implies a generally upward trend of China's LNG import price since 2008, opposite to the declining trends of the prices of other energy variables (except for coal). The volatility of ΔLN_China is also higher than other energy variables, seen in the magnitude of the standard deviation. This may be explained by the rapid growth of China's energy consumption and fast economic development. On average, the growth rates of China's industrial development, natural gas production and consumption, LNG imports, and coal price all show upward trends during the sample period, where natural gas consumption and LNG imports exhibit relatively high levels of volatility.

5. Empirical results

In this part, we analyse the roles of different factors in affecting the

[1] HDD measures how cold the temperature is on a given day, calculated as the difference between 18 °C and the mean temperature during that day, or equals zero if the mean temperature is higher than 18 °C. CDD measures the opposite and is calculated as the mean temperature of a given day subtracted by 26 °C, or equals zero if the mean temperature is lower than 26 °C. The total HDD or CDD for a given period is the summation of each single day's HDD or CDD during the period. HDD and CDD in this study are monthly averages.

Table 2
Descriptive statistics.

Variable	Mean	Maximum	Minimum	St. Dev.	Skewness	Kurtosis	JB	ADF
Panel A: Oil and gas price variables based on original data								
China	8.165	13.951	3.113	2.571	−0.069	2.327	3.027	−1.365
US	3.702	12.676	1.613	1.824	2.504	10.478	519.775***	−7.733***
Europe	8.3	15.93	1.575	3.177	0.081	2.334	3.016	−2.799
Japan	11.714	18.11	5.884	3.315	0.276	1.796	11.26***	−1.872
WTI	71.365	133.927	16.52	24.55	0.218	2.123	6.148**	−3.064
Brent	77	133.873	23.34	27.533	0.195	1.761	10.828***	−2.466
JCC	78.416	135.142	24.555	27.784	0.129	1.775	10.051***	−2.303
Panel B: Transformed variables based on first order logarithmic difference								
ΔLN_China	0.005	0.985	−0.753	0.181	0.433	11.05	417.944***	−7.681***
ΔLN(China-US)	0.035	1.581	−0.908	0.339	0.967	8.259	200.168***	−4.621***
ΔLN_US	−0.008	0.374	−0.373	0.124	0.514	3.992	13.023***	−4.752***
ΔLN_EUR	−0.004	0.463	−0.53	0.106	−0.373	9.104	241.037***	−5.731***
ΔLN_Japan	−0.002	0.111	−0.205	0.059	−1.059	4.301	39.397***	−4.792***
ΔLN_WTI	−0.004	0.547	−0.694	0.127	−1.376	12.477	620.845***	−5.698***
ΔLN_Brent	−0.004	0.284	−0.691	0.112	−1.986	12.199	640.076***	−5.417***
ΔLN_JCC	−0.005	0.289	−0.525	0.1	−1.607	9.478	333.43***	−5.78***
ΔLN_COAL	0.002	0.266	−0.377	0.071	−0.386	8.773	216.262***	−5.303***
ΔLN_Production	0.007	0.169	−0.288	0.071	−0.835	4.817	38.801***	−8.972***
ΔLN_Consumption	0.01	1.605	−1.828	0.235	−1.122	40.1	8806.584***	−11.583***
IGR	0.091	0.192	−0.011	0.038	0.73	2.928	13.635***	−3.691**
ΔLN_LNG import	0.024	0.938	−0.597	0.258	0.405	4.028	10.916***	−7.478***
ΔLN_(HDD+1)	0	2.528	−2.49	0.845	−0.122	4.358	12.128***	−15.153***
ΔLN_(CDD+1)	0	1.459	−1.459	0.384	−0.327	8.615	203.724***	−8.035***

Note: The definition of each variable is shown in Table 1. The statistics shown in Panel A are calculated by the original data. The statistics shown in Panel B are calculated by the first-order logarithmic difference of each variable, except for IGR which already represents China's industrial economic growth rate and is not processed by logarithmic transformation. St. Dev. denotes standard deviation. JB denotes the statistics of the Jarque Bera test of normality. ADF denotes the statistics of the Augmented Dickey Fuller test of the presence of unit roots. *. ** and *** represent the 10%, 5% and 1% significance level, respectively.

Table 3
Model design.

	Model		Model1	Model2	Model3	Model4	Model5	Model6	Model7
Dependent variable	China's LNG import price		✓	✓	✓	✓	✓	✓	
	China's LNG premium								✓
Independent variables	International crude oil price	WTI	✓						
		Brent		✓		✓	✓	✓	✓
		JCC			✓				
	Chinese domestic variables	COAL	✓	✓	✓	✓	✓	✓	✓
		Production	✓	✓	✓	✓	✓	✓	✓
		Consumption	✓	✓	✓	✓	✓	✓	✓
		LNG import	✓	✓	✓	✓	✓	✓	✓
		IGR	✓	✓	✓	✓	✓	✓	✓
		HDD	✓	✓	✓	✓	✓	✓	✓
		CDD	✓	✓	✓	✓	✓	✓	✓
	International natural gas prices	US	✓	✓	✓	✓			
		Europe	✓	✓	✓		✓		
		Japan	✓	✓	✓			✓	

Note: ✓ indicates that the variable is incorporated in the model.

dynamics of China's LNG import price, using the methodology introduced in Section 3.1. The forgetting factor combinations in the models are selected by minimizing the value of RMER and MAE. When the temporal probability of a variable being included in the DMA prediction model exceeds 0.5, we consider that the variable has a significant explanatory power of China's LNG import price at that given point of time.

5.1. The effects of alternative energy prices

To investigate how oil price volatility may affect China's LNG import price, the WTI, Brent and JCC crude oil prices are introduced in Models 1 to 3 respectively as the explanatory variables to proxy the international crude oil price. Fig. 2(a) plots the time-varying impacts of crude oil prices on China's LNG import price. Notably, the impacts of the crude oil prices increase significantly in early 2011 and 2012. When the international crude oil price falls in the second half of 2014, however, its impacts on China's LNG import price drop to a notable extent. Similarly, its impact decreases sharply in 2020, concurrent with the plummet of international oil prices in 2020. Though substantial fluctuations of the international oil prices could induce volatility of China's LNG import price, the overall probability of incorporating crude oil price variables in the optimal prediction models is less than 50% during the sample period, seen in the figures in the parentheses of Fig. 2(a), which represent the probabilities of significant observations over the full sample period. The probabilities of WIT, Brent, and JCC being significant are 30.94%, 23.74% and 17.27%, respectively. We can therefore argue that the impacts of crude oil prices on China's LNG import price are not significantly pronounced during not only the full sample, but also a large part of it.

Compared with crude oil, coal consumption has accounted for a higher proportion of primary energy consumption in China. China's LNG import price should also, if not more, be affected by the domestic coal price alongside international crude oil prices. The time-varying impact

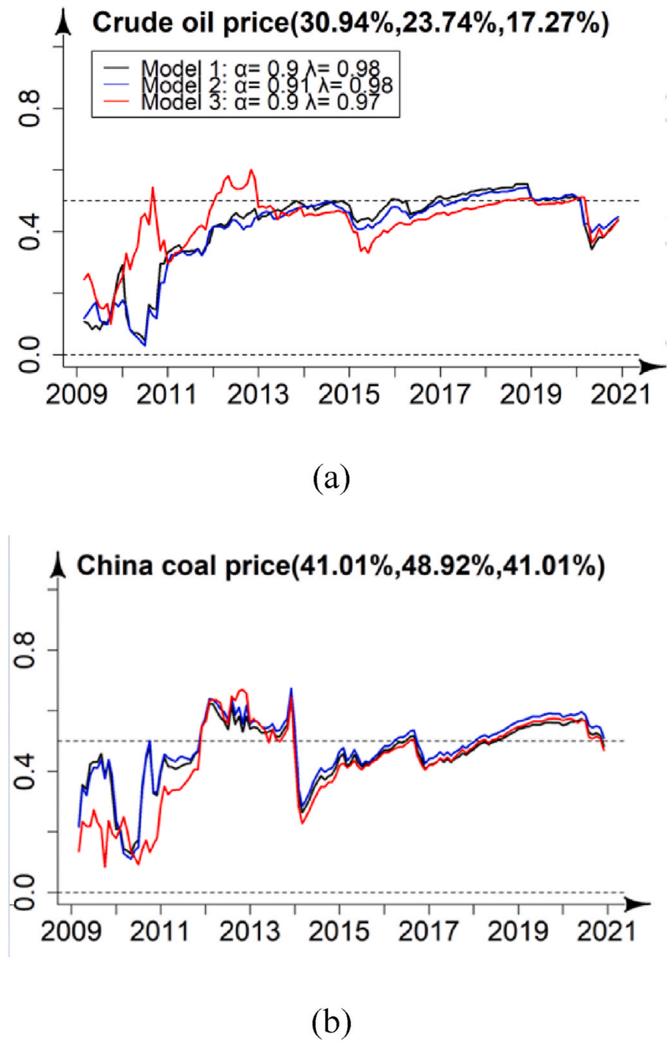


Fig. 2. Time-varying impacts of alternative energy prices on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the value of MAE. When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 1 to 3, respectively.

of China's domestic coal price on LNG import price is plotted in Fig. 2(b). It rises rapidly in 2011 and exerts significant impacts on the LNG import price from July 2011 to October 2013. Close to the end of 2013, the contribution of coal price to directing China's LNG import price slumps. After a period of remarkable fluctuation, it starts to rise gradually in the middle of 2016. Hit by the COVID-2019 pandemic, China's coal price fell by approximately 16.4% during January and April in 2020. Seen in Fig. 2(b), the impact of coal price on the LNG import price also falls. Over the full sample, the probabilities of China's coal price being a significant explanatory variable in Models 1 to 3 are 41.01%, 48.92% and 41.01%, respectively, all higher than that of any of the three crude oil price variables. Despite temporal variations of its contribution to the LNG import price, China's domestic coal price should be considered an important explanatory variable and be kept in the DMA prediction model.

The significant role of coal in affecting the LNG import price can be linked back to and explained by some stylized facts in the Chinese coal market in recent years. National coal phase-out is a key step for China to achieve carbon emission peak and carbon neutrality [55]. Since the beginning of 2016, Chinese government has implemented a series of coal

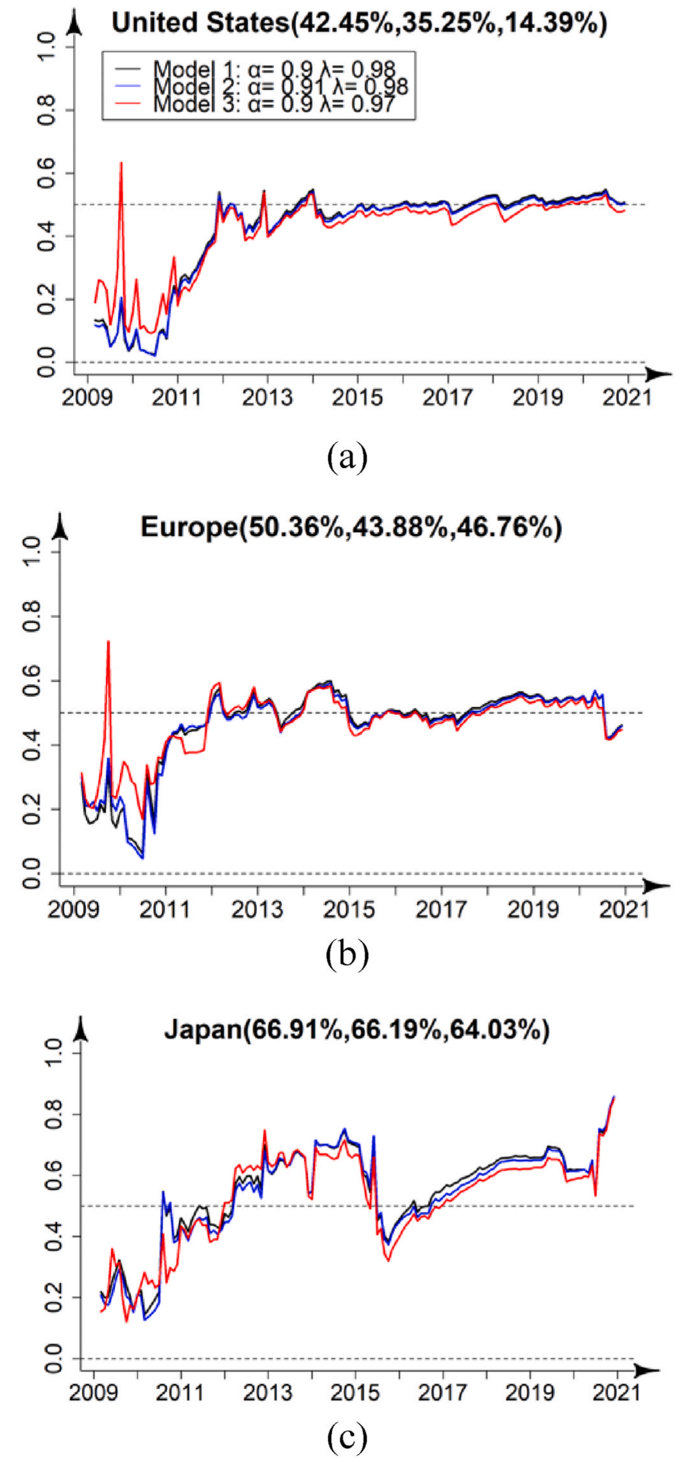


Fig. 3. Time-varying impacts of international natural gas prices on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the value of MAE. When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 1 to 3, respectively.

de-capacity policies alongside stipulated plans to reduce and eventually eliminate overcapacity. As coal is phasing out, fuel switching from coal to natural gas is a necessary solution to bridging China's energy transition and meanwhile to reducing carbon dioxide emissions. While the large-scale transition from coal to natural gas substantially increases the

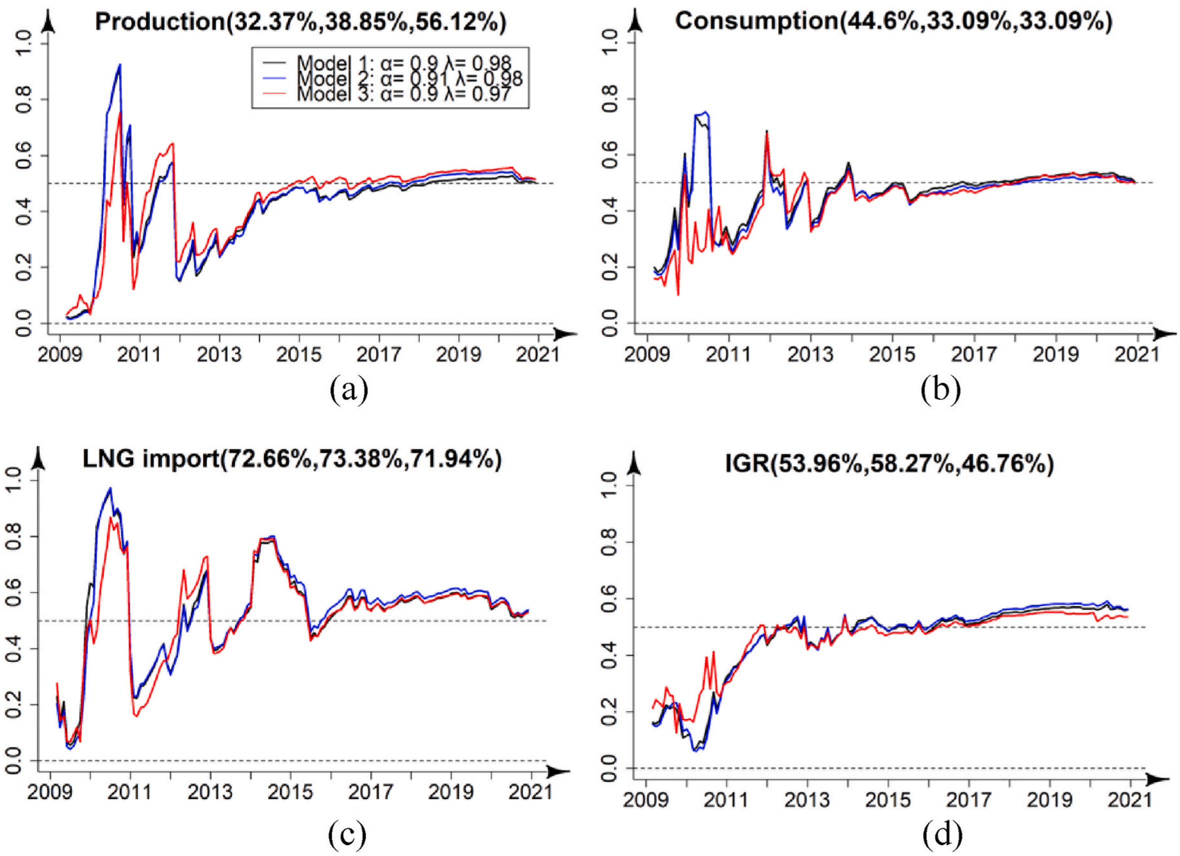


Fig. 4. Time-varying impacts of the fundamental factors on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the value of MAE. When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 1 to 3, respectively.

demand of natural gas, China's natural resource endowment is characterized by rich in coal but poor in gas. Gas shortage might be triggered by such a friction, such as the serious one in 2017. Increasing LNG imports can be a direct and effective solution for filling the gap between fast-growing demand of natural gas and poor gas endowment in China. Meanwhile, as natural gas increasingly plays a substituting role, the coal and natural gas markets become more entangled and the impact of coal prices on the LNG import price is enhanced. It is not hard to understand that coal market dynamics can significantly affect the natural gas market fundamentals and further affect the LNG import prices. In fact, the influence of the domestic coal price on directing China's LNG import price is shown to increase gradually from the middle of 2016.

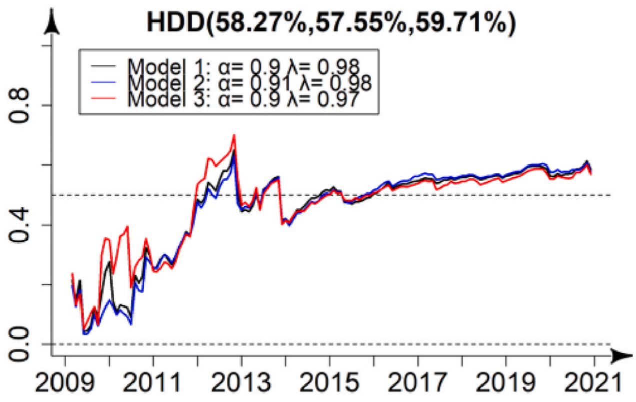
Another plausible explanation is the cross-market risk contagion, which is enhanced due to the proposal of the carbon peak and carbon neutrality goal. Under the dual pressure of continuous coal capacity reduction and energy consumption control, China's coal price experienced explosive growth in 2021. The volatility and risks in the coal price have spread to other energy prices. On the other hand, with the promotion of pricing marketisation of natural gas, the links between coal and gas prices will be more tightly connected, as both prices are market oriented.

5.2. International natural gas prices and China's LNG import price

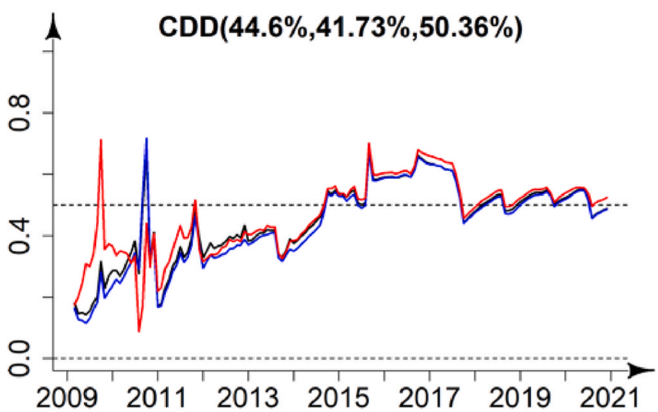
We then consider the potential influences of the international natural gas prices on the dynamics of China's LNG import price. Fig. 3 shows time-varying impacts of three regional natural gas prices (US, Europe and Japan) on China's LNG import price. Compared to the other two market prices, the probability of Japan's LNG import price being included in the optimal prediction model is significantly higher, irrespective of model selection. This can be explained by the pricing mechanism linked with crude oil prices. The US gas market is the most competitive natural gas market. The impact of Henry Hub's natural gas price on China's LNG import price starts to increase significantly from 2011, and then levels off around 50% since 2015. The European market is based on both oil-indexation pricing and hub pricing, and its impact on China's LNG import price ranges between those of the US and Japan markets.

Interestingly, the probability of Japan's LNG import price being in the prediction model fluctuates in a similar fashion to that of the crude oil prices, only within a larger range. For example, while the influence of international natural gas prices on China's LNG import price starts to increase from the end of 2011, the role of Japan's LNG import price becomes increasingly pronounced and then achieves almost 80% in 2013. In the second half of 2014, when the impacts of international crude oil prices decrease, Japan's LNG import price also becomes a less important factor. The first quarter of 2020 also witnesses significantly declined influence of Japan's LNG import price on China's LNG import price, following the sharp fluctuation of international crude oil prices, which then bounce back rapidly to 80% by the end of 2020.

These findings imply that the natural gas price links between China and other regional gas markets are mainly determined by degree of similarity between the pricing mechanisms rather than market trades. While China's LNG import price is gradually getting connected with international natural gas prices over time [27], Japan's LNG import price exerts significantly stronger influence relative to the US and European markets, which could be attributed to their similar pricing mechanisms. In other words, the connection between China's natural



(a)



(b)

Fig. 5. Time-varying impacts of climate conditions on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the value of MAE. When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 1 to 3, respectively.

gas market and the international gas market still roots in the pricing form linked to crude oil, rather than market-oriented trade. To promote the integration of China's natural gas market into the international natural gas market, it is necessary to continue to promote the marketisation of natural gas, to give full play to the roles of natural gas trading centres (such as Shanghai and Chongqing), to speed up the establishment of natural gas pricing forms in line with international standards, and to fully realize market-oriented pricing.

5.3. The effects of domestic fundamental factors

The time-varying influences of China's domestic fundamental factors on the LNG import price are plotted in the four panels of Fig. 4. Among these fundamental factors, LNG import volume is shown to be the most important factor affecting China's LNG import price, despite the violent fluctuation of its impacts during the first half of the sample period from 2009 to 2015. This is in line with the economic intuition that the LNG import price is most sensitive to the aggregate demand of import. On the other hand, the impact of the industrial economic growth rate (IGR) on the LNG import price starts to rise rapidly from mid-2010, and then maintains at a relatively high level. Till then end of the sample period, it achieves around 60%. Compared to the influences of other fundamental factors, the impact of IGR is in general significantly higher than that of consumption but lower than that of LNG import.

The probability of including the natural gas production volume in the DMA prediction model is mostly higher than 50% between February 2010 and August 2011. The plausible explanation is that LNG shortage caused by insufficient supply tends to induce the rise of LNG import price. The influences of natural gas production, consumption and LNG import volume all show significantly declining trends during the second half of 2010. While the impact of natural gas production then rebounds quickly after that, the LNG import volume only starts to exert increasing influence from the end of 2011. Since then, the LNG import volume is shown to be an important determinant of China's LNG import price, especially in 2012 and 2014. As a bridge fuel for China's low-carbon economic transition under the goals of carbon peak and carbon neutrality, China's total natural gas consumption and import demand are expected to rise continuously. LNG shortage, caused by demand growth and insufficient supply, tends to induce the LNG import premium.

5.4. The effects of climate conditions

Climate factors can affect natural gas prices through changing heating fuel demand or electricity demand. Residential and commercial heating demands increase during cold months, leading to greater demands of natural gas fuel, while hot weather in summer often increases the demand for air conditioning by residents and buildings. As an important alternative fuel to coal in the process of power generation, the price of natural gas is inevitably affected by climate conditions. During the high seasons with soaring energy demand, the price of natural gas in the spot market usually rises sharply, especially if there is presence of insufficient or restricted natural gas supply. Fig. 5 shows the effects of HDD and CDD, two proxies of climate conditions, on the dynamics of LNG import price.

Seen in Fig. 5, the impact of HDD exhibits a moderate upward trend after a quick rise from end 2011 and a peak in 2013. The probability of including HDD in the prediction model is on average above 55%, irrespective of the model selection. This implies that HDD should be regarded as an important factor affecting LNG import price, through its direct influence upon energy demand. It is in line with the fact that there is usually a surge of heating demand during wintertime in China, especially the northern part, to cope with the bitter weather condition. By contrast, the impact of the hot weather conditions proxied by CDD is less pronounced relative to HDD and also exhibits more obvious seasonal characteristics. The probability of including CDD in the prediction model is also no greater than 50%.

5.5. Robustness test and the effect of pricing marketisation

To test the robustness of the main results obtained by Models 1 to 3, we use the Brent crude oil price to represent the international crude oil price. The Henry Hub natural gas price, Europe natural gas price, and Japan LNG import price are respectively included in Models 4 to 6, which are shown in Table 3. The probabilities of including each explanatory variable into the prediction models are similar to the main results based on Models 1 to 3, as shown in Figs. 6 and 7. By reducing the number of variables, the significance levels of all explanatory variables are generally higher than in the main models, but the general trends remain robust.

Combining the results in Figs. 6 and 7, we could argue that China's LNG import price tends to be more driven by several domestic fundamental factors and weather conditions, relative to an oil-indexation pricing mechanism. Seen in Fig. 6, the average probabilities of including natural gas consumption and LNG imports in the prediction model are notably higher than that of Brent. This indicates the much weaker impacts of the international crude oil price volatility on China's LNG import price than those domestic fundamental and climate factors. Regarding the effects of regional gas prices, Fig. 7 shows that the impacts

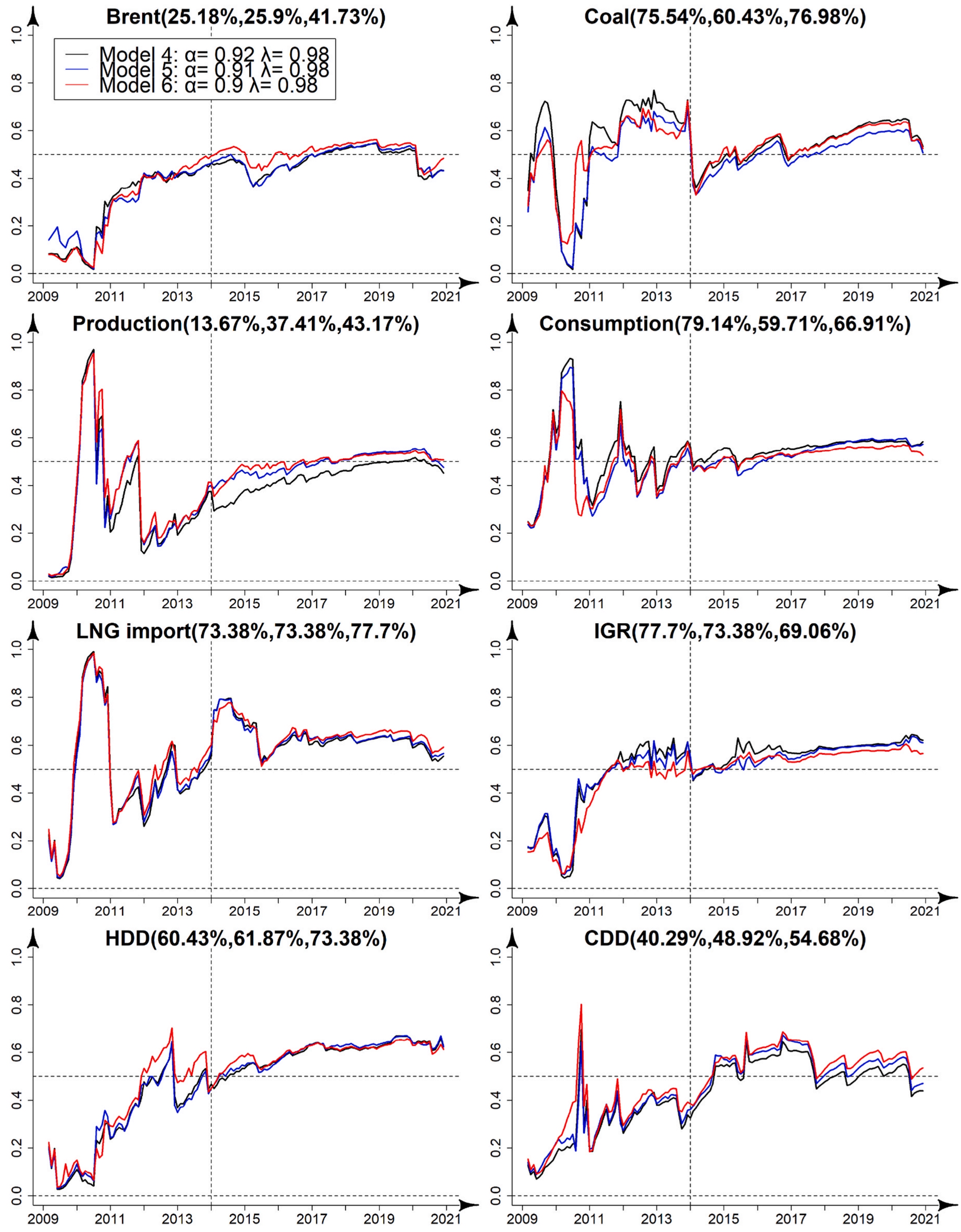


Fig. 6. Robustness test of the time-varying impacts of various factors on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the value of MAE. When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 4 to 6, respectively.

of all these markets on China's natural gas price are increasingly pronounced during the sample period. There are, however, regional differences across the US, European and Japanese markets [22]. Japan's LNG import price exerts stronger impacts on the China market relative to the European and US markets, which can be explained by the similar pricing mechanisms between Japan and China markets. These findings are consistent with the main results based on Models 1 to 3.

We also set China's LNG premium as the dependent variable. Fig. 8 plots the time-varying probabilities of including Brent or other explanatory factors in Model 7. Comparing the impacts of alternative energies, international crude oil prices tend to exert more impact on China's LNG import premium, relative to the domestic coal price. This implies that

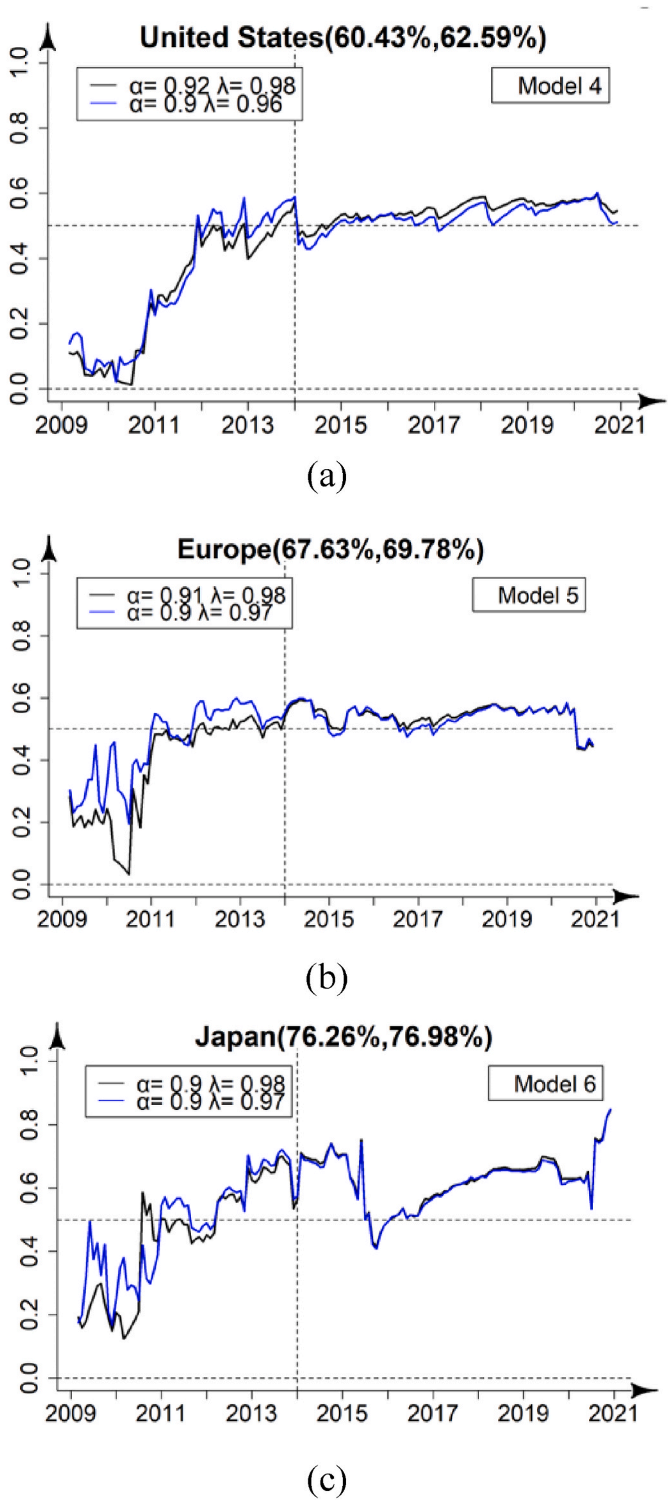


Fig. 7. Robustness test of the time-varying impacts of regional natural gas prices on China's LNG import price. Note: The forgetting factor combinations in the models are featured by minimizing the values of MAE (black line) and RMSE (blue line). When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on models 4 to 6, respectively.

the oil-indexation pricing of China's LNG imports is still a dominant driver of the high premium of natural gas in China and in Asia. Besides the pricing mechanism, the ever-growing demand of natural gas in China is another major driver of the high LNG premium. This is evidenced by our findings that among the domestic factors, those demand-side factors such as natural gas consumption, the industrial growth and climate conditions, are shown to be the main reasons forming the high premium of China's LNG import price. Furthermore, the effects of several domestic variables on China's LNG import premium are clearly higher than that of Brent, indicating greater influences from the demand-side drivers in the domestic market than from the oil-indexation pricing mechanisms.

We could therefore argue that the major sources of China's LNG import premium are the growing domestic gas demand, and the gas pricing mechanism linked to crude oil prices, with the former being more influential based on our analysis results. This finding provides important policy implications that to reduce the high level of China's LNG import premium, one efficient policy measure is to continuously promote and accelerate the marketisation of natural gas prices in China, drawn on the empirical evidence that the marketisation contributes to the decoupling of gas and oil prices [20], therefore weakening the contribution of the oil-indexation pricing mechanism to forming a high level of gas price premium. On the other hand, to tackle the high premium formed by increasing gas demand and insufficient domestic supply, policies should be geared towards optimizing the domestic energy consumption structure on the demand side, and accelerating the development and utilization of renewable energy on the supply side. Alleviating the imbalance between supply and demand in China's natural gas market will be conducive to lowering the high premium of China's LNG import price as well as to ensuring the country's energy security.

5.6. Further discussions

Since 2014 when China's domestic LNG ex-factory price became no longer controlled by the government, the supply and demand fundamentals in the domestic energy market and climate factors are increasingly influential on China's LNG import price [28]. We therefore consider January 2014 as a potential breakpoint to evaluate the changes of the impacts made by each factor caused by such a pricing reform.

As shown in Figs. 6 and 7, the probabilities of including each variable in Models 4 to 6 generally experience sharp fluctuations before 2014. After 2014, their impacts gradually stabilize. With the further promotion of the pricing mechanism marketisation, the demand side factors in the domestic natural gas market, including total natural gas consumption and weather conditions, tend to exert strengthened impacts on China's LNG import price. Also, the effects of these demand side factors on China's LNG import premium are increasingly pronounced after 2014. Based on these findings, the pricing mechanism reform has contributed positively to enhancing the connection between the level of China's LNG premium and market information. Nevertheless, IEA [56] argues that market price still has not played a leading role in China's natural gas market and there is still a long way to go for China to achieve a fully competitive natural gas market. The integration of the China natural gas market into the international market needs to be further strengthened through deepening the marketizing of natural gas prices in the domestic market.

6. Conclusion and policy implications

China's natural gas import price has adopted the oil-indexation pricing method, while China has been actively promoting a marketisation reform of its natural gas pricing mechanism. These recent trends imply that China's LNG import price is affected by multiple factors from both domestic and global sources.

In this study, a dynamic model averaging (DMA) methodology is

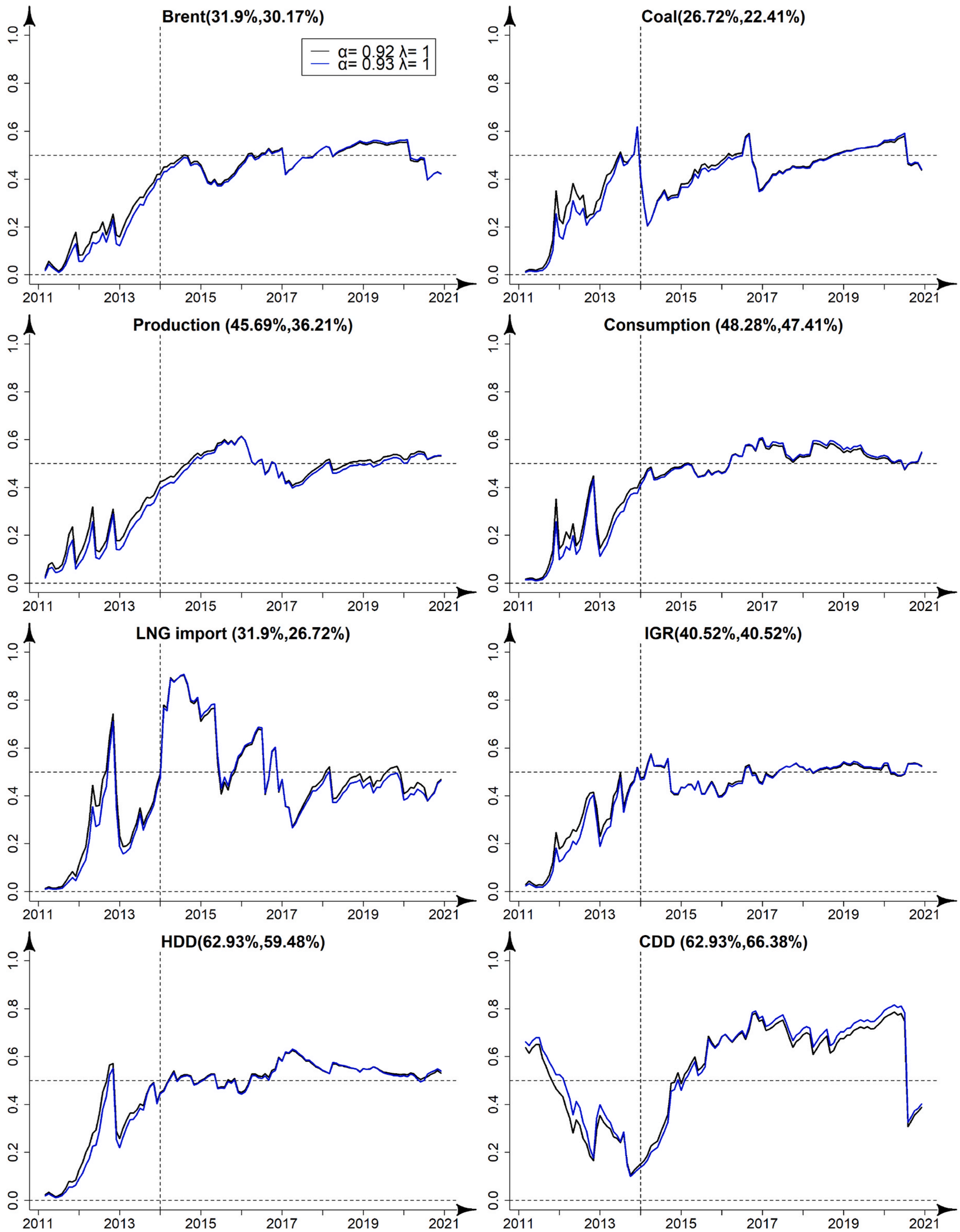


Fig. 8. Time-varying impacts of various factors on China's LNG import premium. Note: The forgetting factor combinations in the models are featured by minimizing the values of MAE (black line) and RMSE (blue line). When the probability of including an independent variable in the model is higher than 0.5, this variable is considered to have significant impacts on China's LNG import price at the given point of time. Figures in the parentheses represent the probability of significant observations over the full sample period based on model 7.

used to analyse the time-varying impacts of several potential determinants on China's LNG import price. We first find that China's LNG import price is gradually getting connected with international natural gas prices over time, among which Japan's LNG import price exerts significantly stronger influence relative to the US and European markets. The underlying reason could be the similar pricing mechanisms between the gas markets of China and Japan. Affected by the similar pricing mechanism, China's LNG import price is more sensitive to the volatility in Japan's LNG import price. The policy implication is that the connectedness between China's natural gas market and the international gas market is still dominated by a pricing mechanism linked to crude oil prices, rather than by market trade. To promote the integration of the domestic gas market into the global gas market, China should continue to accelerate the marketisation of the natural gas pricing mechanism, through enhancing the role of its natural gas trading hubs such as Shanghai, Chongqing and Shenzhen centres, promoting the adoption of and harmonization with international standards, and encouraging market-oriented pricing.

We then find that China's LNG import price is more affected by fundamental factors in the domestic market relative to the international oil and gas market factors. The high premium of China's LNG import price is largely driven by its fast industrial development and growing domestic energy demand, especially the seasonal demands caused by extreme weather conditions. The contributions made by these fundamental factors are notably higher than those by crude oil prices. It is also observed that the process of marketisation of the natural gas market has diversified the driving factors of China's LNG import price and enhanced the links between the LNG import price and market information.

China's natural gas price has become increasingly market-oriented as the marketisation of gas pricing continues to progress. As the world's largest natural gas importer, unflaggingly promoting such a reform is expected to benefit the development of China's natural gas market and speed up its integration into the international market. During this process, it is critical to continue to open up the Chinese market, increase energy efficiency and reduce China's dependence on imports of natural gas, as the high premium of China's LNG import price is mainly driven by the ever-growing domestic demand. Meanwhile, it is important for China to make more efforts to increase its bargaining power in the international natural gas market, so as to secure the domestic gas supply and reduce the level of import premium.

Furthermore, as domestic industrial growth is shown to be a major driver of both the volatility and premium of China's LNG import price, it is a long-standing critical issue to balance between economic development and energy consumption. This objective is clearly reflected in government plans. For example, the modern energy system plan embedded in the government's "14th five-year plan" sets out to shift from increasing natural gas consumption to increasing natural gas storage and supply capacities as the new directions for the future development of China's natural gas industry [57].

Natural gas is considered a "bridge fuel" to realize China's low-carbon economic development [58]. Based on our results, both domestic economic development and coal price exert significant impacts on the level of LNG import premium. Policymakers should thus be reminded that alongside reducing import costs and securing gas imports, the development of cleaner fuels is an equally effective, if not more, measure to reduce the country's dependence on natural gas imports. The Chinese government has proposed to vigorously promote the development and use of renewable energy power generation, to achieve the goal that renewable energy will have accounted for over 50% of the increment of primary energy consumption by the end of the 14th Five Year Plan period [57].

During China's green transition to achieve carbon emission peak and carbon neutrality, marketisation is considered an important driving force that accelerates energy transition in the long run [59] and may further diversify the determinants of natural gas prices. While this study focuses on the influences of the global and Asian crude oil markets and three regional gas markets that are generally considered the major and most direct forces affecting the energy market risks in China, it should be noted that with the ongoing energy marketisation, there may exist heterogeneity in the relationships between China's natural gas market and various regional crude oil markets other than those covered in this study (Such as Dubai/Oman). Also, the trade links between the Chinese and different regional gas markets are evolving and potentially tightening, most notably the Middle East, whose trade nexus with China has expanded beyond oil [48]. Limited by the scope of this study, it is of future interest to investigate the heterogeneity in the relationships between China's natural gas market and other regional oil/gas markets, especially the Middle East.

CRediT author statement

Tiantian Wang: Data collection and curation, Software. Wan Qu: Visualization, Investigation, Validation, Software. Dayong Zhang: Conceptualization, Methodology, Supervision, Writing- Reviewing and Editing. Qiang Ji: Conceptualization, Supervision, Writing- Reviewing and Editing. Fei Wu: Validation, Methodology, Writing- Original draft preparation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This research is supported by the National Social Science Foundation of China (NSSFC) Major project Grant No. 20&ZD110.

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