Journal of
Risk and Financial
Management

Article

Effects of the 2008 Financial Crisis and COVID-19 Pandemic on the Dynamic Relationship between the Chinese and International Fossil Fuel Markets

Chaofeng Tang and Kentaka Aruga *

Graduate School of Humanities and Social Sciences, Saitama University, 255 Shimo-Okubo, Sakura-ku, Saitama 338-8570, Japan; chaofengtang88@yahoo.co.jp
* Correspondence: aruga@mail.saitama-u.ac.jp; Tel.: +81-48-858-3336

Abstract: This study examines whether the dynamic relationship between the Chinese and international fossil markets changed during the 2008 financial crisis and is changing during the COVID-19 pandemic. The impact of the crises are analyzed by including the periods affected by the crises as dummy variables in the VAR and VECM models. Monthly data for the 2000:1–2020:12 period were used in the study. Our results suggest that the effects of the COVID-19 on the linkages between the Chinese and international fossil fuel markets are not as evident compared to the 2008 financial crisis. The study identifies that the effects of the 2008 financial crisis and the COVID-19 pandemic on the linkages are mostly driven by the impacts of these crises on the Chinese fossil fuel markets. The study indicates the importance of controlling the risk involved in the Chinese fossil fuel market when events like the 2008 financial crisis and the COVID-19 pandemic are changing the linkages between the Chinese and international fossil fuel markets.

Keywords: Chinese fossil fuel; COVID-19 pandemic; 2008 financial crisis; natural gas

Citation: Tang, Chaofeng, and Kentaka Aruga. 2021. Effects of the 2008 Financial Crisis and COVID-19 Pandemic on the Dynamic Relationship between the Chinese and International Fossil Fuel Markets. *Journal of Risk and Financial Management* 14: 207. https://doi.org/10.3390/jrfm14050207

Academic Editor: Michael McAleer

Received: 7 April 2021
Accepted: 3 May 2021
Published: 5 May 2021

1. Introduction

According to the WHO report (World Health Organization WHO), Coronavirus disease 2019 (COVID-19) was first reported in Wuhan City, Hubei Province of China, in late December 2019. In response to minimize the threat of the coronavirus, the Chinese government sealed off Wuhan City on 23 January 2020, and then all the cities in China were compelled to restrict business activities (Wu et al. 2020). Subsequently, Covid-19 was confirmed as a widespread pandemic over the world, affecting many industrial sectors, and restrictive measures are used to prevent the spread of the virus (Aruga et al. 2020).

With these restrictions, many industries, including agriculture, manufacturing, finance, education, healthcare, sports, tourism, and food are largely at a halt, causing adverse impacts on energy demand and consumption (Jiang et al. 2021). According to the International Energy Agency (IEA), it is predicted that countries in full lockdown will experience a 25% decline on average in energy demand per week, where countries in partial lockdown will decline 18% on average. The Asian demand for oil and gas was expected to fall by 15 percent, with the possibility of a 17 percent drop due to the pandemic in 2020 (Energy 2020). According to the Chinese government (SIPA 2020), national energy consumption and power demand declined 2.8% and 6.5%, respectively, in the first quarter of 2020 compared to that of 2019.

The COVID-19 shock on energy markets in the Asian-Pacific region became more evident in the fossil fuel market. The World Bank calculated that there was a 63.5% drop in Dubai crude oil price, a 15.9% drop in the Australian coal price, and a 1.2% increase in the Japanese Liquefied Natural Gas price from January 2020 to April 2020. In China, the domestic petroleum and natural gas price indices fell 31.4% and 58.6%, respectively, during the same period (CEINET Statistics Database 2021). We expect that the drop in fossil fuel prices in 2020 is related to the decline in oil consumption due to the COVID-19 outbreak and political factors affecting the supply side like the price war between Saudi Arabia and Russia in March 2020 (Turak 2020). However, in this study, based on Fama's efficient market hypothesis (Fama 1991), we focus on the price itself rather than the factors behind the price changes assuming that the demand and supply factors are incorporated in the market price.

China is an interesting case study for the following three reasons (Norouzi et al. 2020). First, China is the first country suffering from the COVID-19, which is feasible for capturing the early stage of the shocks of the COVID-19 crisis. Second, it is the second-largest economy and largest developing country, having the highest fossil fuel consumption in the world. Thus, we believe conducting a case study on China can serve as a proxy for understanding the impacts of the COVID-19 crisis on fossil fuel-consuming countries. Finally, China is the world's largest energy importer, and thus, we can learn from this case study how an energy importing country is affected by the COVID-19 pandemic.

Furthermore, the above drastic price fluctuations in the Chinese and international fossil fuel prices will increase the risk of uncertainty for energy trading participants and policymakers. To better understand the above drastic price fluctuations caused by the COVID-19 crisis, it would be interesting to compare the impacts with another well-known exogenous shock affecting the fossil fuel market: The 2008 financial crisis. Before the 2008 financial crisis, energy-producing companies increased their investments significantly. However, when global energy demand dropped sharply due to the crisis, companies addressed the drastic decline in cash flow with a reduction of prices (Hauser et al. 2020). Spatt (2020) suggests that the examples of two crises analyzed simultaneously can lead to more insight than a single one to help understand the covid-19 crises and the causes and consequences of both crises. The 2008 financial crisis reflects the infection of the financial system due to excess leverage and poor-quality mortgage loans while the COVID-19 crisis is related to a substantial global economic shock due to the outbreak of the coronavirus.

We expect that the dynamic relationships between the Chinese and international fossil fuel markets are changing differently from the 2008 financial crisis during the COVID-19 pandemic periods. The impact of the 2008 financial crisis on the energy market is related to financial market behavior, which will act differently in bear and bull markets (Mollick and Assefa 2013). So, the relationship between the variables may be subject to drastic changes during the crisis (Mollick and Assefa 2013), and thus, we expect that it would be more difficult for the stakeholders of the fossil fuel market to predict the effects of the impact from the 2008 financial crisis.

On the other hand, the information for the impact of the COVID-19 crisis on the energy market could be predicted according to historical production data announced by the government. When a lockdown is announced by the government it is easy to forecast that the energy demand will decrease. Thus, energy stakeholders can expect beforehand that the COVID-19 crisis would cause a sharp drop in energy prices when a lockdown is conducted. If the cause and timing of the event are known to the market participants, effects of the shock will likely be quickly incorporated into the market, and hence, we anticipate that the shock from the COVID-19 crisis will have little change on the linkages between the Chinese and international fossil fuel markets.

Therefore, analyzing the impacts of the 2008 financial crisis and the COVID-19 pandemic on the relationship between the Chinese and international fossil fuel markets will provide useful information for the market participants and policymakers of the fossil fuel markets to hedge against the uncertainty and risk involved with the energy price fluctuations related to the economic crises. If the study identifies that the dynamic relationships between the Chinese and international fossil fuel markets are changing during the crisis periods, it will imply that stakeholders and policymakers trading between the Chinese and international fossil fuel markets need to consider the shocks from these crises in their price discovery processes. Thus, we expect that the study will provide valuable information for stakeholders and policymakers managing risks in the Chinese energy markets.

We describe and explain the previous research in the second section. The third section presents the materials and methodology of the study. Then in the fourth section, we will report the results of the analyses performed in the study. Finally, the discussion and conclusion will be introduced in the fifth and last sections.

2. Previous Research

Numerous papers have investigated the impact of the COVID-19 epidemic crisis on different countries and regional energy markets (Aruga et al. 2020; Nyga-Lukaszewska and Aruga 2020; Bahmanyar et al. 2020; Norouzi et al. 2020; Jiang et al. 2021). Aruga et al. (2020) found that a long-run relationship holds between the COVID-19 cases and energy consumption and that the COVID-19 cases have a positive effect on Indian energy consumption. Bahmanyar et al. (2020) suggested that the energy consumption profiles reflect the difference in peoples' activities in different European countries using various measures in response to the Covid-19 pandemic. Norouzi et al. (2020) suggested that the elasticity of petroleum and electricity demand toward the population of the infected people in China is −0.1% and −0.65%, respectively. Jiang et al. (2021) showed that although the overall energy demand declines, the extra energy for COVID-19 fighting is non-negligible for stabilizing energy demand, and the energy recovery in different regions presents significant differences.

Next, some studies brought important implications in the risk management of energy during the pandemic (Akhtaruzzaman et al. 2020; Chang et al. 2020). Akhtaruzzaman et al. (2020) showed that oil supply industries benefit from positive shocks to oil price risk in general, whereas oil and financial industries react negatively to positive oil price shocks. Chang et al. (2020) believed that there are strong cross-sector herding spillover effects from US fossil fuel energy to renewable energy, especially before the 2008 financial crisis, while the US fossil fuel energy market has a significant influence on the European and Asian renewable energy returns during the COVID-19 pandemic.

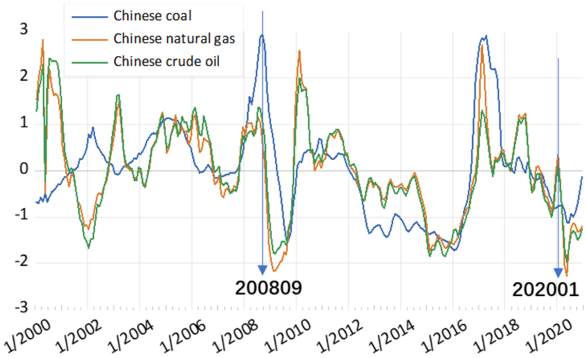
On the other hand, there is a large amount of literature studying the volatility spillovers in commodity and financial markets to understand the cross-market linkages during the COVID-19 crisis (Bouri et al. 2021a; Bouri et al. 2021b; Shahzad et al. 2021). For example, Bouri et al. (2021a) examine the realized volatility connectedness across 15 international commodity futures showing strong and moderate levels of volatility connectedness among energy and metals and moderate connectedness within the group of agricultural commodities. Shahzad et al. (2021) indicated that the impact of volatilities on the inter-sectoral stock market is asymmetric and time-varying during the COVID-19 period.

However, few prior studies examined whether the dynamic cointegration relationships between the Chinese and international fossil fuel markets are changing during periods related to the 2008 financial crisis and the COVID-19 pandemic. Unlike the previous study, the current study is among the first studies to explore this issue. In addition, recently, many studies investigating energy market linkages use the cointegration methods (Aruga and Kannan 2020; Hu et al. 2020) but up until now, no studies have applied both the recursive cointegration test and the VAR or VECM model including the crises as dummy variables for identifying market linkages. By including the dummy variable, the model can grasp the impact of the crisis on the dynamic relationships. The study not only contributes to understanding how the crises influenced the dynamic relationship between the Chinese and international energy sectors but also becomes a good reference for analyzing the effects of events causing economic shocks on other Asian-Pacific countries.

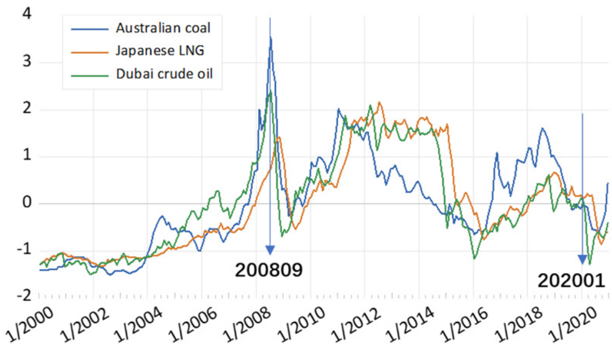
3. Materials and Methods

To identify the dynamic cointegration relationships between the Chinese and international fossil fuel markets during the 2008 financial crisis and COVID-19 pandemic, we used the recursive Johansen cointegration test developed by Hansen and Johansen (1993). Our cointegration tests are performed between January 2000 to December 2020.

As Chinese and international fossil fuel prices have different units, they are standardized as shown in Figure 1. First, we used the monthly price indices of the domestic coal, natural gas, and petroleum industrial sectors to represent the Chinese fossil fuel market because different provinces of China use different fossil fuel prices. These price indices are obtained from the CEINET statistics database (2021). Second, for the international fossil fuel prices, we used the Australian coal, Dubai crude oil, and Japanese liquefied natural gas (LNG) prices. These international fossil fuel prices are gathered from the World World Bank (2021).



(**a**) Chinese fossil fuel price



(**b**) International fossil fuel price

Figure 1. Plots of the Chinese and international fossil fuel prices.

It is necessary to test the stationarity of time series data and identify the optimal lag orders before performing a cointegration test. For this purpose, we conducted the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and KPSS unit root tests on our time series data. Trend and intercept are included in the unit root tests. The Akaike Information Criterion (AIC) is used for selecting the optimal lag length for the unit root tests, and the Parzen kernel is used for the estimations. Table 1 illustrates the results of these tests. The result shows that all our test variables are non-stationary at their level data but are stationary when first differencing them at the 5% significance level.

Table 1. Unit root tests.

Variables	Level Data (t-Value)			First Difference Data		
	ADF	PP	KPSS	ADF	PP	KPSS
Australian coal	−2.46	−2.41	0.85 *	−11.5 *	−11.59 *	0.05
Japanese LNG	−1.81	−1.73	0.92 *	−7.45 *	−9.44 *	0.19
Dubai Crude-oil	−2.55	−1.97	0.67 *	−9.67 *	−8.92 *	0.18
China coal	−2.60	−3.10	0.38 *	−4.55 *	−6.90 *	0.03
Chinese natural gas	−3.27	−4.12	0.37 *	−7.45 *	−13.4 *	0.02
Chinese crude oil	−2.88	−3.75	0.43 *	−12.89 *	−12.88 *	0.02

Note: * Significant at the 5% significance level.

As the precondition of the cointegration test was satisfied, we performed the recursive Johansen cointegration test between the Chinese and international fossil fuel prices. To apply the recursive cointegration test, we identified the optimal lag orders to be included in the test model based on the vector autoregressive (VAR) model. The optimal lag lengths are determined based on the Schwarz Information Criterion (SC). The lag orders selected by the criterion are based on the lowest SC value. The results of the optimal lag orders are presented in Table 2.

Table 2. Optimal lag orders.

Relationship between Variate	Lag	Lowest SC
Chinese coal vs. Australian coal	2	−1.35 *
Chinese coal vs. Dubai crude oil	2	−1.62 *
Chinese coal vs. Japanese LNG	2	−2.38 *
Chinese crude oil vs. Australian coal	2	−0.41 *
Chinese crude oil vs. Dubai crude oil	2	−1.04 *
Chinese crude oil vs. Japanese LNG	4	−1.60 *
Chinese natural gas vs. Australian coal	2	−0.02 *
Chinese natural gas vs. Dubai crude oil	2	−0.69 *
Chinese natural gas vs. Japanese LNG	4	−1.28 *

Note: The * symbol represents the lowest value of SC.

The algorithms for recursive estimation are first performed by estimating the Johansen trace test over an initial sample (Aruga and Kannan 2020). Thus, the base initial sample will be automatically treated as the first k observations by the program. Then, additional observations are added to this base sample, and at each iteration, the trace statistic is estimated recursively. Finally, this recursive estimation continues until the final sample period, December. 2020, is reached. The above Algorithms for the recursive estimation process are used in the CATS 2.0 package in RATS Version 10.0. The results are plotted and evaluated graphically. The recursive Johansen trace statistics are reported in the graph, and the critical values larger than one in the graph indicate that the two series are cointegrated.

To check the cointegration relationship for the whole period investigated in the study, we also performed the Johansen test (Johansen and Juselius 1990).

Finally, to find out if the changes in the cointegration relationship identified by the recursive cointegration test were related to the changes in the Chinese and international fossil fuel prices due to the shocks from the 2008 financial crisis and COVID-19 pandemic, we applied the VAR and VECM models by including these events as dummy variables.

To verify whether the VAR or VECM model should be used, we use the results obtained from the Johansen test. If the Johansen test revealed that there is not a cointegration relationship between the Chinese and international fossil fuel prices, the VAR model is used while the VECM model is applied when a cointegration relationship is found.

The mathematical representation of the VAR model is given by:

$$\Delta P_t = \beta_0 + \beta_1 \Delta P_{t-1} + \cdots + \beta_n \Delta P_{t-n} + \varepsilon_t \tag{1}$$

where P_t is the column vector of the k fossil fuel price series of this study. Δ is the first difference operator, β_0 is a constant vector ($k \times 1$), $\beta_1 \cdots \beta_n$ are matrices of coefficients to be estimated ($k \times k$), n is the optimal lag order, and ε_t is the $k \times 1$ vector of error terms.

The mathematical representation of the VECM model is given by:

$$\Delta P_t = \lambda EP_{t-1} + \sum_{i=1}^{n-1} \phi'_{t-i} \Delta P_{t-i} + \varepsilon_t \tag{2}$$

here the difference from Equation (1) is that in this equation the error correction term EP_{t-1} is included in the VAR model. The error correction term captures the long-run relationship between the Chinese and international fossil fuel markets.

To capture the impacts of the 2008 financial crisis and COVID-19 pandemic on Chinese and international fossil fuel markets for analyzing the change in the relationship between the Chinese and international fossil fuel markets, we applied the VAR model (1) and VECM model (2) including these events as dummy variables.

The mathematical representation of the VAR model (1) with dummy variables is given by:

$$\Delta P_t = \beta_0 + \beta_1 \Delta P_{t-1} + \cdots + \beta_n \Delta P_{t-n} + dummy1 + dummy2 + \varepsilon_t \tag{3}$$

The mathematical representation of the VECM model (2) with dummy variables is given by:

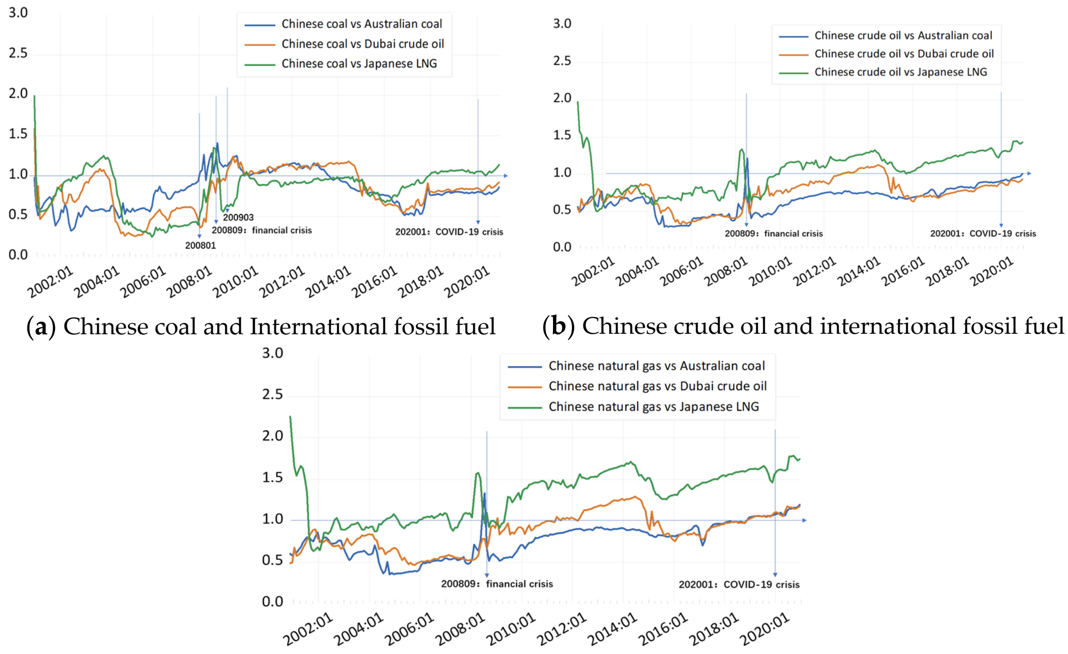
$$\Delta P_t = \lambda EP_{t-1} + \sum_{i=1}^{n-1} \phi'_{t-i} \Delta P_{t-i} + dummy1 + dummy2 + \varepsilon_t \quad (4)$$

The models in Equations (3) and (4) have prices and the same dummy variables. *Dummy1* considers the effects of the COVID-19 pandemic on the price relationships, which takes the value "1" for the 2020:01–2020:12 periods and "0" otherwise since the coronavirus patient was first reported in China in late December 2019. *Dummy 2* takes "1" if the data belong to the 2008:09–2009:08 period and "0 "otherwise capturing the impact of the 2008 financial crisis. *Dummy 2* is defined as this period since the bankruptcy of Lehman Brothers occurred on 15 September 2008 (Adrian and Shin 2010) and it is often assumed that the 2008 financial crisis began in September 2008 (Aruga and Kannan 2020).

4. Results

4.1. Recursive Cointegration

Figure 2 illustrates the results of the recursive cointegration test conducted between the Chinese and international fossil fuel markets.



(**a**) Chinese coal and International fossil fuel (**b**) Chinese crude oil and international fossil fuel

(**c**) Chinese natural gas and international fossil fuel

Figure 2. Recursive cointegration of Chinese and International fossil fuel prices.

It is observable from Figure 2a that the Chinese domestic coal price is not cointegrated with the Australian coal and Dubai crude oil markets until January 2008 and March 2009, respectively. On the other hand, the Chinese domestic coal and the Japanese LNG markets were mostly not cointegrated during periods before the 2008 financial crisis but they became cointegrated just before the crisis and again became not cointegrated after the shock from the crisis. These results were also confirmed by Li et al. (2019) showing that the co-movement between the Chinese coal and international energy prices has different trends before and after mid-2008 due to inter-fuel substitution of crude oil and inter-market contagion of the international coal market.

From the figure, it is also discernible that the COVID-19 pandemic did not have impacts on the Chinese coal and international fuel market relationships. Both the Australian coal and Dubai crude oil markets continued to have no cointegration relationships with the Chinese coal market and the Japanese LNG market remained to show a cointegration relationship with the Chinese coal market even after the COVID-19 pandemic occurred.

Next, we would like to look into the effects of the two crises on the Chinese crude oil and international fossil fuel market linkages. Figure 2b suggests that both the relationships between the Chinese crude oil vs. the Australian coal and the Chinese crude oil vs. the Japanese LNG market received impacts from the 2008 financial crisis since the cointegration relationships have altered before and after the crisis for these relationships. However, the Dubai crude oil market remained to have no cointegration relationship with the Chinese crude oil market during this crisis.

Regarding the COVID-19 shock, none of the relationships between the Chinese crude oil and the international fossil fuel market were influenced by this shock.

Finally, Figure 2c illustrates the results of the impacts of the crises on the Chinese natural gas market. Similar to the results of Figure 2b while the relationship between the China natural gas vs. the Australian coal and that between the China natural gas vs. the Japanese LNG were influenced by the 2008 financial crisis, the relationship between the Chinese natural gas and Dubai crude oil market did not change during this crisis. The COVID-19 shock also did not show any impact on the Chinese natural gas and international fossil fuel market linkages.

4.2. Johansen Cointegration

Table 3 illustrates the results of the Johansen test between the Chinese fossil fuel and international fossil fuel prices.

Table 3. Results of the Johansen cointegration test.

Between Different Market	Rank Number	Trace Statistic	0.05 Critical Value	Max-Eigenvalue Statistic	0.05 Critical Value
Chinese coal vs. Australian coal	None * At most 1 *	25.95 * 4.5 *	15.49 3.84	21.45 * 4.5 *	14.26 3.84
Chinese coal vs. Dubai crude oil	None * At most 1 *	27.65 * 4.45 *	15.49 3.84	23.19 * 4.45 *	14.26 3.84
Chinese coal vs. Japanese LNG	None * At most 1	38.54 * 2.69	15.49 3.84	35.84 * 2.69	14.26 3.84
Chinese crude oil vs. Australian coal	None * At most 1*	23.16 * 4.34 *	15.49 3.84	18.81 * 4.34 *	15.49 3.84
Chinese crude oil vs. Dubai crude oil	None * At most 1 *	23.64 * 4.5 *	15.49 3.84	21.45 * 4.5 *	15.49 3.84
Chinese crude oil vs. Japanese LNG	None * At most 1*	39.54 * 3.89 *	15.49 3.84	35.65 * 3.89 *	15.49 3.84
Chinese natural gas vs. Australian coal	None * At most 1 *	28.59 * 5.04 *	15.49 3.84	23.55 * 5.04 *	15.49 3.84
Chinese natural gas vs. Dubai crude oil	None * At most 1	26.18 * 3.49	15.49 3.84	22.68 * 3.49	15.49 3.84
Chinese natural gas vs. Japanese LNG	None * At most 1	45.01 * 4.20	15.49 3.84	40.81 * 4.20	15.49 3.84

Note: * Significant at the 5% significance level.

First, Table 3 suggests that the Chinese domestic coal price is not cointegrated with the Australian coal and Dubai crude oil prices during the 2001:01–2020:12 period. The reason for this is perhaps because the Chinese domestic coal price has been controlled by the Chinese government until 2013 (Zhang et al. 2018). In contrast, the Chinese domestic coal market is cointegrated with the Japanese LNG market. This is likely related to China's shift from coal to natural gas to reduce its carbon emission.

Secondly, Table 3 indicates that the Chinese crude oil price is not cointegrated with the Australian coal, Dubai crude oil, and Japanese LNG prices. The reason for the Chinese crude oil not having linkages with the international market is perhaps because the crude oil market is still regulated by the government (Lin and Ouyang 2014). For example, prices of gasoline, diesel, and aviation kerosene are subsidized by the Chinese government.

Thirdly, the Chinese natural gas price is not cointegrated with the Australian coal price, while the Chinese natural gas price is cointegrated with the Dubai crude oil and Japanese LNG prices. This is because China's natural gas is still mainly imported. The imported natural gas prices of the Asian countries are often linked with the Japan Crude Cocktail (JCC) oil price, which represents the average price of Dubai crude oil imported to Japan (Tang and Aruga 2020).

4.3. Results of the Impact of Both Crises on the Chinese and International Fossil Fuel Market

Table 4 shows the impact of the two crises on the Chinese and international fossil fuel markets estimated with the VAR and VECM. These analyses are conducted to see whether the changes in the linkages between the Chinese and international fossil fuel markets are related to the effects of the two crises on the Chinese and international fossil fuel prices.

Table 4. Results of the impact of both crises on Chinese and international fossil fuel.

Chinese and International Fossil Fuel	Used Model	Independent Variables	Dummy Variate	Coefficient	t-Value
Chinese coal vs. Australian coal	VAR	China coal	dummy1	−0.129 *	−2.994 *
			dummy2	0.036	0.920
		Australian coal	dummy1	−0.160 *	−2.549 *
			dummy2	0.043	0.742
Chinese coal vs. Dubai crude oil	VAR	China coal	dummy1	−0.147 *	3.203 *
			dummy2	0.048	1.131
		Dubai crude oil	dummy1	−0.067	−1.291
			dummy2	−0.020	−0.414
Chinese coal vs. Japanese LNG	VAR	China coal	dummy1	−0.181 *	−3.890 *
			dummy2	0.037	0.841
		Japanese LNG	dummy1	−0.037	−1.103
			dummy2	0.033	−1.029
Chinese crude oil vs. Australian coal	VAR	Chinese crude oil	dummy1	−0.097	−0.925
			dummy2	−0.071	−0.723
		Australian coal	dummy1	−0.145 *	−2.320 *
			dummy2	0.050	0.852
Chinese crude oil vs. Dubai crude oil	VAR	Chinese crude oil	dummy1	−0.066	−0.699
			dummy2	−0.036	−0.392
		Dubai crude oil	dummy1	−0.051	−1.014
			dummy2	−0.023	−0.475
Chinese crude oil vs. Japanese LNG	VAR	Chinese crude oil	dummy1	−0.208 *	−2.252 *
			dummy2	−0.081	−0.899
		Japanese LNG	dummy1	−0.048	−1.573
			dummy2	−0.044	−1.451
Chinese natural gas vs. Australian coal	VAR	Chinese natural gas	dummy1	−0.263 *	−2.194 *
			dummy2	−0.241 *	−2.138 *
		Australian coal	dummy1	−0.162 *	−2.536 *
			dummy2	0.033	0.553
Chinese natural gas vs. Dubai crude oil	VECM	Chinese natural gas	dummy1	−0.186	−1.675
			dummy2	−0.193	−1.781
		Dubai crude oil	dummy1	−0.082	−1.552
			dummy2	−0.058	−1.123
Chinese natural gas vs. Japanese LNG	VECM	Chinese natural gas	dummy1	−0.304 *	−3.005 *
			dummy2	−0.242 *	−2.421 *
		Japanese LNG	dummy1	−0.048	−1.523
			dummy2	−0.039	−1.243

Note: * Significant at the 5% significance level. Dummy1 is defined as the 2008 financial crisis dummy variable. Dummy2 is defined as the COVID-19 dummy variable.

It is discernible from Table 4 that the shock from the 2008 financial crisis at least became significant in one of the three linkage models in all three Chinese fossil fuel markets where the effect of COVID-19 was only evident in the Chinese natural gas market. Furthermore, comparing the coefficients of the two dummy variables in the Chinese natural gas model, it is evident that the negative shock from the 2008 financial crisis on the Chinese natural gas market was severer than that of the COVID-19.

On the other hand, except for the Australian coal market, none of the coefficients of the international fossil fuel prices in Table 4 became significant suggesting that the shocks from the two crises on the linkages between the Chinese and international fossil fuel markets were not influenced by the shocks on the international fossil fuel markets. Even the shock from the 2008 financial crisis found on the Australian coal market is likely related to the effects of the Chinese energy policy since the Chinese government has implemented a 4 trillion yuan ($586 billion) stimulus package during the 2008 financial crisis and that this stimulus package has led China to increase its coal imports from Australia (Yuan et al. 2010a). Hence, it is believable that all the shocks affecting the linkages between the Chinese and international fossil fuel markets are driven by the shocks in the Chinese fossil fuel market.

In sum, the results of Table 4 indicate that the linkages between the Chinese and international fossil fuel markets were more severely affected by the 2008 financial crisis compared to the COVID-19 pandemic and both the shocks from the 2008 financial crisis and the COVID-19 pandemic on the linkages are likely driven by the impacts on the Chinese fossil fuel markets.

5. Discussion

The results indicate that besides the Chinese fossil fuel and Dubai Crude oil, the cointegration relationships between the Chinese and international fossil fuel markets were changing during the 2008 financial crisis. However, our results suggest that the cointegration relationships between the Chinese and international fossil fuel markets remained unchanged when the COVID-19 pandemic occurred except for the linkages between the Chinese natural gas market vs. the Australian coal and Japanese LNG markets.

We believe this difference in the shock on the relationship between the Chinese and international fossil fuel market is due to the different causes and consequences of the crises (Spatt 2020). The 2008 financial crisis reflected infection of the financial system due to excess leverage and poor-quality mortgage loans (Spatt 2020), and this financial behavior is likely to be considered as endogenous structural breaks, which caused immense impacts on energy markets (Aruga and Kannan 2020; Yuan et al. 2010b). Furthermore, since the date of the occurrence of the 2008 financial crisis was uncertain, the energy stakeholders could not expect the timing of the shock, and hence, it is likely that this uncertainty affected the dynamic linkages between the Chinese and international fossil fuel markets.

On the other hand, the COVID-19 pandemic was somewhat predictable and the shock on the financial system was not as severe compared to the 2008 financial crisis. Indeed, even during the COVID-19 pandemic, the world's major stock markets like the Dow Jones and Nikkei 225 index have plummeted briefly but quickly recovered. One likely reason for the financial market to remain stable compared to the 2008 financial crisis during the COVID-19 pandemic is that the causes of the pandemic were clear and the investors were possible to forecast that the economy will recover when the pandemic ends (Jackson et al. 2021). Thus, it is probable that the impact of the COVID-19 on energy markets was somewhat anticipated by the stakeholders and this kept the Chinese coal and crude oil markets to have the same relationship with the international fuel markets.

Although the linkages between the Chinese and international fossil fuel markets were not changing before and after the COVID-19 pandemic, we identified that the incident at least affected negatively on the Chinese natural gas price. This reduced Chinese natural gas price during the COVID-19 pandemic might be reflecting the reduced natural gas demand during the lockdown periods.

6. Conclusions

The study revealed that the cointegration relationships between the Chinese and international fossil fuel markets are affected by the 2008 financial crisis, while the COVID-

19 pandemic did not have a clear impact on the relationships. Thus, we identified that the effects of the COVID-19 on the linkages between the Chinese and international fossil fuel markets are not as evident compared to the 2008 financial crisis. As the stock and energy markets are recovering quickly to levels before the COVID-19 pandemic hit the world economy (Höhler and Lansink 2021), the market participants of the Chinese fossil fuel markets were likely able to anticipate the outcomes of the shock of the incident compared to that of the 2008 financial crisis.

These conclusions provide some suggestions regarding risk management and policy recommendations. As we found that the shocks from the 2008 financial crisis and the COVID-19 on the relationships between the Chinese and international energy markets were driven by the effects on the Chinese fossil fuel market, the stakeholders in the Chinese fossil fuel market need to pay more attention to the Chinese fossil fuel market when considering the risk involved in trading between the Chinese and international energy markets. As argued by Chan and Woo (2016), China should consider its domestic fossil fuel market when examining the dynamic relationship between the Chinese and international energy markets suggesting that policymakers should account not only for the dynamics relationships but also attach importance to the dynamic relationship driven by the Chinese fossil fuel market when stabilizing energy prices during the crises.

Our study is limited in the sense that the impact of the recent 2008 financial crisis is only considered in this study. Furthermore, our research may be expanded to involve other global events, such as the 1997 Asian Financial Crisis and SARS.

Author Contributions: Conceptualization, C.T. and K.A.; methodology, C.T. and K.A.; software, C.T. and K.A.; validation, C.T. and K.A.; formal analysis, C.T. and K.A.; investigation, C.T. and K.A.; resources, C.T. and K.A.; data curation, C.T. and K.A.; writing—original draft preparation, C.T. and K.A.; writing—review and editing, C.T. and K.A.; visualization, C.T. and K.A.; supervision, C.T. and K.A.; project administration, C.T. and K.A.; funding acquisition, K.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the 2021 Special Fund from the Research Center for Sustainable Development in East Asia, The Strategic Research Area for Sustainable Development in East Asia, Saitama University, Japan.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Our data are downloadable from the homepages of the CEINET Statistics Database: https://db.cei.cn/, accessed on 12 January 2021 and the World Bank: https://www.worldbank.org/en/research/commodity-markets, accessed on 12 January 2021.

Conflicts of Interest: The authors declare no conflict of interest.

References

Adrian, Tobias, and Hyun Song Shin. 2010. The Changing Nature of Financial Intermediation and the Financial Crisis of 2007–2009. *Federal Reserve Bank of New York Staff Reports* 439: 1–34. [CrossRef]

Akhtaruzzaman, Md, Sabri Boubaker, Mardy Chian, and Angel Zhong. 2020. COVID-19 and oil price risk exposure. *Finance Research Letters* 5: 2–7. [CrossRef]

Aruga, Kentaka, and Sudha Kannan. 2020. Effects the 2008 financial crisis on the linkages among the oil, gold, and platinum markets. *Cogent Economics & Finance* 8: 1807684.

Aruga, Kentaka, Md. Monirul Islam, and Arifa Jannat. 2020. Effects of COVID-19 on Indian Energy Consumption. *Sustainability* 12: 5616. [CrossRef]

Bahmanyar, Alireza, Abouzar Estebsari, and Damien Ernst. 2020. The impact of different COVID-19 containment measures on electricity consumption in Europe. *Energy Research & Social Science* 68: 2–4.

Bouri, Elie, Brian Lucey, Tareq Saeed, and Xuan Vinh Vo. 2021a. The realized volatility of commodity futures: Interconnectedness and determinants. *International Review of Economics and Finance* 73: 139–51. [CrossRef]

Bouri, Elie, Xiaojie Lei, Naji Jalkh, Yahua Xu, and Hongwei Zhang. 2021b. Spillovers in higher moments and jumps across US stock and strategic commodity markets. *Resources Policy* 72: 102060. [CrossRef]

CEINET Statistics Database. 2021. Available online: https://db.cei.cn/ (accessed on 12 January 2021).

Chan, Hing Lin, and Kai-Yin Woo. 2016. An investigation into the dynamic relationship between international and China's crude oil prices. *Applied Economics* 48: 2215–24. [CrossRef]

Chang, Chia-Lin, Michael Mcaleer, and Yu-Ann Wang. 2020. Herding behavior in energy stock market during the Global Financial Crisis, SARS, and ongoing COVID-19. *Renewable and Sustainable Energy Reviews* 134: 1–15. [CrossRef]

Energy. 2020. The impact of COVID-19 on Asian oil demand. Available online: https://www.energydigital.com/oil-and-gas/impact-covid-19-asian-oil-demand (accessed on 21 December 2020).

Fama, Eugene F. 1991. Efficient capital markets: II. *The Journal of Finance* 46: 1575–617. [CrossRef]

Hansen, Henrik, and Soren Johansen. 1993. *Recursive Estimation in Cointegrated VAR Models*. Unpublished Manuscript. Copenhagen: University of Copenhagen, pp. 1–20. ISSN 0902-6452.

Hauser, Philipp, Carl-Philipp Anke, Julia B. Gutiérrez-López, Dominik Möst, Hendrik Scharf, David Schönheit, and Steffi Misconel. 2020. The Impact of the COVID-19 Crisis Energy Prices in Comparison to the 2008 Financial Crisis. *IAEE Energy Forum* Covid-19 Special Issue: 100–5.

Höhler, Julia, and Alfons O. Lansink. 2021. Measuring the impact of COVID-19 on stock prices and profits in the food supply chain. *Agribusiness* 37: 171–86. [CrossRef] [PubMed]

Hu, Haiqing, Wei Wei, and Chun-Ping Chang. 2020. The relationship between shale gas production and natural gas prices: An environmental investigation using structural breaks. *Science of the Total Environment* 713: 136545. [CrossRef] [PubMed]

International Energy Agency (IEA). 2020. Global Energy Review 2020. Available online: https://www.iea.org/reports/global-energy-review-2020 (accessed on 20 December 2020).

Jackson, James K., Martin A. Weiss, Andres B. Schwarzenberg, Revecca M. Nelson, Karen M. Sutter, and Michael D. Sutherland. 2021. Global Economic Effects of COVID-19. *Congressional Research Service R* 46270: 2–22.

Jiang, Peng, Yee Van Fan, and Jiří Jaromír Klemeš. 2021. Impacts of COVID-19 on energy demand and consumption: Challenges, lessons and emerging opportunities. *Applied Energy* 285: 116441. [CrossRef]

Johansen, Soren, and Katarina Juselius. 1990. Maximum likelihood estimation and inference on cointegration: With applications to the demand for money. *Oxford Bulletin of Economics and Statistics* 52: 169–210. [CrossRef]

Li, Jianglong, Chunping Xie, and Houyin Long. 2019. The roles of inter-fuel substitution and inter-market contagion in driving energy prices: Evidences from China's coal market. *Energy Economics* 84: 104525. [CrossRef]

Lin, Boqiang, and Xiaoling Ouyang. 2014. A revisit of fossil-fuel subsidies in China: Challenges and opportunities for energy price reform. *Energy Conversion and Management* 82: 124–34. [CrossRef]

Mollick, André V., and Tibebe A. Assefa. 2013. U.S. stock returns and oil prices: The tale from daily data and the 2008–2009 financial crisis. *Energy Economics* 36: 1–18. [CrossRef]

Norouzi, Nima, Gerardo Zarazua de Rubens, Saeed Choupanpiesheh, and Peter Enevoldsen. 2020. When pandemics impact economies and climate change: Exploring the impacts of COVID-19 on oil and electricity demand in China. *Energy Research & Social Science* 68: 2–14.

Nyga-Lukaszewska, Honorata, and Kentaka Aruga. 2020. Energy Prices and COVID-Immunity: The Case of Crude oil and Natural Gas Prices in the US and Japan. *Energies* 13: 6300. [CrossRef]

Shahzad, Syed Jawad Hussain, Muhammad Abubakr Naeem, Zhe Peng, and Elie Bouri. 2021. Asymmetric volatility spillover among Chinese sectors during COVID-19. *International Review of Financial Analysis* 75: 101754. [CrossRef]

SIPA. 2020. COVID-19 Pandemic's Impacts on China's Energy Sector: A Preliminary Analysis. Available online: https://www.energypolicy.columbia.edu/research/commentary/covid-19-pandemic-s-impacts-china-s-energy-sector-preliminary-analysis (accessed on 25 December 2020).

Spatt, Chester S. 2020. A Tale of Two Crises: The 2008 Mortgage Meltdown and the 2020 COVID-19 Crisis. *Review of Asset Pricing Studies* 10: 760–90. [CrossRef]

Tang, Chaofeng, and Kentaka Aruga. 2020. A study on the Pass-Through Rate of the Exchange Rate on the Liquid Natural Gas (LNG) Import Price in China. *International Journal of Financial Studies* 8: 70. [CrossRef]

Turak, Natasha. 2020. Oil Nose-Dives as Saudi Arabia and Russia Set Off 'Scorched Earth' Price War. Available online: https://www.cnbc.com/2020/03/08/opec-deal-collapse-sparks-price-war-20-oil-in-2020-is-coming.html (accessed on 28 April 2021).

World Bank. 2021. Latest Commodity Prices Published (Monthly Prices). Available online: https://www.worldbank.org/en/research/commodity-markets (accessed on 8 February 2021).

World Health Organization (WHO). 2020. Novel Coronavirus (2019-nCoV) Situation Report-1. Available online: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200121-sitrep-1-2019-ncov.pdf (accessed on 8 December 2020).

Wu, Jing, Michelle Gamber, and Wenjie Sun. 2020. Does Wuhan Need to be in lockdown during the Chinese Lunar New Year? *International Journal of Environmental Research and Public Health* 17: 1002. [CrossRef]

Yuan, Chaoqing, Sifeng Liu, and Junlong Wu. 2010a. The relationship among energy prices and energy consumption in China. *Energy Policy* 38: 197–207. [CrossRef]

Yuan, Chaoqing, Sifeng Liu, and Naiming Xie. 2010b. The impact on Chinese economic growth and energy consumption of the Global Financial Crisis: An input-output analysis. *Energy* 35: 1805–12. [CrossRef]

Zhang, Yanfang, Rui Nie, Ruyi Shi, and Ming Zhang. 2018. Measuring the capacity utilization of the coal sector and its decoupling with economic growth in China's supply-side reform. *Resources, Conservation and Recycling* 129: 314–325. [CrossRef]