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CONTENT

CORRELATION AMONG OIL PRICE, STOCK RETURNS AND COUNTRY RISKS: AN EMPIRICAL ANALYSIS BASED ON 31 COUNTRIES

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ABSTRACT: Existing studies have purely paid attention to the relationship between oil price and stock returns or the relationship between oil price and country risks; however, simultaneous correlations among the three are highly neglected. Using monthly panel data from 31 countries between 2000 and 2020, we simultaneously examine the correlations among oil prices, country risks, and stock returns. By adopting a panel vector autoregressive model (PVAR), our research finds that a positive shock to oil prices and stock returns reduces country economic risks. A positive shock to country risks (risk reduction) reduces oil prices and stock returns. In addition, the oil price has a positive impact on stock return in the short term and a negative effect in the long term. The stock return is also positively related to the

oil prices. Our study contributes to understanding the correlation among the country risks, financial and oil markets.

Keywords: oil Price, country economic risk, stock Return, PVAR model

1. INTRODUCTION

The relationship between stock and oil markets is of great interest to academics and practitioners owing to its important implications for asset allocation, policymaking, and risk management; However, the findings are inconsistent due to the heterogeneity of all countries. (Kang & Ratti 2013; You et al., 2017; Fang, 2018; Kilian & Park, 2009; Huang et al., 2017; Liu et al., 2019). The controversial finding may be due to the neglection on country risks as a simultaneous interactive role within the mechanism.

It is widely acknowledged that a country's political, economic, and financial may bring risks that could be transmitted to the stock market and affect changes in the supply and demand of the oil market (Sari et al.,2013;Mensi et al., 2017). As a result, there are complex interactions among the three of them.As shown in figure 1, the country risks of the world have experienced a fluctuation evolvement during these recent 20 years (ICRG, 2021, https://www.prsgroup.com/). At the beginning of the 21st century, the risks of various countries showed a downward trend. The 2003 Iraq war and the 2008 economic crisis caused a significant drop in the risk scores of various countries. In the post-financial crisis period, due to de-globalization, the country risks of various countries showed a fluctuating trend. The impact of the new crown epidemic in 2020 has caused the risk scores of countries to drop to the bottom. The increasing of country risks may inevitably affect the global financial markets, which leads to subsequent fluctuation of global oil prices and stock prices of many nations. Some documents have noticed the impact of the COVID-19 shock on the stock and crude oil markets (Ashraf, 2020; Sharif, 2020; Rout, 2020), but they are mainly concerned about the changes in the stock and oil markets before and after the impact of the COVID-19. Our research intends to explore the systemic relationship between oil prices, country risk, and stock returns. This can provide us with some insights into the impact of the new crown epidemic on oil prices and the stock market. There are already some literatures on the relationship between country risk and oil prices (Abdel-Latif & El-Gamal, 2020; Lee et al., 2017; Liu et al., 2016), country risk and stock market(Mensi et al., 2016; Suleman et al., 2017; Hoque et al., 2020).

However, there is missing literature taking consideration on simultaneous linkages between the oil market, stock market and systematic measurement of country risks.

Though a single-country research context is helpful to identify the specific links among variables, a multi-country context can examine the effects more systematically (Liu et al., 2019). Therefore, this paper links oil prices and stock markets with the country's risk using a panel vector autoregression with data across 31 countries and regions.

Figure 1 Global Average National risk change

Note: The average value of risk in countries around the world was calculated. The higher the risk score, the lower the risk. Data were obtained from the ICRG.

2. LITERATURE REVIEW

2.1. Oil prices and stock price

There are three main perspectives regarding the relationship between oil prices and stocks. On the one hand, it is put forward that there is a negative correlation between oil prices and the stock market (Ceylan et al., 2020; Cunado & Gracia, 2014; Singhal et al., 2019; Diaz, 2021; Diaz et al., 2016; Raza et al., 2016). For instance, it is argued that oil is an essential means of production for enterprises. Therefore, rising oil prices may increase production costs, reducing expected cash flow, thereby lowering stock prices (Ceylan et al., 2020). Diaz (2021) and Diaz et al. (2016) find empirical evidence supporting that oil price volatility is negatively related to the return of stocks with data from the United States and the G7 economies. Raza et al. (2016) adopted a nonlinear ARDL method and found that oil price fluctuations harm the stock returns from emerging economies in both the short-term and long term.

On the other hand, it is also put forward that the oil price is negatively related to the stock price. Changes in global aggregate demand will affect stock prices and oil prices. Ni et al. (2020) found that when oil prices rise by more than 10%, investors may profit from trading stocks because such increases may be considered as a positive signal to the market. Cheema and Scrimgeour (2019) studied the relationship between China's oil prices and stock market abnormalities. It is also found that the increase in oil prices is interpreted by investors as a positive signal, especially when the increase in oil prices is related to an increase in oil demand. Dagher & El Hariri (2013) studied the dynamic interaction between the daily Brent spot price and the Lebanese stock price within the vector autoregression framework and found evidence that the oil price caused the stock price to rise.

In addition, it is further argued that the relationship between oil prices and stock prices changes dynamically with time evolvement. In other words, this relationship may be asymmetric, whether oil prices are high or low, and the impact of rising or falling oil prices on stock prices is different (Ceylan et al., 2020). Nusair and Al-Khasawneh (2018) used panel quantile regression to study the impact of oil price shocks on Gulf Cooperation Council countries. The results show that the positive relationship exists only when the stock market is in the middle and high quantile, while the negtive relativeness exists in the low and middle quantile. By adopting the same method, Chang et al. (2020) found that when the oil market is in a bullish (bearish) status, the DJ Islamic Index is in a bearish (bullish) condition. However, when both markets are in a bullish or bearish state, this effect becomes positive. Ceylan et al. (2020) used 2000M1-2017M3 data from developing countries (Brazil, Russia, India, South Africa, South Korea, Turkey, and Mexico) and the time-varying panel smooth transition vector error correction (TV-PSTRVEC) model to study the relationship between international oil prices with stock prices. The results show that the short-term and long-term causality between oil prices and stock prices is time-dependent. Moreover, oil prices will cause stock prices to rise in the long run. However, in the short term, there is a neutral effect between oil prices and stock prices.

It could be concluded that though many studies have investigated the relationship between oil and the stock market, there is no clear consensus on the form and strength of this relationship. In particular, few systematic studies use panel data from many countries to analyze the relationship between oil prices and stock prices.

2.2. Oil price and country risk

Some studies find that the oil price fluctuations are related to national risks, especially political risks. By analyzing the impacts of Chinese oil imports on international oil prices, Wu and Zhang (2014) found that unexplained oil price fluctuations may be related to geopolitical events. It is found that geopolitical risks led to oil price increases (Abdel-Latif & El-Gamal, 2020). Chen et al. (2016) found that the contribution rate of OPEC political risk to oil price fluctuations during the sample period was 17.58%, which was only lower than the contribution rate of oil demand shocks.

On the other hand, some studies believe that oil price shocks cause changes in national risks. By following the concept of the study by Bouchet et al. (2003), Liu et al. (2016) put forward that macroeconomic uncertainty is the primary manifestation of country risk. Lee et al. (2017) used the structural vector autoregressive method to study the impact of oil price shocks on national risks. He found that different oil price shocks have other implications for national risks of oil-importing countries and oil-exporting ones and have different sub-risk types.

2.3. Country risk and stocks

The correlations between the country risks and stock markets have also been examined. Sari et al. (2013) used the ARDL method to study the long-term and short-term relationships between the Turkish stock market trend and the country's risk rating's political, financial, and economic risk. Economic, financial, and political risk scores are all driving variables of stock market trends in the long run. However, in the short term, only political and economic risks show impacts on market trends. Mensi et al. (2016) and Liu et al. (2013) studied the asymmetric relationship between the stock markets of the BRIC countries (Brazil, Russia, India, China, and South Africa) and country risk ratings. This kind of mismatch depends on the direction of the country's risk shock and the specific type of risk. Suleman et al. (2017) used data from 83 developed and developing economies to analyze whether the overall country risk and its components (economic, financial, and political) can predict stock returns and volatility. Finally, Hoque et al. (2020) examined the nonlinear impact of global and country-specific geopolitical risk uncertainty on stock returns in Brazil, India, Indonesia, South Africa, and Turkey. It is found that the global geopolitical risks on the stock market depend on the contemporary time, lag time, volatility regimes, and stock market in all countries except India.

3. RESEARCH METHOD

A PVAR model is adopted for this study. Though the vector autoregressive (VAR) model is also widely used in researches on oil and stock markets (Sims,1980), with the increasing number of variables in the model, the parameters to be estimated also increase exponentially. Therefore, the model parameters can only be effectively estimated when there are sufficient sample observations. Compared with the VAR model, the PVAR model may deal with this issue. The PVAR was first developed by Holtz-Eakin et al. (1988). It maintains the advantages of the VAR model proposed by Sims (1980). According to the reality of interdependence, the current PVAR model does not distinguish between endogenous and exogenous variables. On the contrary, all variables are taken as endogenous variables. The PVAR model can analyze the impact of each variable and its lagged variables on other variables in the model (Zouaoui & Zoghlami, 2020; Salisu et al., 2020). In addition, the advantage of panel data is that more sample observations can be obtained. Using the PVAR model with panel data may effectively solve the problem of individual heterogeneity and fully consider individual and time effects. Therefore, as a combination of panel data and VAR, PVAR has been widely used to analyze related problems.

We consider the general form of the panel vector autoregressive model. We assume that the matrix form of the p-order PVAR model with k variables is

$$Y_{it} = C_i + A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + \cdots + A_p Y_{i,t-p} + \Xi_{it}\ , \mathrm{i} = 1,2,\ldots 17; \mathrm{t} = \mathrm{T_i}$$

Where $Y_{it} = \begin{bmatrix} Y_{1it} \\ Y_{2it} \\ \cdots \\ Y_{kit} \end{bmatrix}, C_i = \begin{bmatrix} C_{1i} \\ C_{2i} \\ \cdots \\ C_{ki} \end{bmatrix}, \Xi_{it} = \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \cdots \\ \varepsilon_{kit} \end{bmatrix}, A_p = \begin{bmatrix} A_{11}^p & \cdots & A_{1k}^p \\ \vdots & \ddots & \vdots \\ A_{k1}^p & \cdots & A_{kk}^p \end{bmatrix}$

Where Y_{it} represents the column vector of k study variables, The C_i represents the individual fixed effect, Ξ_{it} is the residual term, A_p is the to-estimated coefficient of the p-order lag terms. Finally, i represents the individual, and Ti represents the time. It is worth noting that this model allows each individual to have a different length of time. The data in this article is precisely the unbalanced panel data, which we will further explain in the following data. Compared with the VAR model with k-variable and p-order lags that need to estimate k*p+1 coefficients, the k-variable p-order lag PVAR model needs to estimate the k*p+k coefficients. Although a small number of generation estimation coefficients have been added, our data volume has increased several times, which make our estimation more reliable.

4. DATA

Oil price. We use the oil price multiplied by the exchange rate of each country as the actual international oil price faced by the government (Antonietti & Fontini, 2019). We use Brent oil price as our benchmark analysis and WTI oil price for robustness analysis. The monthly oil price data is obtained from EIA (https://www.eia.gov). The exchange rate is calculated based on the monthly average price, and the unit is the national currency/USD. The monthly price of the exchange rate comes from the CEIC database.

Country risk level. The data of country risks is obtained from ICRG, which has been most widely used (Mensi et al., 2016; Suleman et al., 2017). ICRG publishes the country risk level scores of nearly 140 countries surveyed by the agency once a month, including sub-indicators of country risk level: political risk level, economic risk level, and financial risk level scores. ICRG measures of country risk level based on the starting point of factors affecting country risk. The total score is 100 points; the higher the score, the lower the country's risk. ICRG divides the country risk level score and the degree of country risk. A score of 0-49.9 points indicates a high country risk, 50-59.9 points indicates a high country risk, and 60-69.9 points suggests that the country risk is moderate. A score of 70-79.9 points suggests that the country risk is low, and a score of 80-100 points indicates that the country risk is very low.

Stock market index. We selected stock market indexes of 31 countries (regions) for analysis. The data of these indexes is obtained from the CSMAR database, which is a widely used database. We choose the most widely used stock index for data on more than one stock index in a country. For China, we choose Shanghai Composite Index instead of the Shanghai 180 Index or others. Table 1 shows the countries (regions) of the 31 stock markets included in our sample, the specific names of the indexes, and the sample period. The data for Sweden, Israel, Norway, Italy, New Zealand, Belgium, and Saudi Arabia do not start from 2000m1. This means that our data is unbalanced panel data. But we mentioned in the research method that the PVAR model does not require our data to be a balanced panel. It allows each sample individual to have a different time period.

Table 1 31 countries (regions) stock index information

region	Index	period
Argentina	Argentina MERV Index	
Austria	Austrian ATX Index	
Australia	Australian Common Stock Index	
Brazil	Sao Paulo IBOVESPA Index	
Germany	Frankfurt DAX Index	
Russia	Russia RTS Index	
France	France Paris CAC40 Index	
Philippines	Philippines Manila Composite Index	
South Korea	Korea Composite Index	
Netherlands	Netherlands AEX Index	2000m1-2020m8
Canada	Toronto Stock Exchange Composite Index	
Malaysia	Malaysia Kuala Lumpur Index	
United States	New York Stock Exchange Composite Index	
Mexico	Mexico MXX Index	
Japan	Tokyo Nikkei 225 Index	
Switzerland	Zurich Market Index	
Spain	Madrid SMSI Index	
Singapore	Singapore Straits Index	
India	Mumbai, India Sensex30 Index	
Indonesia	Indonesia Jakarta Composite Index	

U.K	London Financial Times 100 Index	
China	Shanghai Composite Index	
Taiwan, China	Taiwan Weighted Index	
Hong Kong，China	Hang Seng Index	
Sweden	Sweden OMXSPI Index	2001m1-2020m8
Israel	Israel TA-100 Index	2001m1-2020m8
Norway	Norway OSEAX Index	2001m2-2020m8
Italy	Italy MIB Index	2003m11-2020m8
new Zealand	New Zealand Stock Market NZ50 Index	2004m4-2020m8
Belgium	Belgium BFX Index	2005m2-2020m8
Saudi Arabia	Saudi Arabia TASI Composite Index	2010m5-2020m8

Regarding selecting sample intervals and sample countries, we follow several rules—first, the observation period from January 2000 to August 2020. Regarding the choice of sample countries, though most countries have their own stock markets, most countries have relatively small stock markets, so we select the main trading indexes for analysis. The Cathay Pacific database has been widely used. The major international trading indexes in the database include 50 indexes from 31 countries, so we set the sample to these 31 countries. Finally, we take the logarithm of all variables and perform first-order differences to start our analysis (Salisu et al., 2020). Table 2 shows the descriptive statistics of the variables. Table 2 shows that the oil prices are characterized with the highest volatility, followed by stocks, with the lowest changes in risk.

Table 2 Descriptive statistics

	(1)	(2)	(3)	(4)	(5)	(8)	(9)
VARIABLES	N	mean	sd	min	max	skewness	kurtosis
stock	7,356	0.00370	0.0539	-0.529	0.479	-0.270	20.58
risk	7,356	-0.000196	0.0104	-0.111	0.120	-0.787	26.17

Oil_bre	7,356	0.00199	0.1056	-0.575	0.528	-1.067	9.445
risk_eco	7,356	-0.000952	0.0281	-0.377	0.452	-2.281	68.71
risk_fin	7,356	0.000099	0.0216	-0.498	0.375	-0.886	75.47
risk_pol	7,356	0.0000052	0.0106	-0.0839	0.172	1.770	29.79

5. RESULTS

5.1. Main results

The PVAR analysis in this study mainly includes three steps: first step, sample stationarity test, to test whether the data meets the basic requirements of the research; Second step, by panel moment estimation (GMM), which explains the regression relationship between variables; Third step, shock response diagram, through dynamic The shock response chart observes the reaction of variables to shocks. We use stata15 to estimate.

When the variable is close to the unit root, the GMM estimator is affected by the weak tool problem, which may cause false regression of the model (Abrigo & Love, 2016). Therefore, we must first perform a unit root test on the sample. As we mentioned above, the data in this study is unbalanced panel data, and thus LLC, HT, and Hadri tests in the panel unit root test are no longer applicable here because they all require balanced panel data. Therefore, we use IPS and ADF-fisher test. The two panel unit root inspection methods allow unbalanced panel data. The null hypotheses of the two unit root tests are that the variables are non-stationary. Table 3 shows our test results. The panel unit root tests of all variables reject the null hypothesis at the 1% significance level, which shows that our variables are all stable.

Table 3 Panel Unit root test

VARIABLES	Ips	ADF-Fisher
stock	-55.34***	26.58***

risk	-65.14***	40.07***
oil_price	52.01***	31.01***
Risk_eco	-67.36***	49.21***
Risk_fin	-64.28***	49.69***
Risk_pol	-61.89***	34.05***

Note: ***, **, * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

We select 6-order lag according to the (Bayesian Information Criterion) BIC, and use the GMM method to perform regression. Because there are too many lag orders, we no longer pay attention to the specific regression coefficients of each lag order. Next, we mainly analyze the Granger causality test and impulse response analysis in the panel vector autoregressive results. The first is the panel Granger causality test. The test results are shown in Table 4.

Table 4 The Granger causal test

X is not Y's Granger reason		Chi2	p	Accept or reject
Y	X			
stock	oil	86.13	0.000	Reject
	risk	8.72	0.195	Accept
risk	oil	24.61	0.000	Reject
	sock	51.01	0.000	Reject
oil	risk	15.12	0.017	Reject
	stock	209.27	0.000	Reject

According to the results in Table 4, we can find that all results except RISK-STOCK reject the null hypothesis at the 5% significance level, which indicates that the latter (X) is the Granger cause of the former (Y). Among them, oil price and stocks, oil price and risk are Granger causality with each other, and stock returns are the Granger cause of country risk, but country risk is not the Granger cause of stock returns.

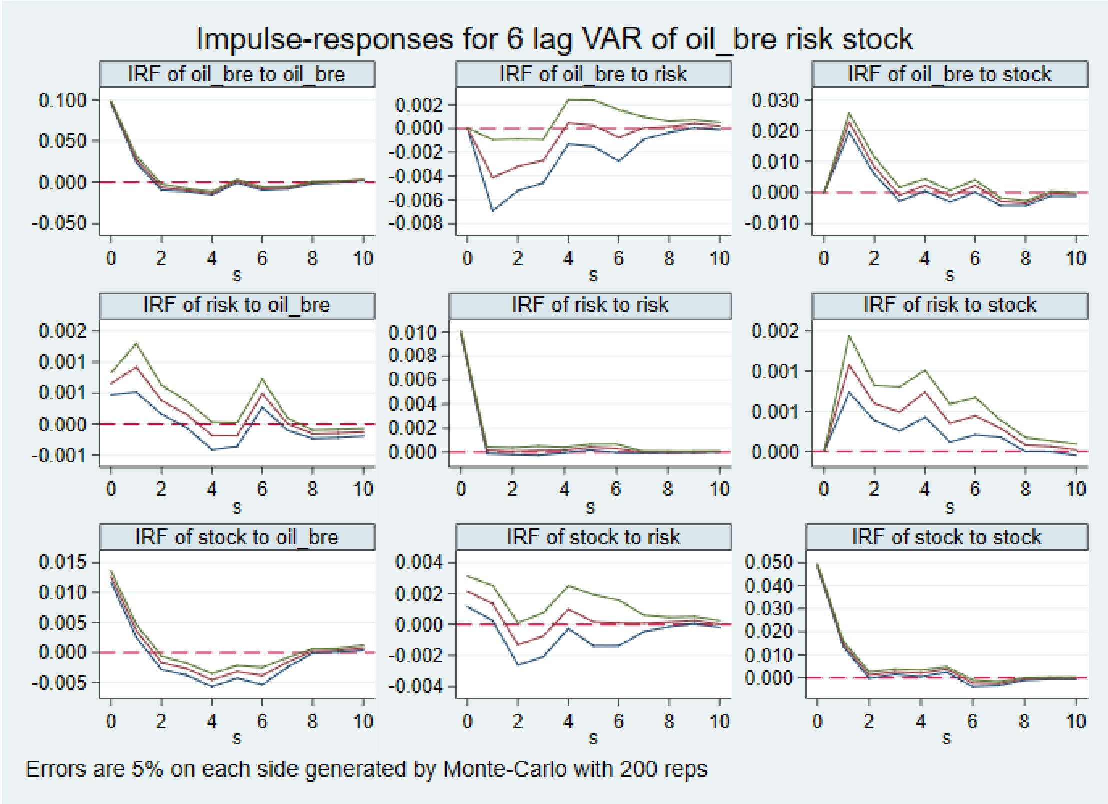

Figure 2 Pulse response plots of oil, risks, and stocks

Next, we observe the impulse response graph. Figure 2 is an impulse response diagram with a lag order of 6 steps. The first column presents the impulse response of country risk levels and stock returns to oil price shocks. It signifies that the shocks of oil prices have led to an increase in the value of risk. This impact reached its peak in the first month, and then the effect gradually became weaker and insignificant after the fourth month. Since the higher the country risk score, the lower the country risk. Therefore it proves that rising oil prices reduce national risks. For oil price shocks, the response of stock was positive in the first month, which indicates that in the short term, rising oil prices will increase stock market returns. However, the stock was significantly negative after the second month, and the impact continued to expand until the ninth month was no longer significant. Thus, the response of stock to oil price shocks is longer than that of country risks, and it is characterized by being positive in the short-term and negative in the long term. This result reflects our first two arguments in the literature on the relationship between oil prices and stocks. First, rising oil prices may be seen as a signal of economic prosperity. Stock return increases in the short term. However, it shows a negative correlation in the long term with increasing oil prices(Ceylan et al., 2020).

The second column shows the impulse response of oil prices and stock to the country's risk shocks. When the country's risk level rises, the cost of oil drops significantly when the risk decreases. This is in line with Abdel-Latif & El-Gamal, (2020) who argued that increased geopolitical risks lead to a drop in oil prices. Lee et al. (2017) found that positive country risk shocks (lower country risks) lead to oil production in oil-exporting countries. The conclusion of the short-term growth of oil prices is consistent with the decline in oil prices. In addition, though we accept that the country risk level is not the Granger cause of stock in the Granger causality test, from the impulse response diagram, the impact of the stock price on the country risk level is still significantly positive in the first period. It signifies that when the country's risk drops, stock returns will rise in the short term, which is consistent with the conclusions by Mensi et al. (2017).

The third column is the response of oil prices and country risk levels to a standardized orthogonal shock to stock. When the stock returns rise, the oil price also increases. It reacesh a peak in the first period, and then begin to decline, and the impact will disappear in the third period. It shows that the boom in the stock market will drive up the price of oil, which is mainly due to the increase in demand for oil, but the duration is relatively short. The response of country risk level to stock return shocks lasts for a long time and continues to be positive, which indicates that the rise of stock returns is beneficial to reducing country risk.

5.2. Sub-dimensions of country risk

We further analyze the three sub-dimensions of country risk-financial risk, economic risk, and political risk. For the sake of comparison, we use 6-order lags for all models.

Table 5 shows the Granger causality test results of the three risks and stocks and oil prices. Figures 3, 4, and 5 show the impulse response of the three sub-risks and oil prices and stock index. Based on comprehensive analysis, we found that economic risk has the most potent response to oil price shocks among the three risks. The impulse response graph is consistent with the response trend of total risk to oil price shocks. The impact degree is greater than the total risk. Financial risk is second, which shows is no longer significant after the fourth period. The political risks are almost unaffected.

For the positive shocks of the three risks, changes in oil prices have different performances. Concerning the shock of economic risks, oil prices are showing a downward trend relatively quickly. The oil price is manifested in volatility-shaped changes with the financial and political risks shocks. In addition, the three sub-risks all accept the assumption that the risk is not the Granger cause of the stock. However, , the response of stock prices on financial risk shock is still significant, while the response to the other two risk shocks is not apparent.

Regarding the positive shock of stocks, although the lag periods for the three risk levels to respond to it are slightly different, overall, the performance of each risk level is positive and consistent with the overall risk performance.

Table 5 The Granger causal test related to three-seed risk

X is not Y's Granger reason		Economic risk		Financial risk		Political risk	
Y	X	p	Accept or reject	p	Accept or reject	p	Accept or reject
Stock	risk	0.196	Accept	0.244	Accept	0.879	Accept
	oil	0.000	Reject	0.000	Reject	0.000	Reject
oil	risk	0.000	Reject	0.012	Reject	0.003	Reject
	stock	0.000	Reject	0.000	Reject	0.000	Reject
risk	oil	0.001	Reject	0.112	Accept	0.374	Accept
	stock	0.000	Reject	0.000	Reject	0.004	Reject

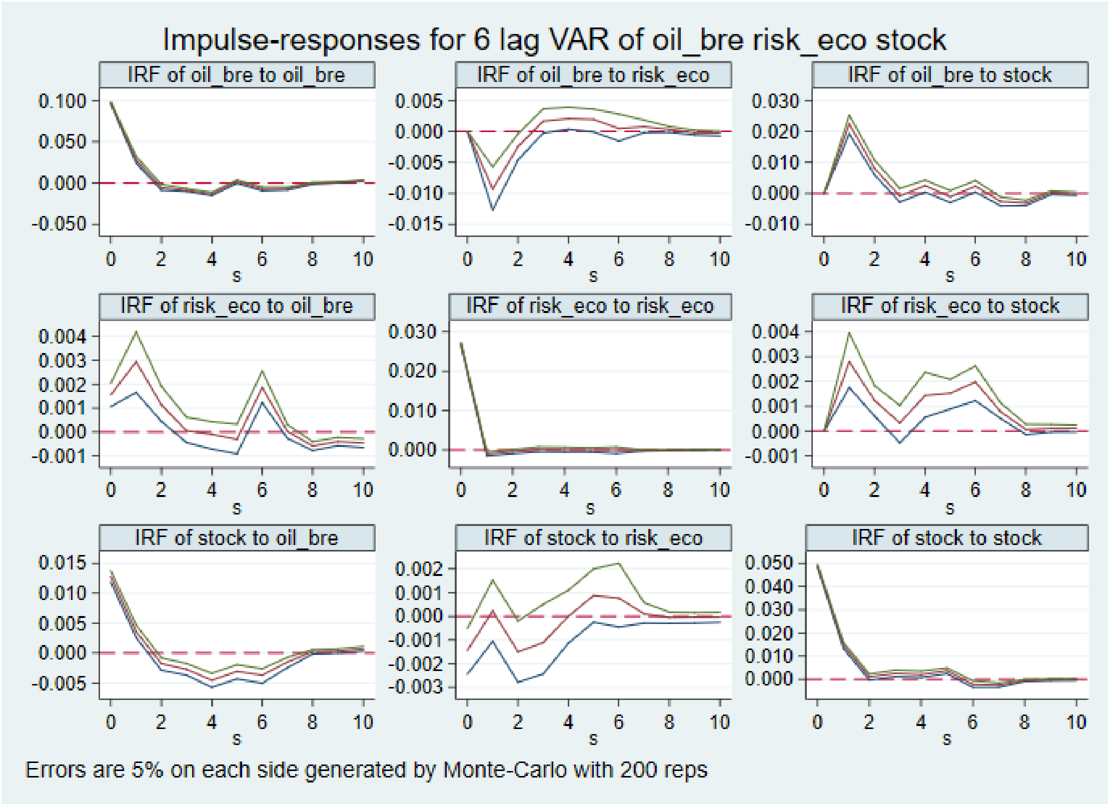

Figure 3 Pulse response plots of oil prices, economic risks, and stocks

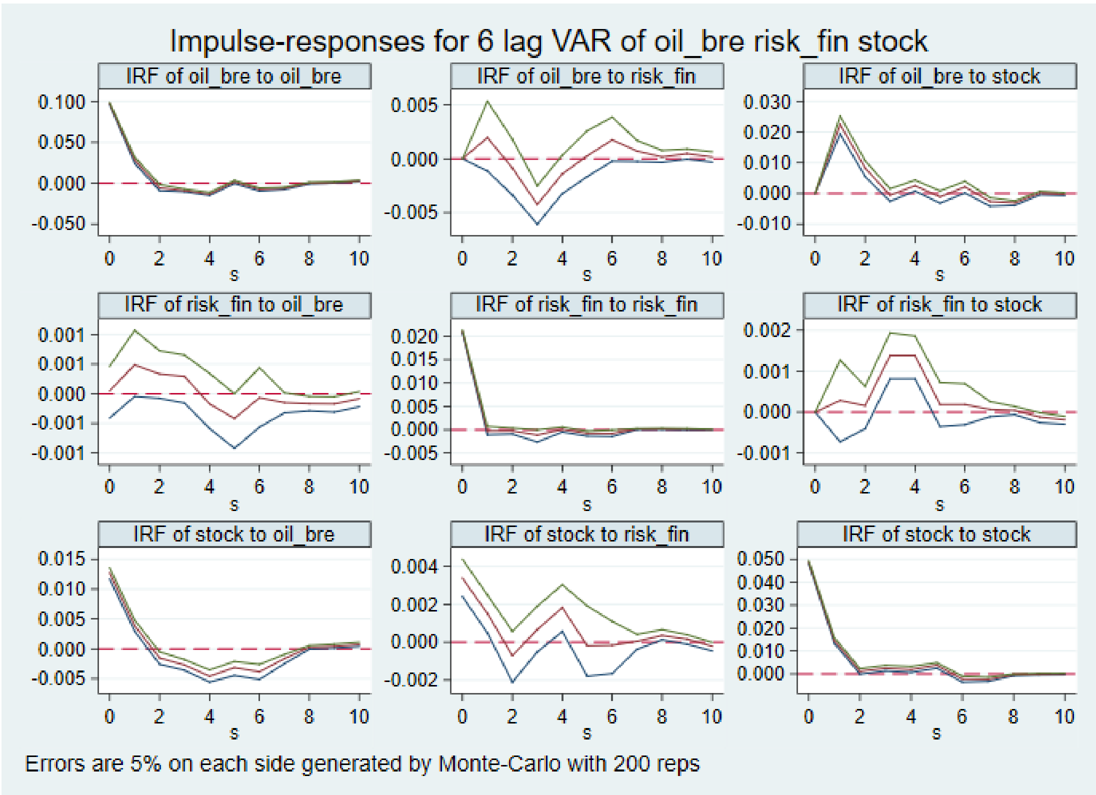

Figure 4 Pulse response plots of oil prices, financial risks, and stocks

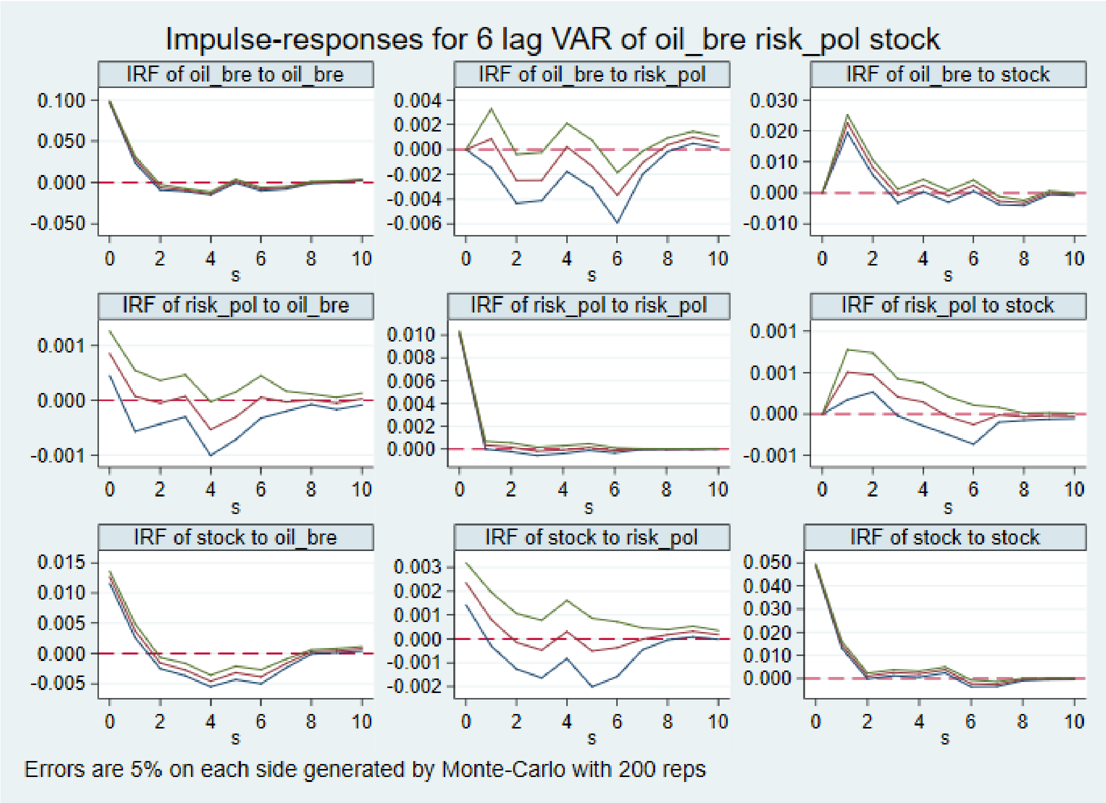

Figure 5 Pulse response plots of oil prices, financial risks, and stocks

5.3. Robustness check and additional tests

We used Brent oil prices in our basic regression. Here, we use WTI oil prices for analysis. The results are presented in the appendix. The results are consistent with the original measurements.

We further analyze the similarities and differences between developed and developing countries. We divide 31 countries into developed countries and developing countries according to the IMF classification standards, of which 21 are developed countries, with ten of which are developing countries. We found that stocks in developed countries have a more pronounced response to risk shocks than stocks in developing countries. When the risk decreases, the return on developing country stocks only shows a positive effect in the first period and is no longer significant. However, the positive impact of developed country stock returns in the first period is not substantial but decrease in the second to third periods. In addition, the risk in developed countries is significantly reduced when oil price shocks, while developing countries are not.

6. CONCLUSION

This paper investigates the relationship between oil prices, country risks, and stock market returns. It uses a PVAR model analyzing monthly unbalanced panel data from 2000 to 2020 in 31 countries. We find that the impact of oil price shocks on the stock market index is positive in the short-term while negative in the long term. Oil price shocks and stock shocks also cause a reduction in country risk. The response of developed countries and developing countries differ in different response levels and response time lags. The country risks are found negatively related to the oil prices. The stock returns in developing countries temporarily increase while delines in developed countries. We further analyzed the three sub-dimensions of country risk-economic, financial, and political risk and the relationship between oil prices and stocks and reached some interesting conclusions.

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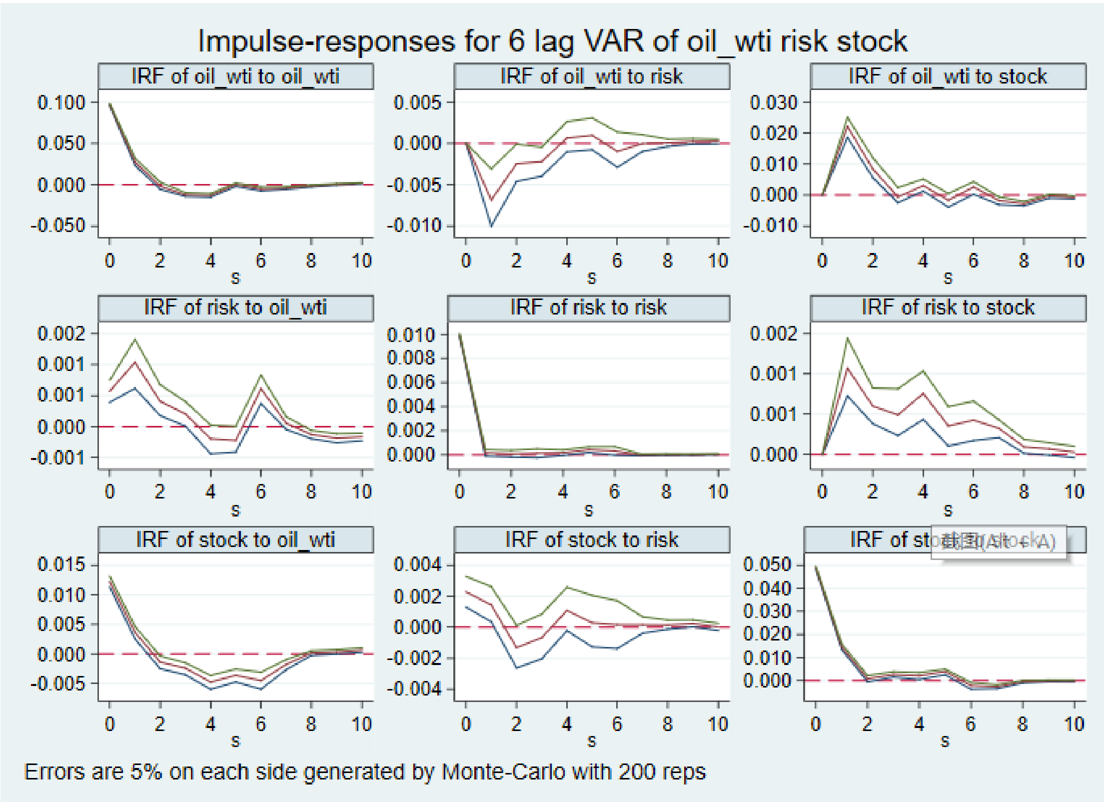
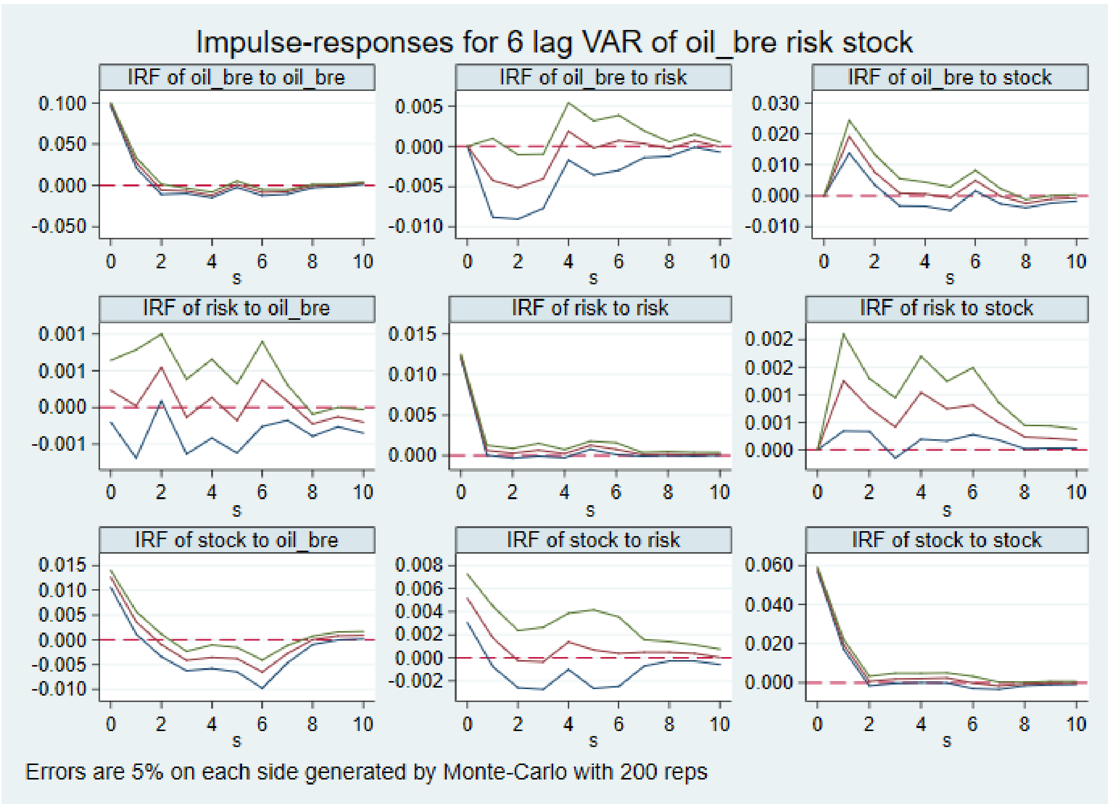
APPENDIX



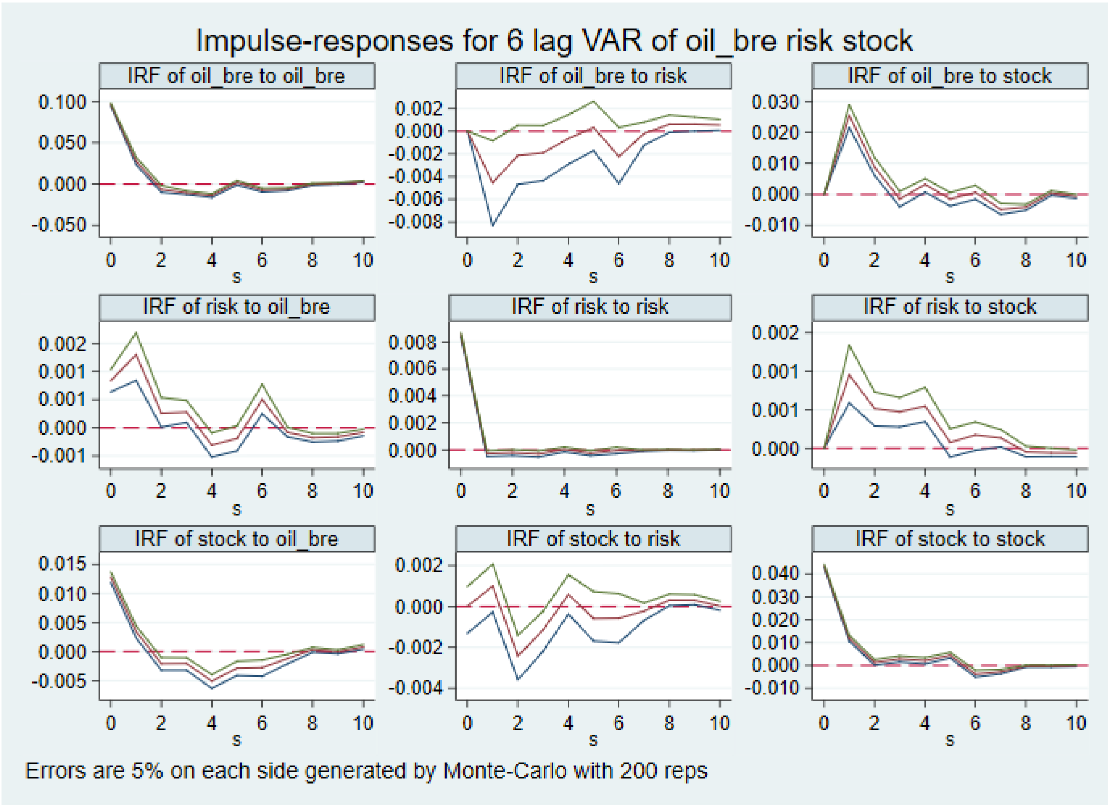
Pulse response plots of WTI oil prices, country risks, and stocks

Granger Causality Test in Developing Countries and Developed Countries

X is not Y's Granger reason		Developing Countries		Developed Countries	
Y	X	p	Accept or reject	p	Accept or reject
Stock	risk	0.994	Accept	0.001	Reject
	oil	0.000	Reject	0.000	Reject
oil	risk	0.053	Reject	0.321	Accept
	Stock	0.000	Reject	0.000	Reject
risk	oil	0.508	Accept	0.000	Reject
	stock	0.003	Reject	0.000	Reject



Impulse response in developing countries



Impulse response in Developed countries

ESTIMATING TIME-VARYING VOLATILITY SPILLOVERS BETWEEN REAL EXCHANGE RATE AND REAL COMMODITY PRICES FOR EMERGING MARKET ECONOMIES

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Abstract: In this study, real effective exchange rates and real commodity prices volatility transmission are investigated for Mexico, Indonesia and Turkey. According to the results, there is a bidirectional causality relationship between precious metals and the real exchange rate. However, this relationship varies over time. Especially in times of crisis such as the Covid pandemic, the transfer of volatility disappears. Precious metals have a safe haven feature against the exchange rate. However, the reverse is not true. On the other hand, during the Covid period, the bilateral risk transfer between crude oil and exchange rate disappears. This situation has the bilateral safe haven feature of crude oil and exchange rate during the Covid period. Only for Indonesia, risk transfer from oil to exchange rate continues.
Keywords: Time-Varying Volatility Spillover, Real Exchange Rate, Real Commodity Prices, Emerging Market Economies.

1. Introduction

The importance of derivative instruments in risk management is increasing for policy makers and investors with the increasing global risks. The effect of derivative instruments on market prices, the development of derivative instruments and the increase in the financialization of commodities also trigger this situation.

Especially since primary goods such as energy, minerals and agricultural products cover the export yields of approximately one third of the countries in the world, changes in global commodity prices significantly affect the terms of trade shocks of these countries and the fluctuations in the values of their currencies (Yip et al., 2017).

The literature explains the relationship between commodity prices and exchange rates in line with two views. The first view argues that changes in the price of a commodity lead to changes in the exchange rate. According to this view, commodity prices determine the exchange rate movements. According to the second view, exchange rates are explained as an important variable that determines economic fundamentals, including commodity prices (Zhang et al., 2016). In line with the first view, Chen and Rogoff (2003) and Cashin et al. (2004), the concept of "commodity currency" was introduced. Real exchange rate changes in commodity exporting countries result from fluctuations in the relative prices of the goods they export (the terms of trade). The currencies of such countries are called "commodity currencies" (Carpantier, 2020). The "commodity currency" literature shows strong and robust real exchange rate response to global commodity price fluctuations (Chen and Lee, 2018). This concept is used to express that the real exchange rate of commodity exporting countries is determined by world commodity prices (Souza et al. 2020). The second view states that changes in exchange rates cause changes in commodity prices (Zhang et al., 2016). Accordingly, in their study, Belasen and Demirer (2019) presented evidence that there are significant risk transfers from exchange rates to commodity markets. Zhang et al. (2016), on the other hand, proved that there is a bidirectional causality relationship between commodity prices and exchange rates. This indicates that the commodity and foreign exchange markets are informative about each other's return dynamics (Belasen and Demirer, 2019).

The transfer of volatility between commodity prices and exchange rates is important in understanding the risk spillover effects arising from commodity and foreign exchange markets. In this respect, examining the volatility spillover effect is of great importance in understanding how risk spillover occurs between different markets. In addition, policy makers and regulators should consider the significant volatility spillover effects in financial markets in policy making, as volatility spillover has a contagious effect between financial markets and has devastating effects on financial markets in times of financial crisis (Çevik et al. 2021). From this point of view, a comparative analysis of the volatility spillover between commodity and foreign exchange markets of emerging economies such as Mexica, Indonesia and Turkey has been made. A time-varying causality test proposed by Cheung and Ng (1996) and developed by Hong (2001) to investigate the effects of volatility spillovers between real commodity prices (precious metals-gold, silver, platinum, palladium- and crude oil) and the real effective exchange rate. used. Thus, it can be analyzed whether the volatility spillover effect among the variables changes during recession and financial crisis periods.

In this study, a comparative analysis of the volatility spillover between commodity and foreign exchange markets was made for emerging market economies Mexico, Indonesia and Turkey. For this, the volatility spillover between real commodity prices (precious metals-gold, silver, platinum, palladium- and crude oil) and the real effective exchange rate is discussed by using the time-varying variance causality test developed by Lu et.al. (2014).

Among emerging market economies, Mexico, Indonesia and Turkey are countries that have the chance to benefit from high current account deficits and large markets in their immediate surroundings to reach the funds needed for growth. Since Indonesia is close to China, Turkey to the European Union and Mexico to the United States of America, it provides great benefits to these countries (Asongu et al., 2018). In addition, in terms of countries' imports and exports of commodities, for example, Mexico, which is an emerging economy, is heavily dependent on oil and petroleum-related products. The largest trading partner is the United States. This bilateral trade is largely due to Mexico's sale of crude oil to the United States and imports of refined petroleum products from the United States. In addition, Mexico is among the top 10 gold miners in the world, and gold is among the top 5 commodities exported by Mexico (Singhal et al., 2019). Turkey is an important oil importer and gold consumer. Although Turkey is the world's 16th leading oil importer, it is the world's fourth largest gold consumer, accounting for approximately 6% of global consumer demand (Akkoç and Civcir, 2019). Indonesia, on the other hand, has abundant energy production capacity and oil resources (Sinaga et al., 2019).

The contribution of the study to the literature is that it first deals with the relationship between real exchange rates and commodity prices for emerging economies in a time-varying structure. The relations between the related variables may vary depending on many variables such as the global conjuncture, the stability of national economies, external and internal shocks and crises. In this context, considering the causality relationship in a structure that changes according to time will enable a better understanding of the causality relationship between real exchange rates and commodity prices. The second contribution is the consideration of volatility based on returns in the study. In times of increased national and global risks, the spread of real exchange rate risk and commodity price risk is an important parameter for policy makers and investors to consider. In this context, our study deals with the volatility spillover in real exchange rates and commodity prices.

2. Data

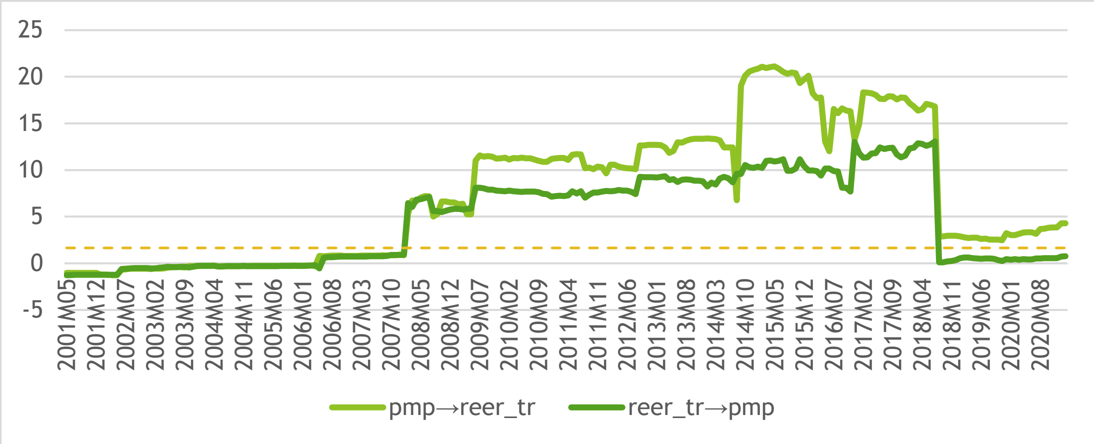
In the study, monthly data covering the 28-year period from January 1993 to February 2021 were used for the sample of Mexico, Indonesia and Turkey. Data on commodity prices were obtained from the IMF Primary Commodity Prices Database. Nominal commodity prices taken from the IMF Primary Commodity Prices database have been converted into real terms with the US CPI.

3. Findings

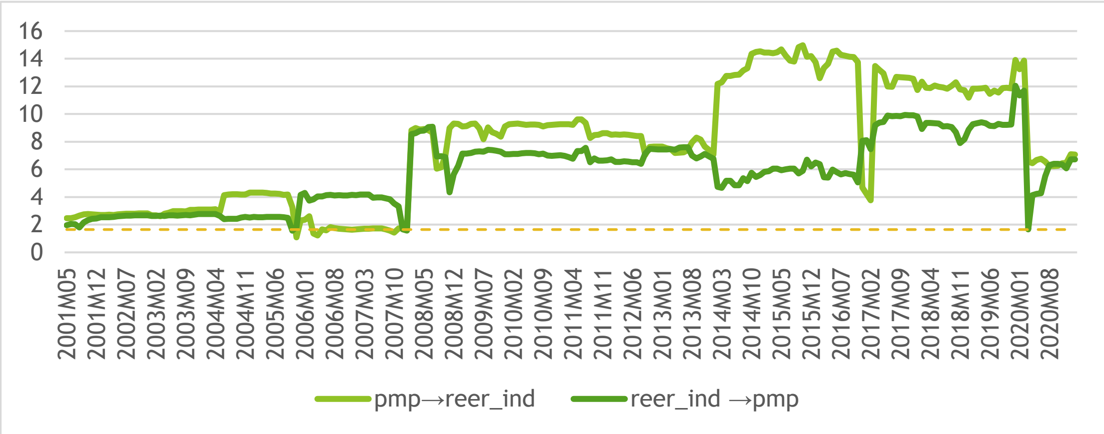
The data set of this study covers the period 1993:M1-2021:M2.

Figure 1 shows the time-varying causality relationships between the precious metal and the exchange rate returns of Mexico, Indonesia, and Turkey.

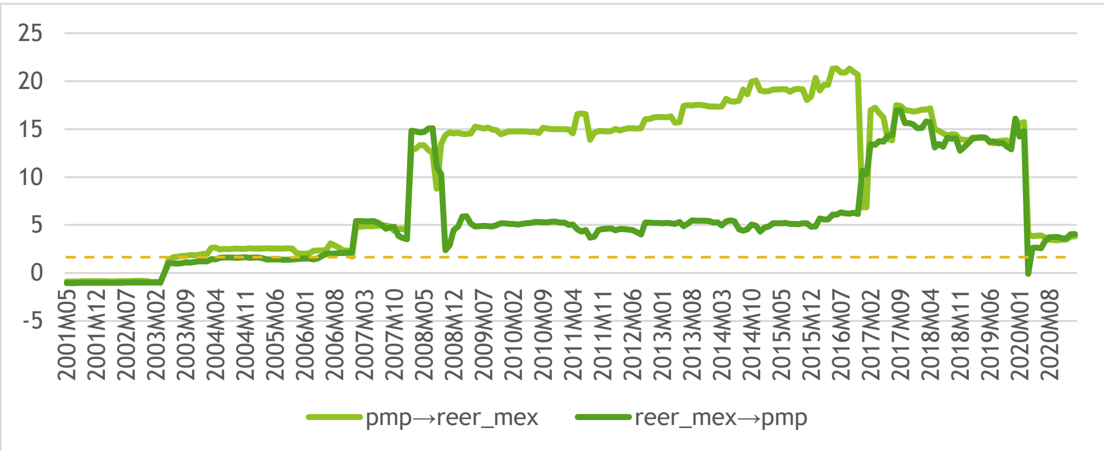
Figure 1: Real Precious Metal Prices and Real Effective Exchange Rate



(a) Turkey



(b) Indonesia



(c) Mexico

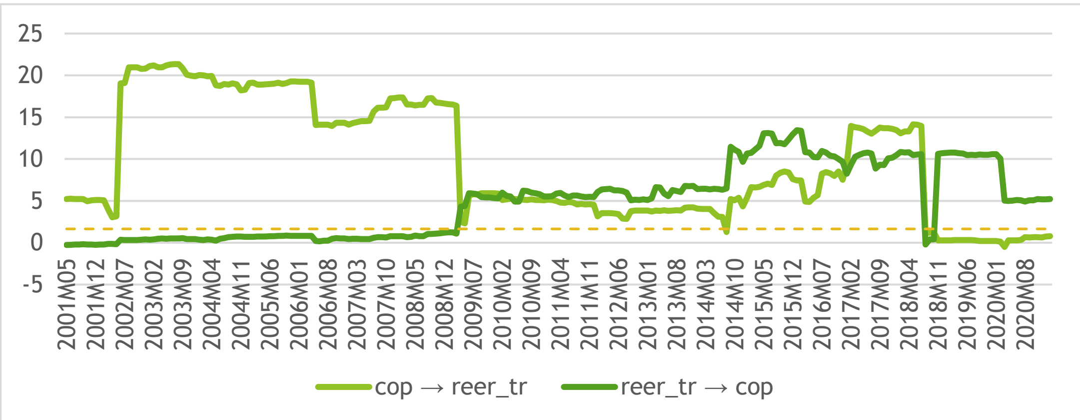
Note: The dashed line shows the critical value at the 5% level (1.65). → refers to the direction of the causality relationship.

In panel (a), it is seen that while there is no causality relationship in the variance between the precious metal and the real effective exchange rate until the second month of 2008, bilateral causality in the variance emerged as of this date. This indicates that there is a risk transfer between the precious metal and the exchange rate after the 2007-2008 global financial crisis. Therefore, the risks that emerged in precious metals and exchange rates with the global crisis cause a risk transfer between the two variables. However, while the causality relationship from exchange rate to precious metal existed until the eighth month of 2018, it is seen that the relationship disappeared as of this date. There was a serious depreciation in the Turkish Lira in May and August 2018. This situation led to an increase in import costs and thus a serious increase in inflation rates. The financial turbulence that emerged in this period in Turkey, on the other hand, precious metals safe haven feature.

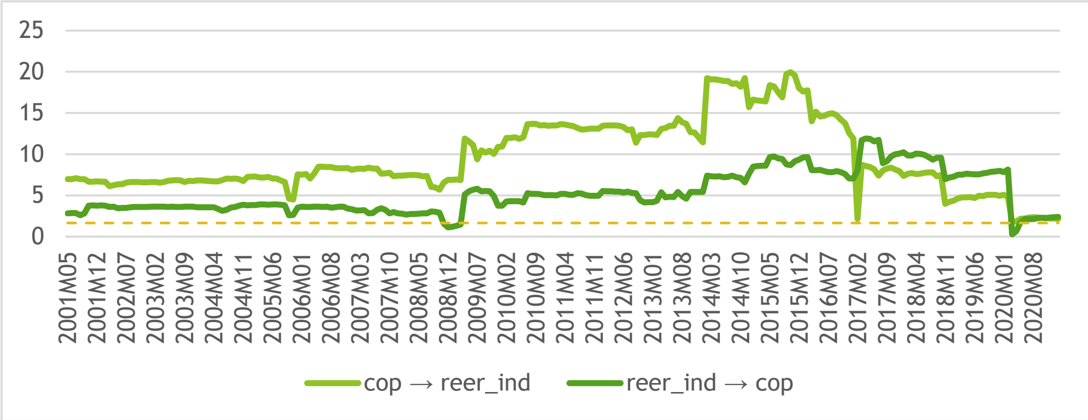
In panel (b), there is a causal relationship from precious metal to real exchange rate for most of the period. It is seen that the causality relationship has changed since the 11th month of 2005 and the 9th month of 2007, and that the relationship does not exist from these dates. There is a causal relationship from real exchange rate to precious metal until the 10th month of 2005. After this date, it is seen that there is no causal relationship. Also, it is seen that the relationship emerged in the 12th month of 2007. This shows that risk spillover has emerged with the effect of the global financial crisis. In the third month of 2020, the relationship has disappeared. This shows that, unlike the global financial crisis of the Covid pandemic, precious metals have a safe haven feature for Indonesia.

In panel (c), the causality relationship from precious metal to exchange rate in Mexico did not exist until the seventh month of 2003, but emerged from this month. While the causality relationship from the exchange rate to the precious metal did not exist until the fifth month of 2006, it is determined that there is a causal relationship in the variance as of the fifth month. In addition, the causality relationship from the exchange rate to the precious metal is observed until the third month of 2020, and the relationship has disappeared since this date. This effect shows that the effect of the Covid-19 health crisis, even if it is short-lived, causes the risk transfer between the variables to disappear.

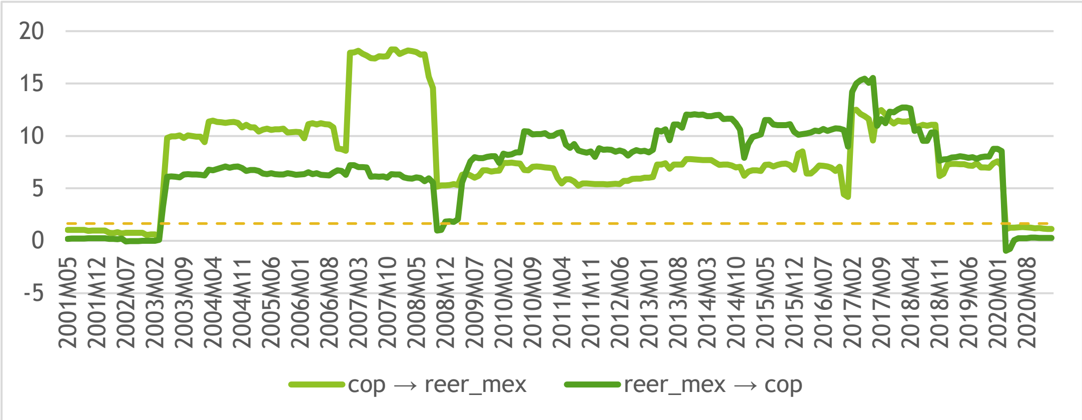
Figure 2: Real Crude Oil Prices and Real Effective Exchange Rate



(d) Turkey



(e) Indonesia



(f) Mexico

Note: The dashed line shows the critical value at the 5%. → refers to the direction of the causality relationship.

Figure 2 shows the time-varying causality relationships between crude oil and exchange rate returns for Mexico, Indonesi and Turkey. Panel (d) shows that while the causality relationship from exchange rate to crude oil did not exist until the fourth month of 2009 in Turkey, there is a causality relationship since then. Therefore, it can be stated that there is a risk transfer between crude oil and the exchange rate for the Turkish economy in the post global financial crisis period. The causality from the exchange rate to crude oil has disappeared from the 8th month of 2018. In other words, crude oil as a conjuncture tool against the exchange rate has the safe haven feature. On the other hand, causality relationship from crude oil to exchange rate has disappeared since the 8th month of 2014 and the 8th month of 2018. With the effect of the financial turbulence experienced in 2018, the risk transfer between the exchange rate and oil in the financial markets is eliminated.

In panel (e), there is a risk transfer for entire period from crude oil to exchange rate in Indonesia. It is observed that the causality relationship from real exchange rate to crude oil disappeared in the 11th month of 2008 and the 3rd month of 2020. This shows that after the global financial crisis and the Covid-19 health crisis, the risk transfer from the exchange rate to crude oil has disappeared in Indonesia.

In panel (f), there is a causal relationship between crude oil and exchange rate in Mexico since the fourth month of 2003. This relationship disappears as of the 3rd month of 2020 with the Covid health crisis. The causality relationship from exchange rate to crude oil has been present since the 4th month of 2003. This relationship disappears in 2008, when the global financial crisis emerged, and after 2020, when the effects of the Covid health crisis were clearly felt.

Conclusion

With the increasing financialization of commodities, the demand for these derivatives has increased especially in times of crisis. In this context, it is important to understand the risk transfer between financial markets or alternative investment instruments. In this study, the volatility spillover between commodity and foreign exchange markets of emerging economies such as Mexico, Indonesia and Turkey is discussed using a time-varying causality test.

According to the results, it is seen that the 2007-2008 global financial crisis and the Covid-19 health crisis are effective in examining the volatility spillover between commodity returns and real effective exchange rate returns. It is seen that the volatility spillover is bidirectional between the precious metal and oil prices with the real effective exchange rates of Mexico, Indonesia and Turkey. However, this transmission varies with time in the analysis period. There is a risk transfer between the precious metal and the exchange rate after the 2007-2008 global financial crisis in Turkey. However, while the causality relationship from exchange rate to precious metal existed until the eighth month of 2018, it is seen that the relationship disappeared as of this date.

In Indonesia, there is a causal relationship from precious metal to real exchange rate for most of the period. Especially, it is seen that the relationships emerged in 2007. This shows that risk spillover has emerged with the effect of the global financial crisis. After third month of 2020, the causality relationship from exchange rate to precious metals has disappeared. This shows that, unlike the global financial crisis of the Covid pandemic, precious metals have a safe haven feature for Indonesia. Similar to Indonesia, the causality relationship continues steadily after the global financial crisis in Mexico. In addition, the causality relationship from the exchange rate to the precious metal is observed until the third month of 2020, and the relationship has disappeared since this date. This effect shows that the effect of the Covid-19 health crisis, even if it is short-lived, causes the risk transfer between the variables to disappear.

According to results of the time-varying causality relationships between crude oil and exchange rate, it can be stated that there is a risk transfer between crude oil and the exchange rate for the Turkish economy in the post global financial crisis period. On the other hands, with the effect of the financial turbulence experienced in 2018, the risk transfer between the exchange rate and oil in the financial markets is eliminated. There is a risk transfer for entire period from crude oil to exchange rate in Indonesia. According to results, the causality relationship from real exchange rate to crude oil disappeared after the 2020. This shows that after the global financial crisis and the Covid-19 health crisis, the risk transfer from the exchange rate to crude oil has disappeared in Indonesia. There is a causal relationship between crude oil and exchange rate in Mexico since the fourth month of 2003. This relationship disappears in 2008, when the global financial crisis emerged, and after 2020, when the effects of the Covid health crisis were clearly felt.

According to test results, there is a bidirectional causality relationship between the commodity and foreign exchange market in most of the period. However, this relationship disappears especially in times of crisis. This situation shows that the information transmission in the markets is not strong enough, on the other hand, they provide alternatives to each other for hedging. In this context, it is seen that commodities have an important protection feature against exchange rate risks and the elimination of risk transfer in investment decisions, especially in crisis periods, allows portfolio diversification.

An important point here is that a causal relationship from the exchange rate to precious metals disappeared during the Covid period. In other words, precious metals have a safe haven feature against the exchange rate. However, the reverse is not true. In other words, risk transfer from precious metals to the exchange rate continues. On the other hand, during the Covid period, the bilateral risk transfer between crude oil and exchange rate disappears. This situation has the bilateral safe haven feature of crude oil and exchange rate during the Covid period. Only for Indonesia, risk transfer from oil to exchange rate continues.

Authors' contributions

All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials section

The datasets generated and/or analysed during the current study are available in the IMF Primary Commodity Prices database, Bruegel Datasets and Federal Reserve (FED) database, https://www.imf.org/en/Research/commodity-prices; https://www.bruegel.org/publications/datasets; https://fred.stlouisfed.org .

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THE ROLE OF ENVIRONMENTAL REGULATION OF THE HOME COUNTRY IN ENHANCING INNOVATION PERFORMANCE OF CHINESE EMNES

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ABSTRACT: EMNEs pursuing for innovation performance via internationalization could be affected by the environmental regulation within a global sustainable development context. Building on the institution-based view, we study how external environmental regulations of the home country impact on the innovation performance of EMNE via internationalization. We also examine the moderation roles of OFDI entry mode choice and state ownership

background of the EMNEs in this framework. Using a sample of 2313 FDI activities by Chinese EMNEs during the period of 2000-2018, we find that the environmental regulations of the home country is positively related to the innovation performance of the EMNEs via internationalization. Compared with greenfields, the entry mode of acquisition strengthens the positive relativeness between the environmental regulations and innovation performance of EMNEs. This tendency is more significant in the developed host countries compared with the developing ones. In addition, it is found that compared with state-owned EMNEs, the effects of environmental regulation on the innovation performance are more significant in non-state-owned firms. Our research sheds light in the IB research areas in understanding between the institution and innovation performance of MNEs by identifying unique roles of environmental regulations of the home countries and the state ownership background of the EMNEs during the internationalization process.
Keywords: Environmental regulation; Innovation performance; FDI entry mode; State ownership

1. INTRODUCTION

How does environmental regulation of home country's innovation performance of emerging economy multinational enterprises (EMNEs)? This question is crucial to address as the world is undergoing a global warming challenge that needs to be dealt with by technology innovation. Internationalization plays a vital role in the innovation performance of MNEs, particularly those from emerging economies (Buckley et al., 2017). Previous studies on innovation performance of EMNEs via internationalization affected by institutional factors mainly focus on its economic and political institution (Carney et al., 2019; Wu et al., 2016). However, with the challenges of the global warming issue, environmental concernings have turned to be an essential consideration while balancing the cost and benefits of social development (Brechet and Jouvet, 2008).

Related studies intend to explain this issue from an economic perspective. It is argued that MNEs from developed economies with stricter environmental regulations are featured with advanced technology in pollution treatment and environmental pollution management experience. These technologies and experiences may spill over to foreign countries when MNEs expand abroad, thus positively impacting the environment (Zhang and Zhou, 2016, Mert and Boluk, 2016, Doytch and Uctum, 2016).

Despite advances in economic theory, little consideration has been given to the environmental regulation of the home country on the innovation performance of

EMNEs via internationalization. Several studies have examined the innovation performance differences between different internationalization strategies (Elia et al., 2020). However, it has just been realized that studies like these generally neglected the new emerging fact that the FDI behaviors are also affected by the environmental protection constraints, particularly as global warming has become a new emerging big issue, which inevitably affects the motivation of technology innovation process (Dai et al., 2021).

Based on this, the object of this study is to take Chinese EMNEs from 2000 to 2018 as a sample, with city-level environmental data, to analyze the impact of environmental regulations on the innovation performance of EMNEs via internationalization. We add the environmental regulations into the institution in IB areas, particularly for the innovation performance of EMNEs. Unlike current studies, which are mainly from the view of developed countries, we choose the research context of China as an emerging economy view that explores a unique mechanism on how EMNEs benefit from their home country's environmental regulation while pursuing innovation performance.

2. THEORY AND HYPOTHESIS DEVELOPMENT

The institution plays a vital role as rules of the game, which is the sum of formal systems (such as laws, regulations, and regulations) and informal institutions (such as norms, cultural customs, and ethics) that individuals and organizations follow (North, 1990). Firms need to respond and adapt their behaviors to various institutional constraints; Those who abide by the rules are more likely to survive and prosper(Dacin et al., 2007). Therefore, the system is the decisive factor in the choice of corporate growth strategy(Peng, 2002). As the rule maker, the government plays a crucial role in its MNEs' decision-making process, especially in emerging markets (Pan et al., 2018). For example, recognizing that technological innovation can stimulate productivity growth, emerging market countries such as China regard innovation as one of the country's highest priorities and encourage companies to invest in innovation and development (Chen et al., 2012).

It is still unclear on the impacts of government intervention in firms' innovation (Yan et al., 2018). However, some studies suggest that the government may publish favorable policies such as giving subsidies, executing intellectual property protection to encourage firms on innovation by sharing part of failure cost (Czarnitzki et al., 2011; Czarnitzki and Toole, 2008). However, since emerging market governments may lack sufficient experience, the policies and executions may be less efficient than expected (Peng, 2014). Further, the imperfect legal system in emerging countries may also condone opportunistic practices or manipulation behaviors that cannot promote these firms' innovation performance(Gilliam et al., 2014).

Further, governments may formulate policies and regulations to regulate the foreign direct investment activities, particularly in emerging economies, due to the considerations of foreign exchange and national strategic development (Hoskisson et al., 2013; Wang et al., 2012). As a result, firms with a state ownership background are more likely to benefit from the government. Furthermore, with lower capital costs, state-owned firms are more capable of dealing with short-term financial losses while retaining all the rights to obtain future profits through sole proprietorship (Cui and Jiang, 2012). However, these advantages may not help them from dealing with external pressure in host countries. On the contrary, the host government may regard them as political threats and act against them). Therefore, the host country government may restrict the EMNEs with a strong state ownership background, finally alleviating the innovation performance via internationalization.

2.1 Environmental regulation and innovation performance

Prior research has provided valuable insights into how external institutions may affect the entry strategy of EMNEs and their innovation performance (Gubbi and Elango, 2016; Pérez-Nordtvedt et al., 2014; Wu et al., 2016). Environmental regulations are a typical formal institutional constraint, which exerts impacts on the firm innovation (Wang et al., 2021; Yu et al., 2017). Traditional economics believes that the social benefits of environmental protection are inevitably generated at the cost of reducing the capital for technological innovation of enterprises (Jaffe et al., 1995). Researches supporting on environmental supervision believe that strict environmental protection policies may encourage firms to improve production processes and obtain innovation offsets (Porter, 1991; Porter and van der Linde, 1995). EMNEs need to abide by the government regulations on environment protection and respond to related government policies when establishing competitiveness. To these firms, it is crucial to reduce the cost of pollution control and prevention through environmental innovation. However, due to the lack of advanced technologies, low innovation capabilities, and imperfect external institutions in emerging markets， it is difficult for these firms to innovate in responding to the environmental regulations by the government (Marzucchi and Montresor, 2017). Several studies prove that domestic environmental regulations may promote the level of innovation of emerging markets (Jiang et al., 2020; Song et al., 2021). Following the resource-based view, it is believed that the knowledge that EMNEs need for environmental innovation to respond to government regulation is procured via internationalization. Therefore, it is proposed that:

Hypotheses 1 : The environmental regulation of the home country is positively related to the innovation performance of EMNEs via internationalization.

2.2 The moderation role of FDI strategy of EMNEs

The specific firm's competitiveness is challenging to transfer and replicate (Barney, 1991). Therefore, EMNEs use internationalization to obtain strategic resources to cultivate competitive advantages (Makino et al., 2002)， to improve the knowledge accumulation Process (Kostova and Zaheer, 1999). Via the entry mode of foreign acquisitions, EMNEs may procure strategic resources such as advanced technologies for innovation quickly, with which EMNEs improve the parent firms' innovation performance in (Anand and Delios, 2002; Nocke and Yeaple, 2008). Compared with the foreign acquisition, pollution-intensive activities are more likely to be transferred into foreign markets with lower environmental regulations via the entry mode of greenfields (Ambec et al., 2013).

Hypothesis 2 : A higher proportion of adopting acquisition (compared with greenfield) is positively related to the positive relationship between the environmental regulation of the home country and firms' innovation performance.

2.3 The moderation role of firms' state ownership background

The state ownership background may also play a moderating role in the effects of the environmental regulation on firms' innovation performance. On the one hand, the state ownership background provides the EMNE protection from the government, making them more easily accessible to resources at a lower cost, which may also alleviate their innovation motivation (Kornai, 1979). More importantly, as state-owned firms play an essential pillar role in the national economy and strategic industry development, the governments may consider it is economic interests when dealing with the environment related to state-owned firms (Pan et al., 2020). Therefore, the government may relax the environmental supervision of EMNEs with a state-owned background. The weakening external pressure may affect firms' motivation to obtain external technologies through internationalization to innovate. On the other hand, there are complex agent conflicts in state-owned enterprises (Grogaard et al., 2019).

Due to the tenure system and the time lag effect of foreign acquisition, the managers of state-owned firms may pursue short-term performance rather than an innovation that usually takes longer. Therefore, it is proposed that:

Hypothesis 3： The state-owned background of the parent EMNEs is negatively related to the positive relationship between the environmental regulation of the home country and firms' innovation performance.

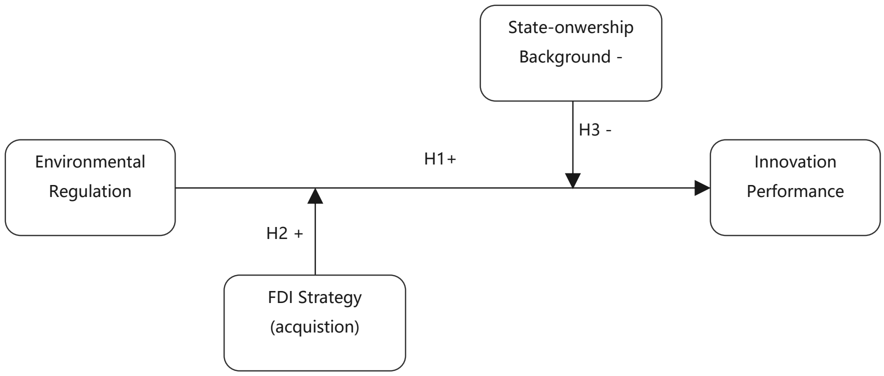

Fig. Framework of environmental regulation of home country on innovation performance of EMNEs via internationalization

3. RESEARCH METHODOLOGY

3.1 Sample and Data

China has become an essential contributor to world EMNEs, yet the Chinese government plays a crucial role in environmental regulation and affecting firm strategy and performance. Thus we choose China as an ideal research context for examining how environmental regulation may impact the firm's innovation performance.

The data employed in this study are mainly from two datasets. First, the firm-level information of Chinese EMNEs was obtained from the CSMAR database- a widely used source of parent firm data on Chinese listed firms (Buckley et al., 2019). Second, we collected all foreign direct investments conducted by on-list firms in China from 2010 to 2016 and finally obtained a sample of 2,312 events of investment activities.

The second data source is the China City Statistical Yearbook. We have collected information on pollutant emissions, and city-level industrial output was obtained from the yearbook. Our data cover all regions of China, including 11 eastern provinces (68 cities), 11 central provinces (36 cities), and seven western provinces (17 cities).

3.2 Variable and measurement

Dependent variable

The dependent variable for this study is innovation performance. The patent numbers are commonly used in prior studies to measure the innovation performance of enterprises (Huang et al., 2021; Li et al., 2019; Phene and Almeida, 2008). Therefore, we adopt the total number of patents granted by the government during the reporting period as an indicator of innovation performance. The total number of patents granted is the sum of the three sub-types of patents granted for invention, utility, and design. In the empirical process, we added 1 to this variable and then took the logarithm. Considering that innovation has a time lag effect, we finally adopted the time lagging for two years (Elia et al., 2020).

Independent variables

This paper estimates the intensity of environmental regulations based on pollutant emission indicators. Although pollution emissions cannot directly reflect the power of environmental regulations, they often have apparent relevance to environmental constraints (Copeland and Taylor, 2004). Therefore, the measurement method based on pollutant discharge can reflect the actual environmental regulation performance. Most companies use water or air to discharge pollutants. From the "China Urban Statistical Yearbook," we obtained the indicators of pollution emissions commonly used in the literature, such as municipal wastewater, SO_2, and smoke, to construct proxy variables for environmental regulation (Song et al., 2008, Li et al., 2016). On the one hand, industrial smoke, wastewater, and SO_2 are three physical forms of pollutants, which reflect the diversity of pollution and consider that the innovative performance of different types of enterprises may have different responses to various pollutants. On the other hand, these three types of pollution can better reflect the local pollution status than carbon dioxide and other global gases (Criado et al., 2011).

We follow the method by Zhao and Sun (2016) to construct a comprehensive measurement system of environmental regulation intensity, including a target level of environmental regulation intensity and three evaluation index levels (smoke, wastewater, SO_2). Different pollutants are assigned different weights, and the power of environmental regulations in each city is calculated. The comprehensive index overcomes the shortcomings of a single index and can more accurately reflect the intensity of environmental regulations. The calculation steps are as follows:

First, linear standardization of the unit pollutant emissions of each city:

$$UE_{ij}^{s} = \left[UE_{ij} - min(UE_j)\right] / \left[max(UE_j) - min(UE_j)\right] \text{ (1)}$$

In the formula (1), UE_{ij} is the pollutant emission per unit output value of category *j* pollutants in city *i*,, $max(UE_j)$ and $min(UE_j)$are the maximum and minimum values of each index in all cities, UE_{ij} is the standardized value of the index.

Second, the proportion of pollutant emissions in different cities differs significantly, and the emission intensity of various pollutants also varies greatly. The use of adjustment coefficients approximates the difference in pollutant characteristics. The calculation formula of the adjustment factor is:

$$W_j = UE_{ij} / \overline{UE_{ij}} \text{ (2)}$$

In the formula (2), $\overline{UE_{ij}}$ is the average level of pollutant emission of the city, calculated by the value of per unit output value of j.

Third, calculate the intensity of command-based environmental regulations in each city.

$$ER_i = \frac{1}{3} \sum_{j=1}^{3} W_j UE_{ij}^{s} \text{ (3)}$$

In the formula (3), ER_i is the final calculated *i* city environmental regulation intensity. The more minor the constructed environmental regulation index, the stronger the degree of environmental regulation intensity is. For the convenience of explanation, we multiply all the environmental regulation intensity by the value of -1, so the more significant the environmental regulation index, the stronger the degree of environmental regulation intensity is.

There are two moderating variables in our study. The first moderator is FDI entry mode strategy portfolio. To study the portfolio of entry mode, we drew the measurement method from the seminal article by Elia et al. (2020), taking the proportion of M&As as a percentage of the total investment of each Chinese FDI activity. The second moderator is the state owernship background. We followed the previous study by Buckley et al., (2010) to use the proportion of equity owned by the home government.

Control variables

First, we use the proportion of R&D investment accounting in the total operating income of the parent firm to control R&D intensity. Second, we use the logarithmic value of the difference between the year of the observation and the year when the firm is on-list (Huergo, 2006). It is argued that firm age has a positive impact on corporate innovation (Majumdar, 1997). Third, we use the total assets of the parent firm to measure the firm size (Hall and Lerner, 2010). Fourth, we use the debt-to-asset ratio to measure the firm's debt level, which is also related to innovation performance. It indicates the firm's financial pressure, which may affect its investment in R&D (Corbett and Jenkinson, 1997). The time, industry, firm, and city are also controlled for the fixed effect.

4. RESULTS

Table 1 presents descriptive statistics. All correlations are relatively low. All correlation coefficients are lower than 0.65, which indicates that no serious problems of multicollinearity. We estimated OLS regressions to test all the hypotheses. Model 1 examines the direct effects of the environmental regulation on the innovation performance of Chinese EMNEs investing overseas.

Table 1 Matrix of correlations and descriptive statistics

	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	Innovation performance	1							
(2	ER	0.021	1						

)									
(3)	M&A_proportion	-0.021	0.016	1					
(4)	Firm size	0.455***	0.026	0.045**	1				
(5)	R&D_proportion	0.016	0.011	0.023	-0.225***	1			
(6)	Firm age	0.041**	-0.006	0.016	0.203***	-0.106***	1		
(7)	Debt	0.186***	0.018	0.015	0.511***	-0.321***	0.253***	1	
(8)	State background	0.066***	0.003	0.066***	0.171***	-0.044**	0.03	0.156***	1
	Obs	2313	2313	2313	2313	2313	2313	2313	2313
	Mean	2.802	-0.022	0.171	8.064	0.047	2.724	0.412	0.029
	Std. Dev.	1.428	0.324	0.314	1.314	0.062	0.342	0.211	0.104
	Min	0.693	-15.311	0	2.944	0	1.386	0.007	0
	Max	8.349	0	1	13.215	0.981	4.06	2.861	0.837

Hypotheses 1 is supported. As shown in model 1, the coefficient of environmental regulation is significantly positive (coef=0.0621, p<0.01), indicating that environmental regulations are positively related to the firms' innovation performance.

Hypothesis 2 is supported. As shown in model 2, the coefficient of the interaction term of the environmental regulation and the FDI entry mode strategy is significantly positive (coef=2.3, p<0.01), the adoption of the acquisition may strengthen the positive effects of the environmental regulations on the innovation performance of the firms.

Hypothesis 3 is also supported. As shown in model 3, the interaction term of the environmental regulation and state-owned background is significantly negative (coef=-4.193, p<0.01). It signifies that the state ownership background alleviates the effect of the environmental regulation on the firm's innovation performance via internationalization.

In addition, the firm size has a positive and significant effect on innovation performance (coef=0.0704; p>0.1). The firm age is significantly positively related to the innovation performance (coef=0.991, p<0.05). Finally, the debt level is negatively related with innovation performance (coef=-0.383, p<0.01).

Table 2 Regression results

	Innovation performance		
Variables	Model 1	Model 2	Model 3
ER	0.0621***	0.0601***	0.0623***
	(0.00226)	(0.00237)	(0.00227)
ER*acquisition		2.300**	
		(0.819)	
ER*state ownership			-4.193***
			(0.759)
M&A_proportion	-0.111*	-0.0827	-0.109*
	(0.0591)	(0.0539)	(0.0591)
Firm size	0.0781***	0.0843***	0.0787***
	(0.0216)	(0.0218)	(0.0217)
R&D	0.323	0.326	0.321
	(0.396)	(0.401)	(0.395)
Firm age	0.991**	0.972**	1.010**
	(0.431)	(0.434)	(0.433)
Debt	-0.383***	-0.381***	-0.384***
	(0.129)	(0.125)	(0.130)
State Ownership	-0.343	-0.351	-0.400**
	(0.202)	(0.202)	(0.186)
Year control	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes

Industry control	Yes	Yes	Yes
City controls	Yes	Yes	Yes
Constant	-0.276	-0.274	-0.332
	(1.219)	(1.220)	(1.226)
Observations	2,124	2,124	2,124
R-squared	0.880	0.880	0.880

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

5. ROBUSTNESS CHECKS AND ADDITIONAL TEST

We conducted the robustness check from three aspects. First, We substituted the measurement of the innovation performance from the total number of patents granted with the patent applications number. Compared with the patents granted, the number of applications signifies the firm's motivations and potentiality of innovation performance. The results maintained consistent with the original measurement (see table 4). Second, we substituted the measurement of the pollution elements with the comprehensive removal rate of sulfur dioxide and carbon dioxide (CRR) at the city level. The results also remain consistent with the raw measurement (see table 3). Third, we substituted the entire industry with the manufacturing industry. The primary sources of environmental pollutants, mainly include productive pollution, domestic pollution, and transportation pollution, are predominantly from the manufacturing industry, particularly in China as an emerging country. Again, the results are consistent with our original measurement (see table 3).

In addititon, in terms of the interaction effects of environmental regulation and FDI strategy on the firm's innovation performance, we further divided the total sample of host countries into two sub-groups: developed and developing countries. When the technology gap between the host country and the home country is significant, the potential for positive technology spillovers is tremendous (Findlay, 1978). Moreover, compared with developing countries, acquisitions in developed countries are more likely to procure strategic assets with more advanced technology (Huang and Zhang, 2017; Ramamurti, 2012). Third, we divided the developed and developing countries by the classification by the World Bank.

In Table 4, model 1 examines the direct effects of the environmental regulations on firms' innovation performance. Model 4 and model 5 add new interaction items based on model 1. The results in model 3 show that adopting the acquisition positively strengthens the effects of environmental regulations on innovation performance (coef=1.303 $p<0.05$) in developed countries. However, this interactive effect is insignificant (coef=7.272; $p>0.01$), as shown in model 4. Therefore it further verifies the practical path of internationalization innovation performance under environmental regulations.

Table 3 Robustness Test (Substitution of Manufacturing Industry and Host Country Division

	Potential Innovation Performance				
VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5
ER	0.0632***	0.0616***	0.0634***	0.0606***	0.0606***
	(0.00893)	(0.00773)	(0.00911)	(0.00759)	(0.00852)
ER* M&A_proportion		1.719**			
		(0.826)			
ER*State background			-4.222		
			(2.998)		
ER*M&A_proportion_developed				1.303**	
				(0.557)	
M&A_proportion_developed				-0.0292	
				(0.125)	
ER* M&A_proportion_developing					7.272
					(4.830)
M&A_proportion_developing					-0.238
					(0.318)
M&A_proportion	-0.107	-0.0829	-0.103		
	(0.116)	(0.115)	(0.114)		

Firm size	0.0835	0.0882	0.0843	0.0851	0.0844
	(0.0738)	(0.0741)	(0.0737)	(0.0742)	(0.0737)
R&D_proportion	0.752	0.757	0.748	0.775	0.765
	(0.609)	(0.609)	(0.609)	(0.612)	(0.608)
Firm age	1.413***	1.398***	1.431***	1.381**	1.395***
	(0.534)	(0.534)	(0.533)	(0.537)	(0.530)
Debt	-0.489**	-0.485**	-0.491**	-0.485**	-0.492**
	(0.204)	(0.203)	(0.204)	(0.204)	(0.204)
State background	-0.0861	-0.0947	-0.160	-0.104	-0.0953
	(0.270)	(0.270)	(0.300)	(0.269)	(0.268)
Time Controls	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Industry Controls	Yes	Yes	Yes	Yes	Yes
City Controls	Yes	Yes	Yes	Yes	Yes
Constant	-1.343	-1.342	-1.399	-1.282	-1.309
	(1.570)	(1.570)	(1.570)	(1.580)	(1.562)
Observations	1,717	1,717	1,717	1,717	1,717
R-squared	0.877	0.877	0.877	0.877	0.877

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4 Robustness Test 2 (Substitution of Environmental Regulation and Innovation Performance)

	Potential Innovation Performance		
VARIABLES	Model 1	Model 2	Model 3
CPRR	0.117***	0.113***	0.119***
	(0.0328)	(0.0308)	(0.0329)
CPRR * M&A_proportion		0.230***	
		(0.0450)	

CPRR * State background			-0.489***
			(0.144)
M&A_proportion	-0.281**	-0.427***	-0.280**
	(0.121)	(0.110)	(0.123)
Firm size	0.111***	0.109***	0.114***
	(0.0363)	(0.0360)	(0.0368)
R&D_proportion	0.972	0.984	0.974
	(1.087)	(1.100)	(1.081)
Firm age	1.810***	1.851***	1.790***
	(0.424)	(0.425)	(0.427)
Debt	-0.413***	-0.437***	-0.412***
	(0.120)	(0.123)	(0.118)
State background	0.476***	0.475***	0.890***
	(0.152)	(0.143)	(0.0868)
Time Controls	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes
Industry Controls	Yes	Yes	Yes
City Controls	Yes	Yes	Yes
Constant	-2.623**	-2.707**	-2.600**
	(1.092)	(1.101)	(1.088)
Observations	1,431	1,431	1,431
R-squared	0.844	0.844	0.844

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

6. DISCUSSION AND CONCLUSION, AND CONTRIBUTION

The study analyzes the impact of environmental regulations on the innovation of multinational companies in emerging markets. The study found a positive relationship between the environmental regulation of the home country and the innovation performance of EMNEs via internationalization. Moreover, this effect is strengthened when the firm adopts more acquisitions than greenfield in its FDI entry mode strategy in foreign countries. However, it is further found that these moderation effects only exist in the host countries as developed ones. Further, the study also finds that the state ownership background also has a positive moderation effect on the environmental regulation on firms' innovation performance via internationalization.

The study contributes to the current research in this area in the following two aspects. First, the study explores the relativeness of environmental regulation and innovation. Many previous studies have mainly emphasized the positive relationship between environmental regulation and corporate innovation based on Porter's hypothesis(Borghesi et al., 2015; Rubashkina et al., 2015; Zhao and Sun, 2016). However, they did not specify why some firms have enhanced innovation capabilities under external environmental regulations, while others have not. Our research shows that the innovation of emerging market enterprises under the Porter hypothesis may be exogenous, whether technological improvement or organizational and management capabilities. That is, environmental regulations promote enterprise innovation through the internationalization of firms.

Second, we consider the home government institution by integrating the firms' FDI strategy and environmental regulation. We further consider that the firms' state ownership background responds to the environmental regulation, affecting its innovation via the internationalization process. Environmental regulation is different from other external systems. It may positively affect firms, but the political asylum brought by the state-owned background will weaken this potential innovation incentive effect. Therefore, we extend the institution-based view theory in this area.

7. LIMITATIONS AND FUTURE STUDY

Although China is the most significant emerging economy, it is still unclear if the conclusions apply to other emerging economies due to its uniqueness in political and economic systems. Future research may further spread the research contexts in the other emerging economies. Second, the proxy indicators of environmental regulation in this article are measured by pollutant emissions. Therefore, it cannot observe the direct impact of formal environmental regulations such as government laws and regulations. Third, our sample companies are listed companies in China. However, small and medium-sized enterprises with weak financial strength and organizational ability may respond differently to environmental regulation. The further study may further apply the research questions on SMEs.

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MULTI-SCALE CORRELATION ANALYSIS BETWEEN CRUDE OIL MARKET AND CHINESE STOCK MARKETS BASED ON PORTFOLIO CONSTRUCTION PERSPECTIVE

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ABSTRACT: Due to the irreplaceable position of crude oil in the industrial system and its important financial function, fluctuations in crude oil prices have a significant impact on global stock markets, especially for energy-consuming countries such as China. This study examines the correlation between the crude oil market and China's stock markets at six time scales after the financial crisis of 2008 for both composite index and sectoral levels, by using the maximum overlapping discrete wavelet transform (MODWT). Based on the MODWT analysis, portfolios are constructed and the corresponding conditional value at risk (CVaR) are calculated to measure the tail risk of each portfolio. This study has attained the following findings. First, the two markets have no influence in the short-term, medium-long-term, and long-term. However, they exhibit a positive correlation in short-medium-term and the medium-term. Moreover, the wavelet cross-correlations indicate an overreaction to the shock

from the crude oil market for the composite indexes and some sectoral indexes. And the CVaR of the portfolios at various time scales are different. Additionally, the optimal portfolio model changes at different time scales when the indexes of the Shanghai stock market and Shenzhen stock market are used to construct portfolios. However, the mean-variance portfolio has the smallest tail risk among all the time scales for the Shenzhen stock market. These findings indicate a possibility for risk diversification for investors with short-term capital allocation needs and mid-long-term capital allocation needs such as pension funds. The findings of this study will help market participants prepare risk management strategies and make related investment decisions.
Key Words: crude oil market; China’s stock market; multi-scale analysis; portfolio construction

1. INTRODUCTION

As an important industrial material and the energy source, crude oil is the most important global commodity in the world (Lang et al., 2019). At present, the crude oil futures and options are the most actively traded financial derivatives in the commodity market (Coppola, 2008; Lang et al., 2019). The fluctuation in the price of crude oil has a great impact on the global stock market, due to its irreplaceable position in industrial system and important financial features (Jones et al., 1996; Ciner 2001; Basher et al., 2006; Driesprong et al., 2008; Park et al., 2008; Hamilton, 2009).

The relationship between the Chinese stock market and crude oil prices has also attracted increasing attention, due to the increasing importance of China's stock market in the global financial market. According to the data from Shanghai Stock Exchange and Shenzhen Stock Exchange, the Chinese continuously expanding stock market has become the second largest stock markets in the world till Novembre 2019.[1] The country’s stock market was included in the world mainstream index. However, the assets holding cycle and investment preferences of various investors are different because investors are not homogeneous (Musciotto et al., 2018). As such, studies investigating the correlation between the crude oil market and China’s stock market are of great significance for investors because they can help reduce investment risks (Hao et al., 2020). In the current literature, however, there is insufficient analysis of the multiple time scales of this relationship. To address this gap, we employ wavelet transform to study the correlation between the crude oil market and China’s stock market, which providing a new perspective regarding the construction of

[1] As of November 2019, the Shanghai Stock Exchange had 1,579 listed stocks with a total market capitalization of 33 trillion yuan (SSE, 2019). The Shenzhen Stock Exchange had 2,225 listed stocks with a total market capitalization of 22 trillion yuan (SZSE, 2019).

investment portfolios. Based on the correlation structures in different time scales, three portfolios (the mean-variance portfolio, the most diversified portfolio, and the risk parity portfolio) are constructed using conditional value at risk (CVaR) to provide some suggestion for investors who have different investment preferences and asset holding cycle.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature, and Section 3 introduces the methodology. Section 4 presents the empirical analysis, including the analysis of the correlation between the crude oil market and the Chinese stock market, as well as the construction of investment portfolios. Section 5 concludes.

2. LITERATURE REVIEW

As the financial properties of crude oil continue to rise while the international crude oil price plummeted during the financial crisis of 2008, many scholars have studied the factors influencing crude oil prices (Buyuksahin et al., 2011; Kaufmann, 2011; Kilian et al., 2014). Regarding the relationship between the crude oil market and the stock market, researchers have found a negative correlation between the U.S. stock market yield and crude oil prices (Ciner, 2001; Chen, 2010). Wei et al. (2008) found that the relationship between the Chines stock market and the crude oil market was not statistically significant, while the authors found some evidence that the rise in oil prices had increased speculation in the market, based on data from the Brent crude oil price and the return of China's stock market. Park et al. (2008) found that the impact of crude oil on the stock market is lagging, and it influenced by whether the country is an importer or exporter of oil. Moreover, scholars pointed out that, after the 2008 financial crisis, the relationship between the crude oil and stock markets has changed (Mollick et al., 2013; Ji et al., 2020). China is not an exception, Mensi et al. (2014) pointed out that the symmetrical dependence structure between the crude oil price changes and the stock market returns has strengthened after 2008 financial crisis using quantile regression model based on the data from West Texas intermediate (WTI) and the BRIC countries' stock markets from 1997 to 2013. Broadstock et al. (2014) found that the correlation between the crude oil price shocks and the stock returns of China changed over time and the impact of different shocks from crude oil to stock returns are heterogeneous. This result is consistent with Kilian (2009a). Nguyen et al. (2012) analyzed the Shanghai Stock Exchange Index and WTI Spot Price Index from 2000 to 2009. They found that there was no tail dependence between the Chinese stock market and changes in the international crude oil prices. However, Li (2018) proposed that the 2008 global financial crisis had amplified the long-term correlation between the Chinese stock market and the crude oil market, whose effect is more significant in the long-term than in the short-term. Research by Yu et al. (2019) partially supports the conclusion of Li (2018), as they also found a long-term increasing co-integration relationship between the crude oil futures market and the Chinese stock market. Xue et al. (2019) noted that the crude oil market and China's stock market were closely linked during depression period. Lv et al. (2020) found that the price of crude oil futures on the Shanghai International Energy Exchange could effectively hedge the risks of portfolios containing the stocks.

In previous research, scholars have mostly used vector autoregression (VAR), generalized autoregressive conditional heteroskedasticity (GARCH), quantile regression, Scalar-BEKK (named by Yoshi Baba, Rob Engle, Dennis Kraft and Ken Kroner), and copula models to investigate the relationship between the crude oil market and the Chinese stock market (Cong, et al.,2008; Nguyen et al., 2012; Mensi et al., 2014; Broadstock et al., 2014; Li et al. 2018). Others have utilized the non-linear threshold cointegration, minimum spanning tree, and hierarchical tree models (Xue et al 2019; Yu et al 2019).

In general, scholars have drawn some conclusions about the correlation between crude oil price changes and the stock market: (1) The correlation between crude oil price changes and the stock market changes over time; (2) The shocks from the crude oil market have heterogeneous effects on the stock market; and (3) The nature of the relationship between China's stock market and the crude oil market changed after the 2008 financial crisis. While lots of research are done, most studies used average data of different time scales, which are over-simplified and cannot adequately capture the characteristics and information at each time scale. And the single time scale analysis no longer sufficed for analyzing the complex relationship between the crude oil market and the stock market. In the short-term, investors become more sensitive to the dependency of the crude oil market and the stock market as the rising financial attributes of crude oil. In the long-term, the financial crisis makes this correlation significantly higher than that in the short-term (Li et al. 2019). Ji et al. (2020) applied the vine copula model based on wavelet analysis to test the multi-scale correlation structure between the crude oil market, the Chinese stock market, and safe-haven assets. However, they did not construct a related investment portfolio for further analysis. For this reason, this study applies the maximum overlap discrete wavelet transform (MODWT) to capture the characteristics and information of the crude oil market and the Chinese stock market at different time scales. Then, we calculated the wavelet correlation coefficients and cross-correlation coefficients. Moreover, in practice, heterogeneous investors with different risk preferences and investment cycles exhibit various investment behaviors. In this study, we construct portfolios and evaluate them using CVaR under different time scales, based on the assumption that investors are heterogeneous. This allows us to further illustrate the application of multi-scale analysis, provide recommendations for investors, and seek out the market characteristics.

3. METHODOLOGY

In this study, we first used wavelet analysis to detect the multi-scale dependence relationship between crude oil market and stock market of China. Then, we constructed portfolios under different time scales and calculated the tail risks to evaluate their performance.

3.1. Wavelet Analysis

Wavelet analysis is widely used in the prediction of oil prices and in the analysis of common fluctuations among commodities (Reboredo et al., 2014). The wavelet transform feature can decompose the signal in both the time domain and the frequency domain. It overcomes the limitation of Fourier transform, which cannot achieve multi-resolution in the time domain and in the frequency domain simultaneously (Selcuk et al., 2001).

3.1.1 Maximum overlapping discrete wavelet transform

Maximum overlapping discrete wavelet transform can be derived from continuous wavelet transform (CWT) and discrete wavelet transform (DWT). And the mother function $\psi(t)$ in wavelet transform is a function of time t, and satisfies the following two conditions:

$$C_{\psi} = \int_{0}^{\infty} \frac{|\Psi(f)|}{f} df < \infty \tag{1}$$

$$\int_{-\infty}^{\infty} |\psi(t)|^2 \, dt = 1. \tag{2}$$

Continuous wavelet transform (CWT) $W(u,s)$ is a function of the translation coefficient u and the scale coefficient s, which can be obtained by projecting the objective function $x(t)$ on the corresponding wavelet ψ:

$$W(u,s) = \int_{-\infty}^{\infty} x(t)\psi_{u,s}(t)\,\mathrm{d}t\ , \tag{3}$$

where $\psi_{u,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)$ is the wavelet function after translation u unit and magnification s times. The objective function $x(t)$ can be obtained through matching the translation and expansion of the wavelet function $\psi_{u,s}(t)$:

$$x(t) = \frac{1}{C_\psi}\int_{0}^{\infty}\int_{-\infty}^{\infty} w(u,s)\psi_{u,S}(t)\,\mathrm{d}u\frac{\mathrm{d}s}{s^2} \tag{4}$$

The discretization of the parameters u and s can be conducted to obtain a small number of key coefficients for analysis. Then, the redundant information is removed. The critical sampling of parameters s and u in continuous wavelet transform is $s = 2^{-j}\ and\ u = k2^{-j}$, where j and k are integers, representing the set of discrete wavelet translation (DWT) and discrete wavelet scale changes. We have

$$\psi_{j,k}(t) = 2^{\frac{j}{2}}\psi\left(2^j t - k\right). \tag{5}$$

Let x be the observation sequence of length equal to $N = 2^J$. The discrete wavelet coefficient vector ω of length N can be obtained as follows:

$$\omega = \mathcal{W}x. \tag{6}$$

The wavelet coefficients vector is expressed as

$$\omega = [\omega_1, \omega_2, \dots, \omega_J, v_J]^T, \tag{7}$$

where ω_j is a wavelet coefficient vector with a length of $N/2^j$ in the jth scale, and v_J is a scale coefficient vector with a length of $N/2^J$. $\mathcal{W}$ is an $N \times N$ orthogonal matrix defining the discrete wavelet transform. Correspondingly, the original sequence x (exponential times of 2) can be decomposed as:

$$x = \mathcal{W}^{-1}\omega \tag{8}$$

Its multi-resolution decomposition can also be written as:

$$x_t = s_k + \sum_{j=1}^{k} d_{j,t}\,, \tag{9}$$

where j represents the decomposition of the jth scale, $j \in \{1, \ldots, k\}$, $d_{j,t}$ is the wavelet detail, $d_{j,t} = \mathcal{W}_{j,t}^{-1}\omega_{j,t}$, and $s_k = \sum_{j=k}^{J+1} d_{j,t}$.

Compared with the DWT, the MODWT can capture the signal characteristics that the DWT cannot capture. It also overcomes the limitation of the DWT, which is only suitable for handling the data with length exponential times of 2.

The coefficient vector of the MODWT is $\widetilde{\omega} = \widetilde{\mathcal{W}}x$， where $\widetilde{\mathcal{W}}$ is a $(J+1)N \times N$ matrix used to define the MODWT. Similarly, the original sequence x can be decomposed into:

$$x(t) = \sum_{l=0}^{L-1} \tilde{h}_l\, \widetilde{w}_{l,t+l\ mod\ N} + \sum_{l=0}^{L-1} \tilde{g}_l\, \tilde{v}_{l,t+l\ mod\ N}. \tag{10}$$

Likewise, we can obtain the resolution expression of the MODWT:

$$x_t = s_J + \sum_{j=1}^{J} \tilde{d}_{j,t}, \tag{11}$$

where j is the decomposition of the jth scale and $\tilde{d}_{j,t}$ is the wavelet detail, $\tilde{d}_{j,t} = \widetilde{\mathcal{W}}_{j,t}^{-1}\widetilde{\omega}_{j,t}$, $s_J = \sum_{j=k}^{J+1} \tilde{d}_{j,t}$.

3.1.2 Wavelet correlation

The wavelet correlation based on correlation and cross-correlation of variables at various time scales provides information for analyzing the relationship between the crude oil market and the Chinese stock market, as well as for constructing investment portfolios.

$$\gamma_X(\lambda_j) = \frac{1}{2\lambda_j} Cov(\omega_{1,j,t}, \omega_{2,j,t})。 \tag{12}$$

Let $X_t = (x_{1,t}, x_{2,t})$ be a bivariate stochastic process and let $W_{j,t} =$

$\left(\omega_{1,j,t}, \omega_{2,j,t}\right)$ be the wavelet coefficients of X_t on the λ_j scale. Then, the wavelet covariance of $\left(x_{1,t}, x_{2,t}\right)$ on the λ_j scale represents the wavelet cross-covariance of the corresponding lag period τ , which is:

$$\gamma_{X,\tau}\left(\lambda_j\right) = \frac{1}{2\lambda_j} cov\left(\omega_{1,j,t}, \omega_{2,j,t+\tau}\right). \tag{13}$$

Correspondingly, the wavelet correlation coefficient and cross-correlation coefficient are defined as follows:

$$\rho_X\left(\lambda_j\right) = \frac{\gamma_X\left(\lambda_j\right)}{\sigma_1\left(\lambda_j\right)\sigma_2\left(\lambda_j\right)}, \tag{14}$$

$$\rho_{X,\tau}\left(\lambda_j\right) = \frac{\gamma_{X,\tau}\left(\lambda_j\right)}{\sigma_1\left(\lambda_j\right)\sigma_2\left(\lambda_j\right)}. \tag{15}$$

Using the asymptotic normality of $\rho_X\left(\lambda_j\right)$, we can obtain the corresponding confidence interval. [2]

3.2 Portfolio selection models

In this study, we constructed portfolios based on the decomposed data. The optimal portfolio weights of selected assets were obtained for each of the following three strategies: global minimum variance portfolio (GMV), most diversified portfolio (MDP), and Risk parity portfolio (RP). The CVaR was used to evaluate the portfolios' performance.

3.2.1 Global minimum variance portfolio (GMV)

Assuming that there are Z assets, r_i is the return of the ith asset, and w_i is the corresponding weight satisfying the condition $\sum_{i=1}^{Z} w_i = 1$. The portfolio return and standard deviation are defined as:

$$r_P = w^T r, \tag{16}$$

$$\sigma_P = \sqrt{w^T \Sigma w}, \tag{17}$$

[2] More details about the confidence interval can be found in Gençay et al. (2001).

where $r = (r_1, \dots, r_i, \dots, r_Z)^T, w = (w_1, \dots, w_i, \dots, w_Z)^T$ and Σ is the covariance matrix of the asset return rate. Then the mean-variance portfolio model can be expressed as the following optimization problem:

$$Max\, r_P = w^T r \tag{18}$$

$$s.t. \sigma_P = \sqrt{w^T \Sigma w} = \sigma$$

$$\sum_{i=1}^{Z} w_i = 1.$$

3.2.2 Risk parity portfolio

The risk parity portfolio was introduced by Qian (2004, 2005, 2011) and the properties of this portfolio optimization approach were analyzed in Maillard et al. (2010). The marginal risk contribution MRC_i of the ith asset is defined as:

$$MRC_i = \frac{\partial \sigma_P}{\partial w_i} = \frac{(\Sigma w^T)_i}{\sigma_P}. \tag{17}$$

The total risk contribution RC_i of ith asset to the portfolio is:

$$RC_i = w_i * MRC_i = \frac{w_i (\Sigma w^T)_i}{\sigma_P}. \tag{18}$$

If the marginal risk contribution of an asset is higher, we reduce the corresponding weight of this asset such that all assets' risk contributions are equal. So, the weight calculation of equal-risk contribution can be represented as the following secondary optimization problem:

$$Min \sum_{i=1}^{Z} \sum_{J=1}^{Z} \left(RC_i - RC_j\right)^2, \tag{19}$$

$$s.t. \sum_{I} w_I = 1.$$

3.2.3 Most diversified portfolio

Investors often diversify their investments to reduce the risk of their portfolios. We define the diversification index (DR, diversification ratio) following Choueifaty ET AL. (2008) and Choueifaty et al. (2013) as:

$$DR(w) = \frac{\sum_{i=1}^{Z} w_i \sigma_i}{\sqrt{w^T \Sigma w}}. \qquad (20)$$

The diversification index $DR(w)$ is the objective function of the maximization procedure. It is also equivalent to maximizing the Sharpe ratio.

4. EMPIRICAL ANALYSIS

Wavelet transform is widely used in the prediction of oil prices and in the analysis of common fluctuations among commodities (Reboredo et al., 2014). The wavelet transform feature can decompose the signal in both the time domain and the frequency domain. It overcomes the limitation of Fourier transform, which cannot achieve multi-resolution in the time domain and in the frequency domain simultaneously (Selcuk et al., 2001).

In this study, we first changed all stock market indexes and original prices into RMB-denominated assets. We calculated the corresponding logarithmic returns, which are divided into six time-scales using MODWT. Then, we calculated the wavelet correlation coefficients and cross-correlation coefficients. Finally, we constructed portfolios under different time scales and calculated the tail risks to evaluate their performance.

4.1 Data and summary statistics

WTI is the benchmark for global crude oil prices, so we selected WTI spot prices as the international crude oil prices. The Shanghai Stock Exchange Index (SSEI) and the Shenzhen Stock Exchange Composite Index (SZSE), which are of most concern to investors, were selected to represent the overall Chinese stock market. The ten sectoral indexes were also used to analyze the dependency structure between different industry sectors and the crude oil market. We used the following indexes to represent various sectors of the Chinese stock market: SSE Energy, SSE Materials, SSE Industry, SSE Cons Disc, SSE Staples, SSE Medicine, SSE Finance, SSE Information, SSE Svc, SSE Utilities, Shenzhen Energy, SZSE Materials, SZSE Industry, SZSE Cons Disc, SZSE Staples, SZSE Medicine, SZSE Finance, SZSE

Information, SZSE Svc and SZSE Utilities. WTI daily data were obtained from the EIA official website, and stock market data were obtained from the WIND database. [3]

After the financial crisis of 2008, the correlation between the international crude oil market and the stock market has changed (Reboredo et al., 2014). To avoid disturbance from the exchange rate, we used the daily closing price of USD against RMB to convert WTI prices into RMB prices. The exchange rate data was derived from the WIND database. The data ranges from June 2, 2009 to December 31, 2019 for analysis including the 2008 global financial crisis. The composite indexes of the SSEI, the SZSE and WTI are shown in Figure 1. The logarithmic return is calculated as $r_t = ln\left(\frac{P_t}{P_{t-1}}\right) * 100\%$ and the descriptive statistics of logarithmic returns are displayed in Table 1.

As we can see in Table 1, the average daily returns of the WTI, the stock markets and the sector indexes are close to or equal to 0. The fluctuation in WTI return is significantly greater than that of the stock markets, and the WTI's extreme value is also higher in terms of absolute value. This indicates that the volatility and amplitude of the crude oil market are higher than those of China's stock markets. Meanwhile, the returns of China's stock markets show left-skewed characteristics. With the exception of the sector indices of the Info Technology, Telecom, and Consumer Staples sectors, the sectoral returns show "spike" characteristics. This indicates that the variance observed in those indexes is mainly attributed to the extreme values with low frequency. According to the results of the Jaque-Bera test, all returns did not satisfy the normality assumption, consisting with the real markets. The Ljung-Box test shows that most of the returns have a certain degree of autocorrelation except for the SSEI, SSE Finance, SSE Energy, and SZSE Finance. The ARCH test shows that all returns have the volatility clustering effect, and the ADF test indicates that all returns are stationary.

3.EIA,2019,data ,
https://www.eia.gov/beta/international/data/browser/#/?pa=0000000000000000000000000000000000vg&f=M&c=00000002&ct=0&tl_id=5-M&vs=INTL.53-1-CHN-TBPD.M&vo=0&v=H&start=199401&end=201907 (accessed 11 November 2020)

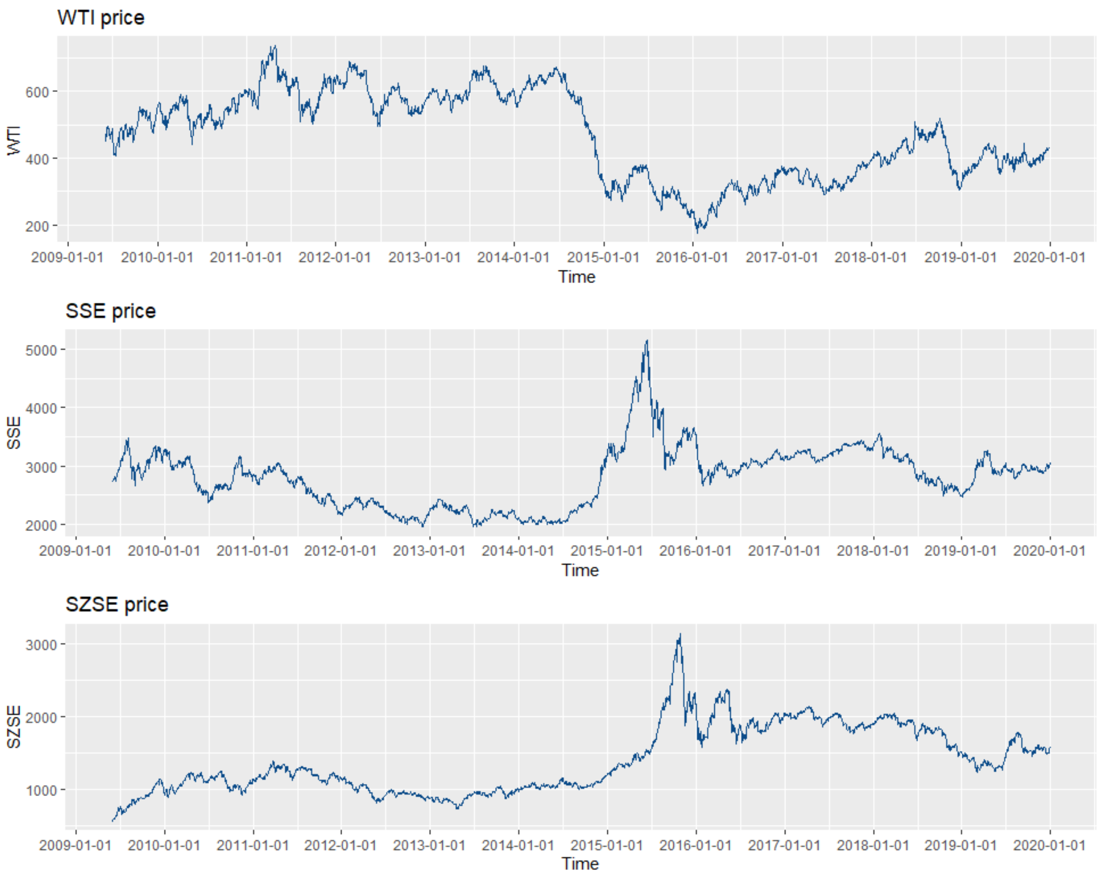

Figure 1: The price of WTI, SSE, and SZSE

Table 1: Summary statistics

	MEAN	SD	MIN	MAX	SK.	KU.	JB	LB	ARCH	ADF
WTI	0.00	2.16	-11.03	13.16	0.10	3.03	0.00	0.00	0.00	0.00
					Panel A: SSE					
SSEI	0.00	1.42	-8.87	6.04	-0.83	5.29	0.00	0.28	0.00	0.00
Ene.	-0.03	1.83	-10.53	8.69	-0.44	3.79	0.00	0.11	0.00	0.00
Mat.	0.00	1.88	-9.65	7.98	-0.66	3.79	0.00	0.01	0.00	0.00
Ind.	0.00	1.69	-9.39	8.22	-0.53	4.81	0.00	0.00	0.00	0.00
ConD.	0.01	1.66	-9.68	6.82	-0.71	3.77	0.00	0.03	0.00	0.00
Con.	0.05	1.61	-9.00	6.70	-0.58	3.10	0.00	0.07	0.00	0.00
Hea.	0.04	1.70	-9.60	7.36	-0.52	3.05	0.00	0.00	0.00	0.00
Fin.	0.02	1.66	-11.79	10.16	-0.14	5.11	0.00	0.47	0.00	0.00
Inf.	0.03	2.09	-9.28	7.40	-0.50	1.82	0.00	0.00	0.00	0.00
Tel.	0.02	2.02	-10.42	10.62	-0.62	3.43	0.00	0.01	0.00	0.00
Uti.	0.00	1.49	-8.30	7.04	-0.76	5.66	0.00	0.09	0.00	0.00
					Panel B: SZSE					

SZSE	0.03	1.69	-8.60	6.32	-0.84	3.24	0.00	0.00	0.00	0.00
Ene.	-0.02	2.04	-12.41	7.77	-0.66	2.96	0.00	0.02	0.00	0.00
Mat.	-0.01	1.83	-9.10	6.80	-0.76	2.72	0.00	0.00	0.00	0.00
Ind.	0.00	1.80	-9.36	6.48	-0.79	3.22	0.00	0.00	0.00	0.00
ConD.	0.02	1.66	-8.96	5.76	-0.69	2.83	0.00	0.08	0.00	0.00
Con.	0.05	1.64	-8.63	6.59	-0.42	2.72	0.00	0.01	0.00	0.00
Hea.	0.04	1.69	-8.75	5.94	-0.51	2.61	0.00	0.00	0.00	0.00
Fin.	0.01	1.93	-9.73	8.96	-0.29	3.22	0.00	0.76	0.00	0.00
Inf.	0.05	2.03	-9.06	7.09	-0.56	1.88	0.00	0.00	0.00	0.00
Tel.	0.03	2.14	-9.87	7.80	-0.60	2.22	0.00	0.00	0.00	0.00
Uti.	-0.01	1.78	-10.34	7.73	-1.05	5.14	0.00	0.00	0.00	0.00

Note: JB is p-value of Jaque-Bera test, LB is the p-value of Ljung-Box test, and ARCH is the p value of ARCH-LM test. The lagged order of ADF test is five. SSEI and SZSE represent the composite indexes of Shanghai and Shenzhen stock markets, respectively. Ene, Mat, Ind. ConD, Con, Hea, Fin, Inf, Tel and Uti represent the Energy, Materials, Industry, Consumer Discretionary, Consumer Staples, Medicine, Finance, Info Technology, Telecom and Utilities, respectively.

4.2 Correlation analysis between the WTI and Chinese stock markets

4.2.1 Wavelet decomposition

The medium-length asymmetric Daubechies wavelet (LA (8)) can capture the characteristics of financial time series effectively. This makes the LA (8) wavelet a powerful tool for analyzing time series data in the financial field (Selcuk et al., 2001). For this reason, we used the LA (8) wavelet for MODWT analysis.

Considering the characteristics of the data and the purpose of the research, we decomposed the daily return of each asset in to six time scales by the inequality $J < \log_2(N/(L-1)+1)$, where J is decomposition scale, N is the number of samples, and L is the wavelet length. The wavelet coefficients at different scales represent different time intervals (see Table 2 for more detailed information). Figures 2-13 in Appendix A displays the WTI, the composite indexes, and the sectoral indexes after the wavelet decomposition.

Table 2: The scale details of wavelet decomposition

Scales	Wavelet coefficients	Time scales	Representation and tendency
1	D1	$2^1 = 2$ trading days	Daily tendency

2	D2	$2^2 = 4$ trading days	2-4 trading days，week tendency
3	D3	$2^3 = 8$ trading days	4-8 trading days，short-medium tendency
4	D4	$2^4 = 16$ trading days	8-16 trading days，month(medium) tendency
5	D5	$2^5 = 32$ trading days	16-32 trading days，long-medium term tendency
6	D6	$2^6 = 64$ trading days	32-64 trading days，long-term tendency
6	S6	——	Residential tendency

4.2.2 Wavelet correlation at different time scales

We calculated the correlation coefficients between the WTI and China's stock market indexes under different time scales for both composite level and sectoral level, based on equations (14) and (15). The corresponding results are displayed by Figures 14-19 in Appendix B.

First, for scale 1 ($2^1 = 2$ trading days), almost all the stock return series showed no correlation or an extremely weak positive correlation with WTI returns. This indicates that the stock market of China is not correlated with WTI returns on a daily scale. For scale 2 ($2^2 = 4$ trading days), the SSEI, SZSE and WTI showed stronger positive correlations. This indicates that, at the weekly scale, China's stock market is overall positively correlated with the WTI. We also found that the Industry, Consumer Staples, Medicine, Information, Finance, and Utilities sectors were not related to the WTI, while the Energy and Materials sectors were positively correlated with WTI returns. For the time scale of $2^3 = 8$ trading days, the correlations between the WTI and SSEI, and SZSE showed an increasing positive relationship. This means that China's stock market is positively related to the crude oil market in the short-medium term time scale. Interestingly, in addition to the Information, Telecom, and Medicine sectors, other sectors showed a positive correlation with the WTI. In the remaining medium and long-term time scales, the correlations between the SSEI, SZSE, and WTI had diminished and became irrelevant. This indicates that the composite stock indexes do not highly correlate with the WTI in the medium- and long-terms. Moreover, as time increases, those correlations become increasingly weaker. For the industry sectors, we found a similar phenomenon. As the time scale increased, the correlation continued to decline, and changed from being positive to becoming irrelevant.

In summary, the correlation between the Chinese stock markets (i.e., at both the composite level and the sectoral level) and the WTI has changed along with the time scale. The relationship gradually shifted from being uncorrelated or weak positive correlations to strong positive correlations. Then, we saw a decline from positive correlations to no correlation. Additionally, the correlations between the return of composite market and the industry sector, and the return of the WTI reached the maximum value under the time scale of $2^3 = 8$ trading days. That is, the correlation between the crude oil market and the Chinese stock market reached their peak in the short-medium-term time scale and then decreased as the time scale continued to increase. Under the medium-long-term time scale, there was practically no relationship between China's stock market and the WTI. Meanwhile, different sectors exhibited the same trend due to the shock from the crude oil market under different time scales. The sectors which were the most sensitive to the fluctuations of the crude oil market are the following: Energy, Industry, Materials, and Consumer companies. The price fluctuations of crude oil affect the costs and expected earnings of energy companies, industrial companies, and materials companies. Theoretically, there should be a negative correlation with the return of the WTI, but our results show an almost opposite trend: they are positive related or even unrelated. A possible reason is the rapid increase in demand for energy and raw materials, caused by the four trillion monetary policies in China and industrial upgrading after the 2008 financial crisis. Another plausible explanation is the uncertainty of price fluctuations, caused by the continuous improvement of the financial attributes of crude oil.

4.2.3 Wavelet cross-correlation at different time scales

We calculated the cross-correlation coefficient between the WTI and stock markets in China under different time scales with the largest lag order of 60 trading days. The corresponding results are shown by Figures 20-27 in Appendix C. The vertical axis represents the cross-correlation coefficient, and the horizontal axis represents the lag order. The two red dotted lines correspond to the upper bound and lower bound of the 95% confidence interval.

We followed the method proposed by Reboredo et al. (2014). A lagged order τ greater than zero represents a cross-correlation coefficient between the WTI return and the stock return with the lag τ periods. Analogously, a lag order lower than zero represents the cross-correlation coefficient between stock returns and the WTI return, with the lag period τ. Correspondingly, if the cross-correlation coefficient is less than 0 and the zero line is not within the 95% confidence interval when the lag order $\tau <$

0, there is an underreaction of the stock market to the shock from WTI. A cross-correlation coefficient greater than zero means that the stock market has an overreaction to the shock from crude oil market's fluctuations. As can be seen in the figures in Appendix C, in the long-term time scale with $2^6 = 64$ trading days, the SSEI and SZSE exhibit overreactions to the changes in the crude oil market. Meanwhile, there is no over-reaction or underreaction in other time scales. In the industry, Information, Telecom, Consumer Staples, and Medicine sectors, there is also evidence of overreaction in the medium and long-term cycle.

4.3 Portfolio construction

With the rapid growth of China's economy and China's huge demand for crude oil, scholars and investors have turned their attention to the dependency structure of the crude oil market and China's stock market. In Section 4.2, we found that the crude oil market and the Chinese stock market showed a positive correlation and peaked under the $2^3 = 8$ trading days. However, they showed a very weak positive correlation or even no correlation in the short-term and long-medium-term time scales. This relationship indicates a possibility of risk diversification for investors with both short-term capital allocation demand and mid-long-term capital allocation needs such as pension funds.

The extreme tail losses caused by black swan events such as the 2008 financial crisis, the sharp drop in crude oil prices in 2014, and the advent of COVID-19 in 2020 have caused a gradual shift in the current risk control toward controlling the tail risk. Therefore, to study the ability of portfolio risk diversification under different time scales, we construct the mean-variance portfolio model, risk parity portfolio model, and most diversified portfolio model by using the differential evolution algorithm. The Shanghai stock market and the Shenzhen stock market are treated separately. Because the sectoral indexes are highly correlated with the composite indexes, the two composite indexes were removed from the empirical study.

Table 3 reports the CVaR of the three portfolios under different time scales. In most cases, the portfolios constructed with the sectoral indexes of the SSEI and WTI had a smaller CVaR than those constructed with the sectoral indexes of the SZSE and WTI. A plausible reason may be that there are more large-cap blue chips in the Shanghai stock market and more small and medium-sized companies in the Shenzhen stock market. This can create greater tail risks in portfolios constructed by sectoral indexes of SZSE and WTI. Additionally, in the Shanghai stock market, as the time scale increased, the tail risk of the portfolios showed a declining trend, while in the Shenzhen stock market this phenomenon was not significant. Interestingly, in the Shanghai stock market the risk-parity portfolio performed well in most time scales, while the mean-variance portfolio performed better in the short- and long-medium term In the Shenzhen stock market, the most diversified portfolio had relatively small tail risk in very short- and long-medium term. And Mean-variance portfolio performed well in short term, while risk parity portfolio performed better in medium term and long term.

Table 3: CVaR of portfolios for SSEI and SZSE

Time scales	**1**	**2**	**3**	**4**	**5**	**6**
Panel A: SSEI						
Mean-variance portfolio	3.16	1.48	1.57	1.09	0.74	0.51
Risk-parity portfolio	2.47	1.53	1.20	0.99	0.80	0.44
Most diversified portfolio.	2.50	1.76	1.35	1.01	0.74	0.50
Panel B: SZSE						
Mean-variance portfolio	3.38	2.50	3.41	3.43	3.19	2.94
Risk-parity portfolio	2.60	2.60	2.60	2.60	2.60	2.60
Most diversified portfolio	2.53	2.69	2.82	2.95	2.58	3.30

In summary, the tail risk characteristics of the SSEI portfolios and the SZSE portfolios are completely different. Investors should consider their investment cycle and find the suitable portfolios in different market. For investors in the Shenzhen stock market, the mean-variance strategy can be considered in short-term. For investors with very short- and long-medium term investment needs, the most diversified investment strategy can be used to reduce tail risk. For investors with short-medium-, medium- and long-term investment needs, the risk parity portfolio with lower tail risks is more suitable. For the Shanghai stock market, the risk-parity strategy is more suitable for investors in most time scales, and typically, the mean-variance portfolio can be considered in the short- and long-medium term.

5. CONCLUSION AND POLICY IMPLICATIONS

In this study, we used the MODWT to investigate the correlation between the international crude oil market and China’s stock market after the 2008 financial crisis at different time scales. The LA(8) wavelet, which can more effectively capture the detailed data in time series, was selected to decompose the original time series into six time scales: daily trends, weekly trends, short-medium trends, monthly trends, medium-long term trends, and long-term trends. Then, we applied three strategies to analyze optimal portfolios constructed by the WTI and stock markets of China at corresponding time scales.

The main findings of this study are as follows: (1) The correlation between the Chinese stock markets (i.e., at both composite level and sectoral level) and the WTI has changed, along with the time scales. The relationship gradually increased from showing no correlation or weak positive correlations to showing strong positive correlations. We then observed a decline, from positive correlations to no correlations. (2) Different sectors exhibited a similar trend in response to the shock from the crude oil market under different time scales. The Energy, Industry, Materials, and Consumer companies were more sensitive to the shock from crude oil market. (3) The cross-correlation analysis indicates that the Chinese stock market had an overreaction to the fluctuation of the crude oil market at the time scale of $2^6 = 64$ trading days, while there was no overreaction or underreaction phenomenon in other time scales.

These findings indicate a possibility for risk diversification for investors with short-term capital allocation needs and mid-long-term capital allocation needs such as pension funds. The mean-variance portfolios, risk parity portfolios, and most diversified portfolios with short selling restriction show interesting features. The tail risk characteristics of the SSEI and SZSE portfolios were completely different. In the Shanghai stock market, the tail risk of each portfolio showed a declining trend as the time scale increased, while it did not change with the time scale in the Shenzhen stock market. Moreover, the portfolios constructed with the sectoral indexes of the SSEI and WTI had a smaller CVaR than those constructed with the sectoral indexes of the SZSE and WTI. This phenomenon may relate to the different composition of the Shanghai stock market and the Shenzhen stock market. There are more blue-chip enterprises in the Shanghai stock market, where listed companies have more capacity to resist risks in the long run. The listed companies in the Shenzhen stock market are mostly small and medium-sized enterprises, which makes the portfolios constructed with the indexes of the Shenzhen market are riskier. In terms of portfolio performance, for the portfolios constructed with the SSEI and WTI, the risk-parity portfolio performed well in the very short-, medium- and long-term time scales and the mean-variance performed better in the short-term and long-medium-term time scales. For the investment portfolios constructed with the SZSE and WTI, the most diversified portfolio is suitable in very short- and long-medium term. And in short term, the Mean-variance portfolio performed better, while risk parity portfolio had smaller tail risk in medium term and long term.

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APPENDIX A: Decompositions of WTI and Stock Indices

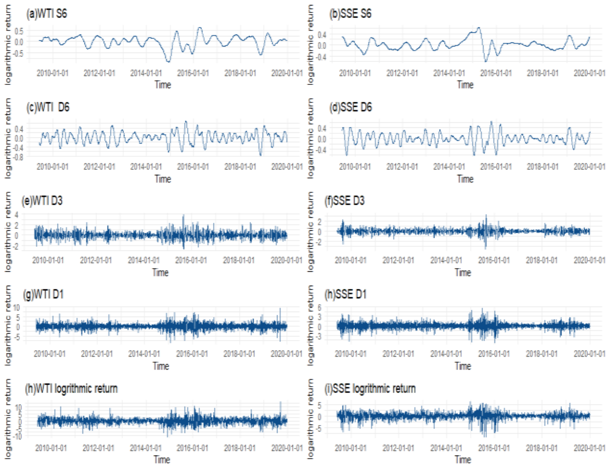

Figure 2: Decomposition of WTI and SSE

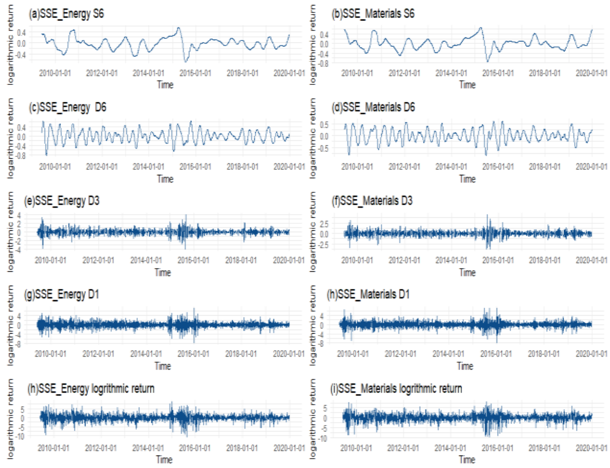

Figure 3: Decomposition of SSE Energy and SSE Materials

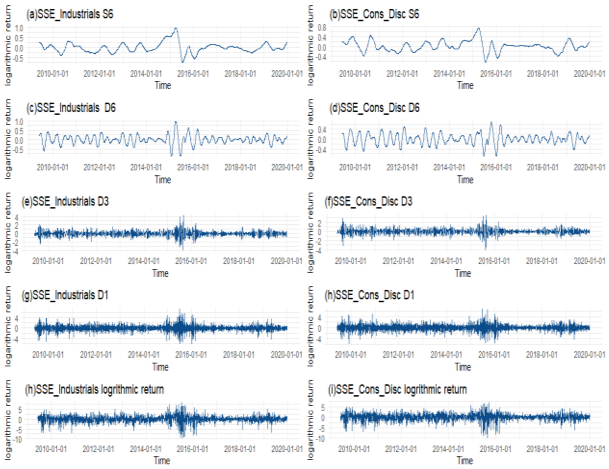

Figure 4: Decomposition of SSE Industrials and SSE Cons Disc

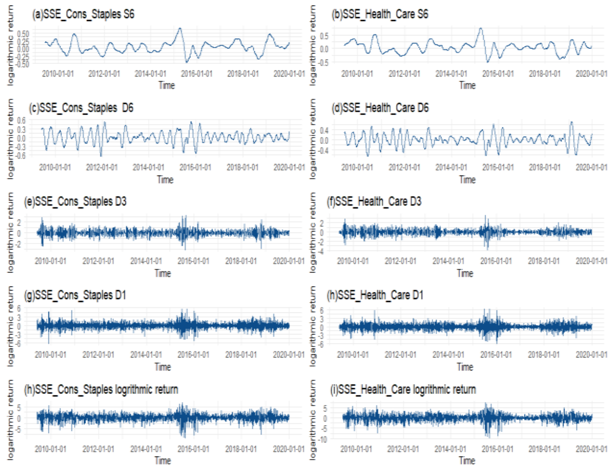

Figure 5: Decomposition of SSE Cons Staples and SSE Health Care

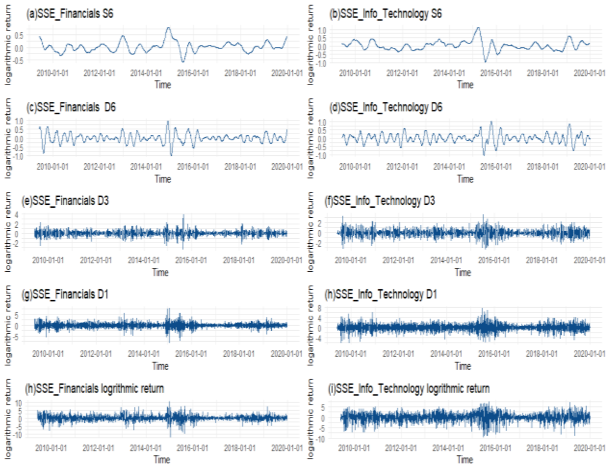

Figure 6: Decomposition of SSE Financials and SSE Info Technology

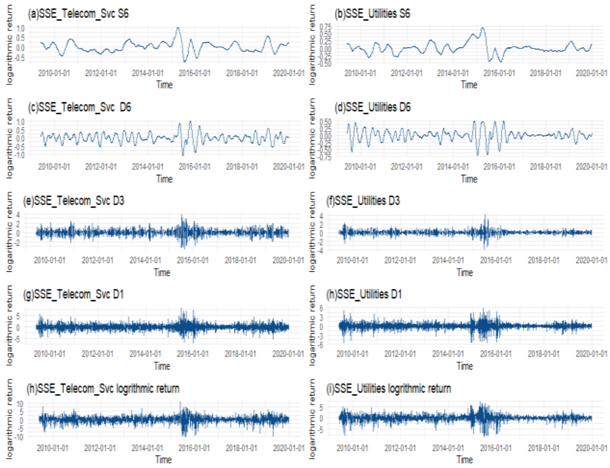

Figure 7: Decomposition of SSE Telecom Svc and SSE Utilities

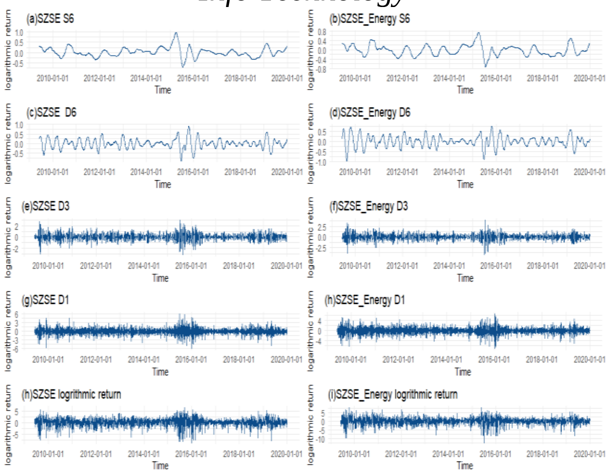

Figure 8: Decomposition of SZSE and SZSE Energy

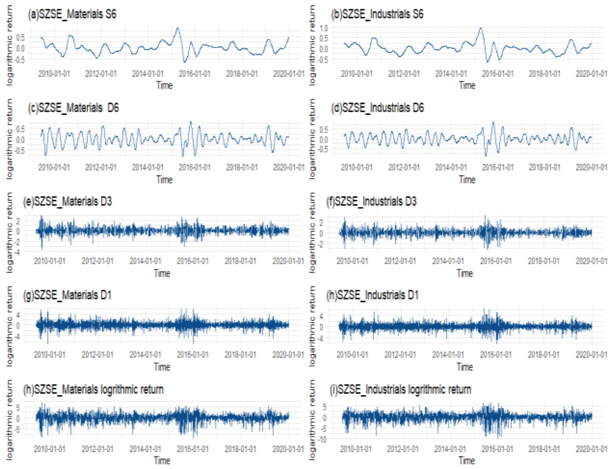

Figure 9: Decomposition of SZSE Materials and SZSE Industrials

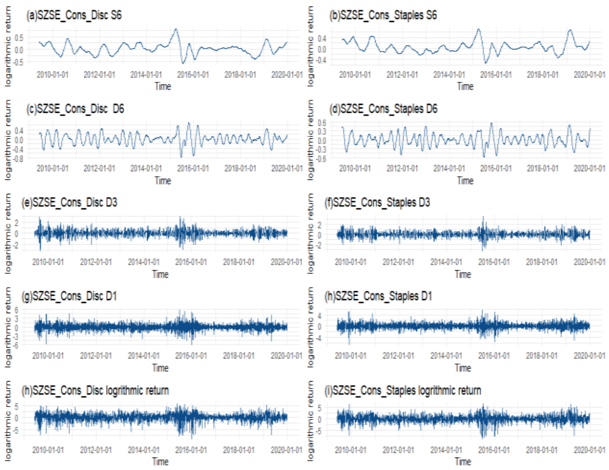

Figure 10: Decomposition of SZSE Cons Disc and SZSE Cons Staples

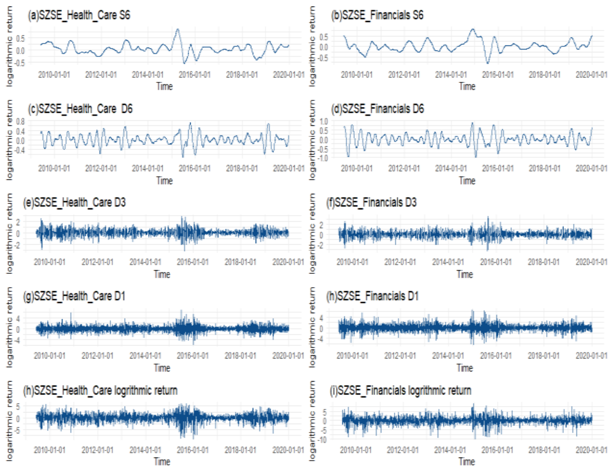

Figure 11: Decomposition of SZSE Health Care and SZSE Financials

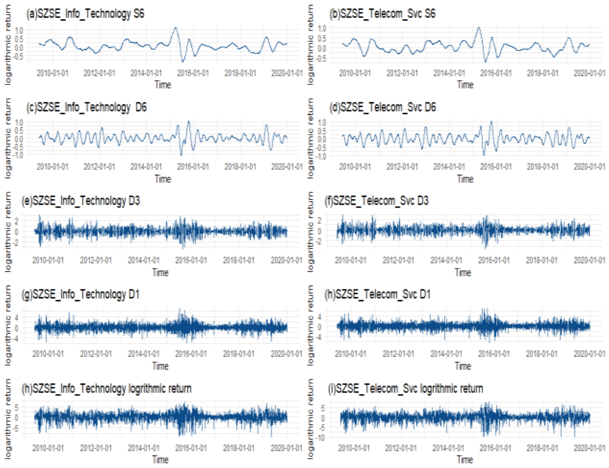

Figure 12: Decomposition of SZSE Info Technology and SZSE Telecom Svc

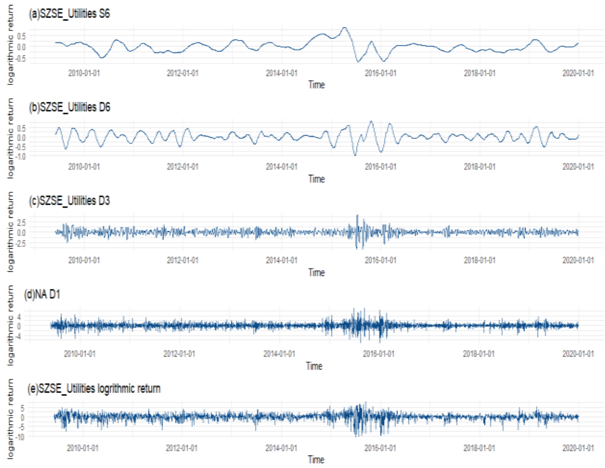

Figure 13: Decomposition of SZSE Utilities

APPENDIX B: Correlations between WTI and Stock Indices

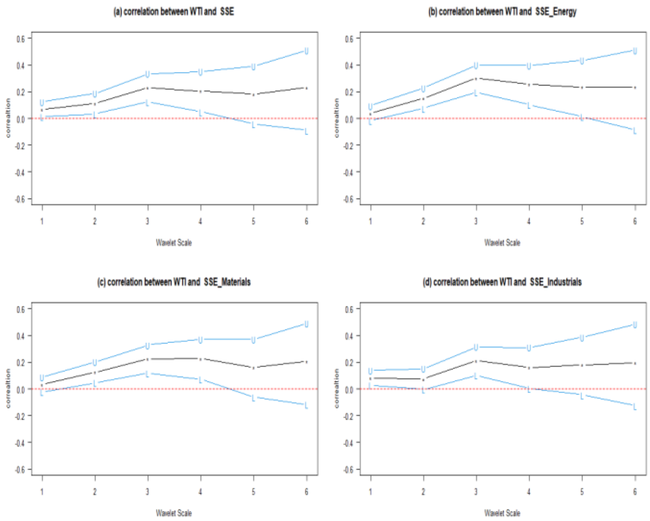

Figure 14: Correlations between SSE, SSE Energy, SSE Materials, SSE Industrials and WTI

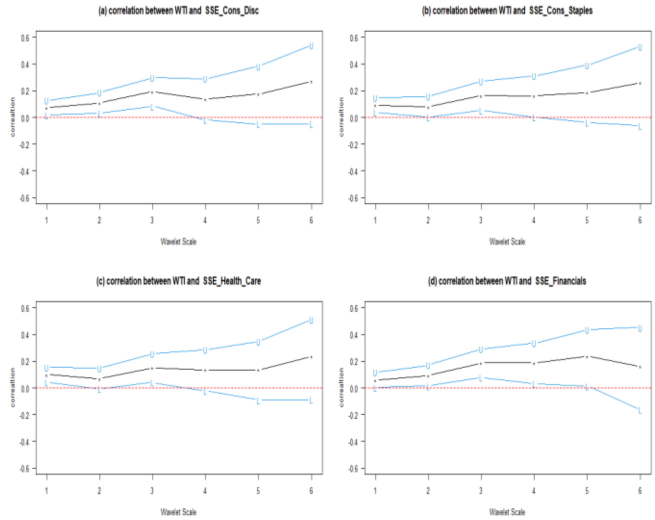

Figure 15: Correlations between SSE Cons Disc, SSE Cons Staples, SSE Health Care, SSE Financials and WTI

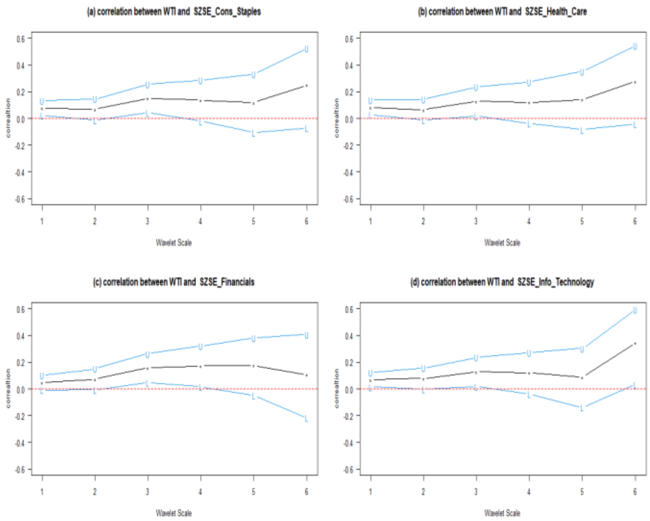

Figure 16: Correlations between SZSE Cons Staples, SZSE Health Care, SZSE Financials, SZSE Info Technology and WTI

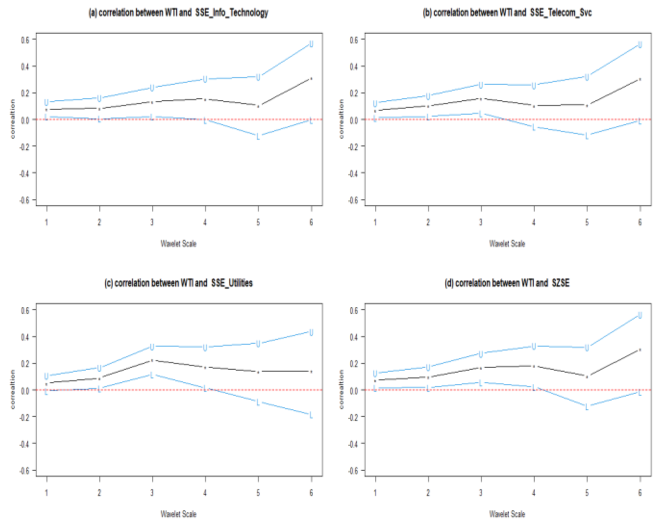

Figure 17: Correlations between SSE Info Technology, SSE Telecom Svc, SSE Utilities, SZSE and WTI

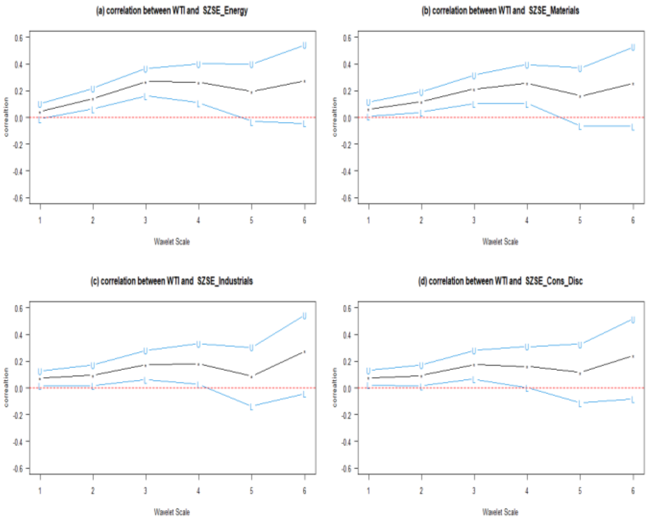

Figure 18: Correlations between SZSE Energy, SZSE Materials, SZSE Industrials, SZSE Cons Disc and WTI

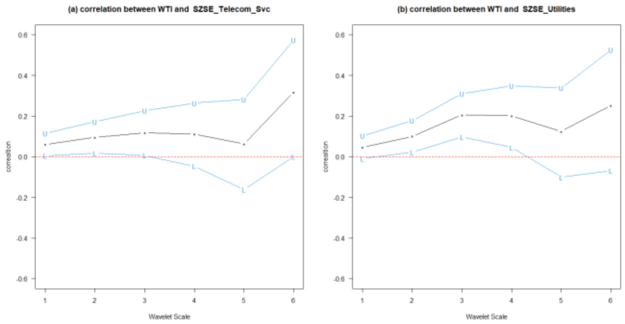

Figure 19: Correlations between SZSE Telecom Svc, SZSE Utilities and WTI

APPENDIX C: Cross-Correlations between WTI and Stock Indices at different time scales

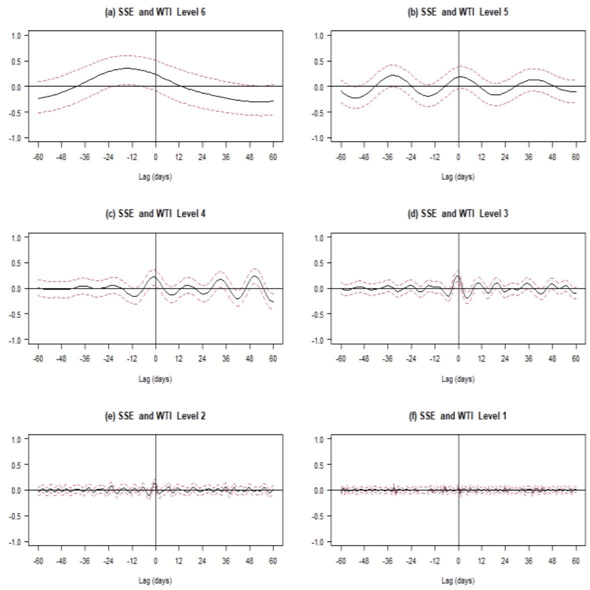

Figure 20: Cross-Correlation between SSE and WTI at different time scales

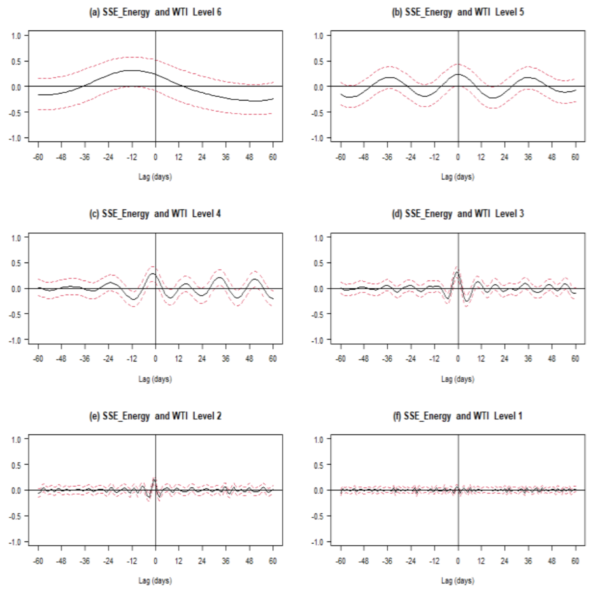

Figure 21: Cross-Correlation between SSE Energy and WTI at different time scales

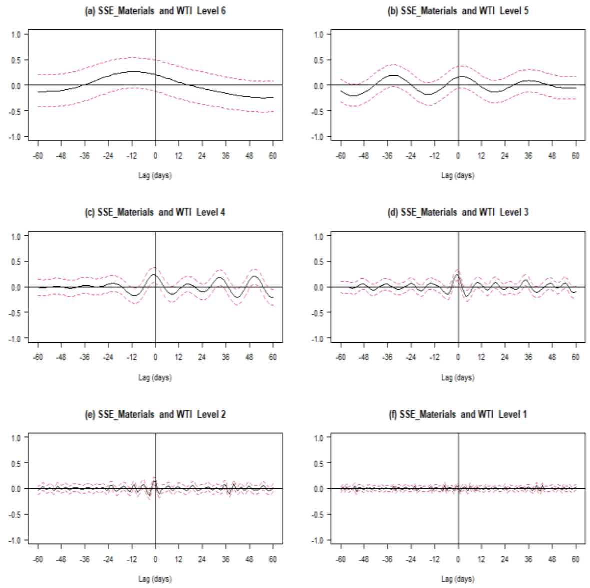

Figure 22: Cross-Correlation between SSE Materials and WTI at different time scales

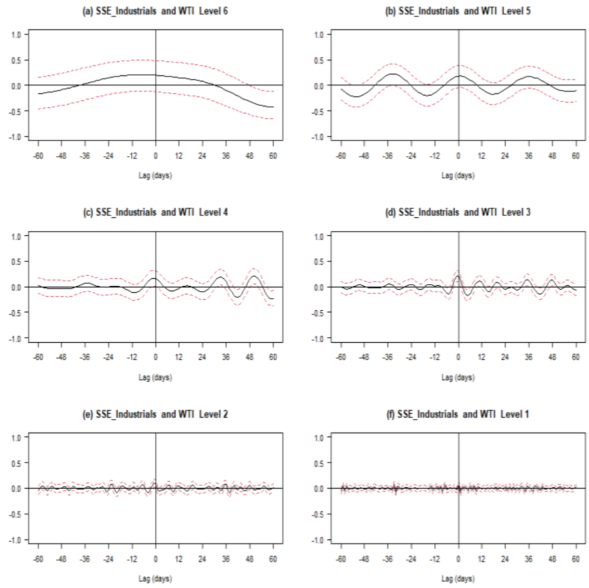

Figure 23: Cross-Correlation between SSE Industrials and WTI at different time scales

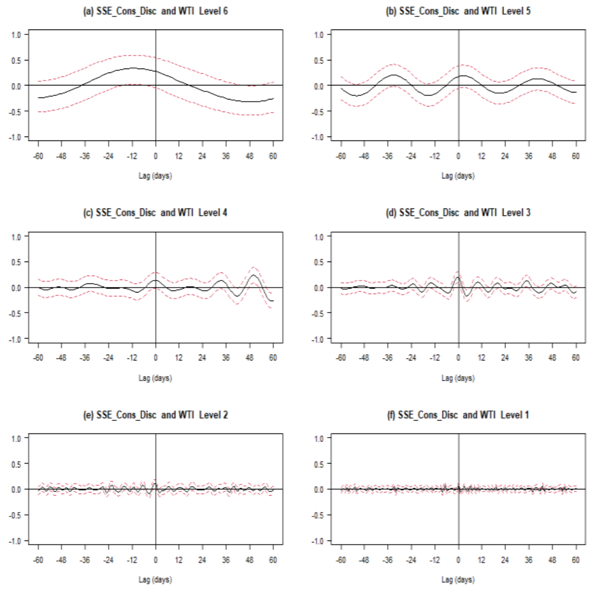

Figure 24: Cross-Correlation between SSE Cons Disc and WTI at different time scales

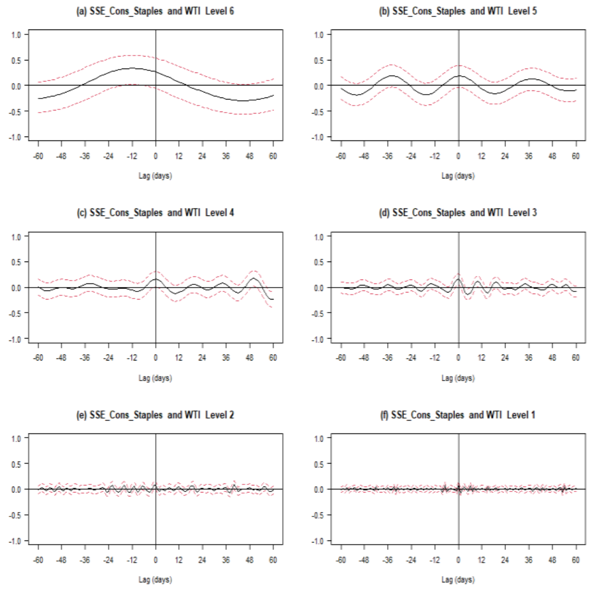

Figure 25: Cross-Correlation between SSE Cons Staples and WTI at different time scales

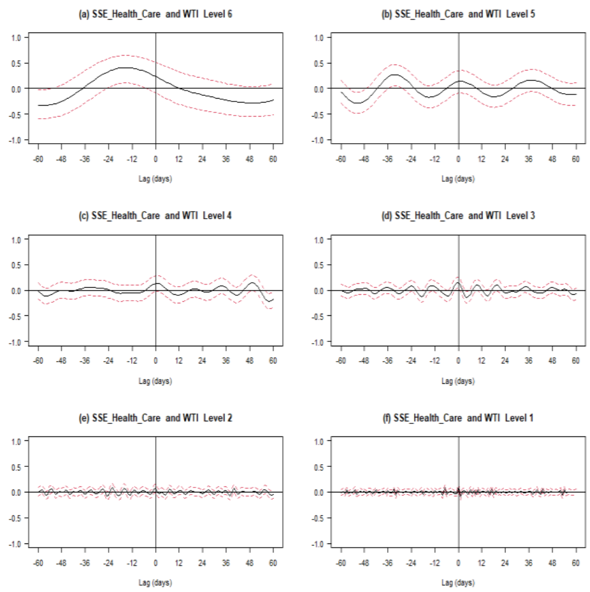

Figure 26: Cross-Correlation between SSE Health Care and WTI at different time scales

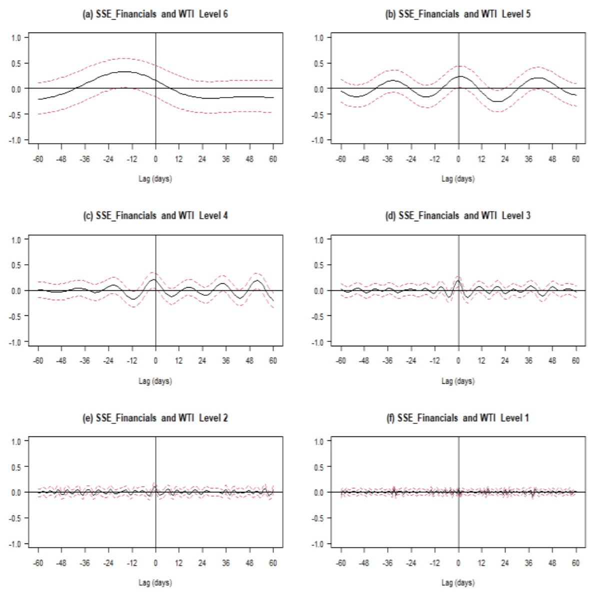

Figure 27: Cross-Correlation between SSE Financials and WTI at different time scales

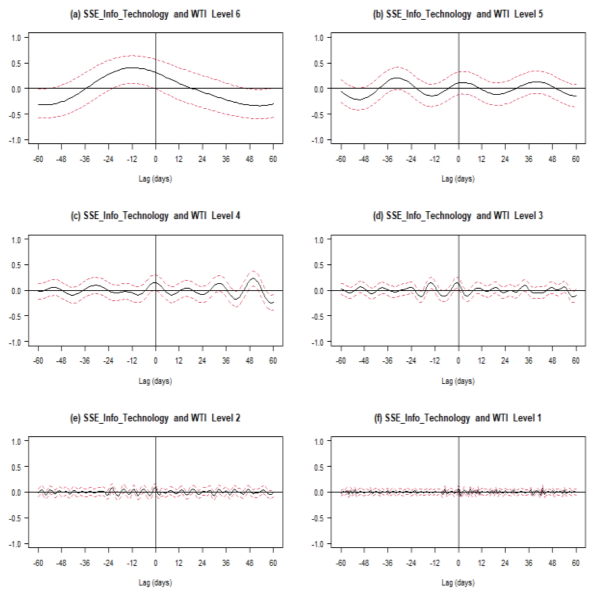

Figure 28: Cross-Correlation between SSE Info Technology and WTI at different time scales

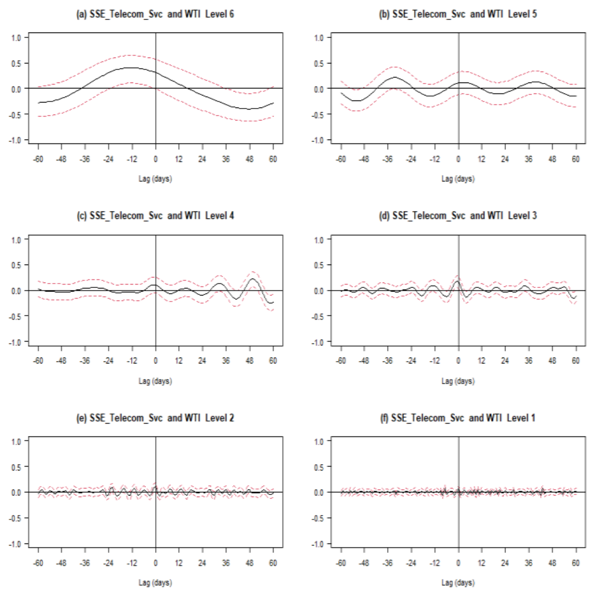

Figure 29: Cross-Correlation between SSE Telecom Svc and WTI at different time scales

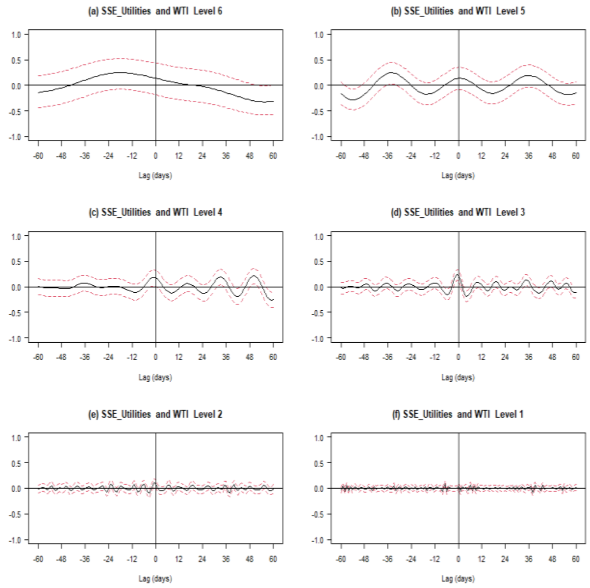

Figure 30: Cross-Correlation between SSE Utilities and WTI at different time scales

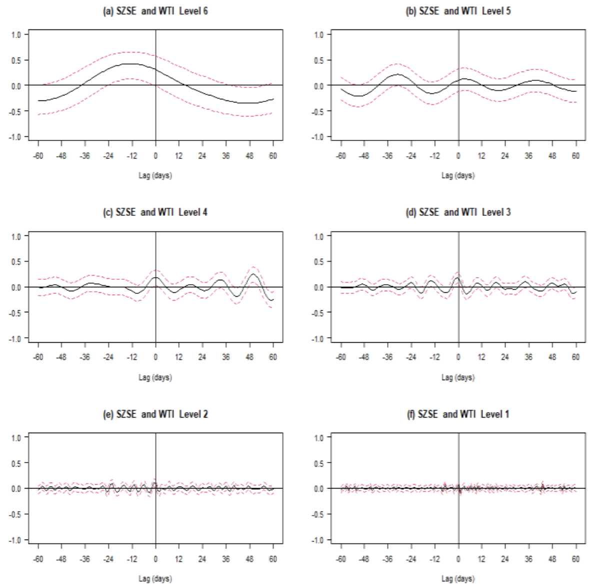

Figure 31: Cross-Correlation between SZSE and WTI at different time scales

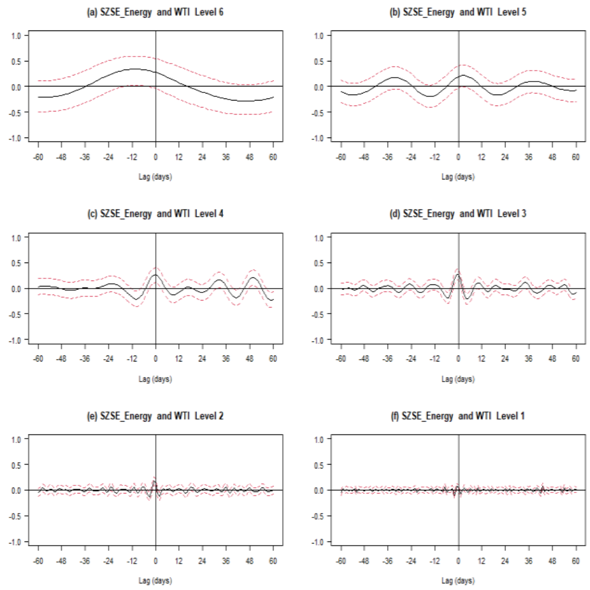

Figure 32: Cross-Correlation between SZSE and WTI at different time scales

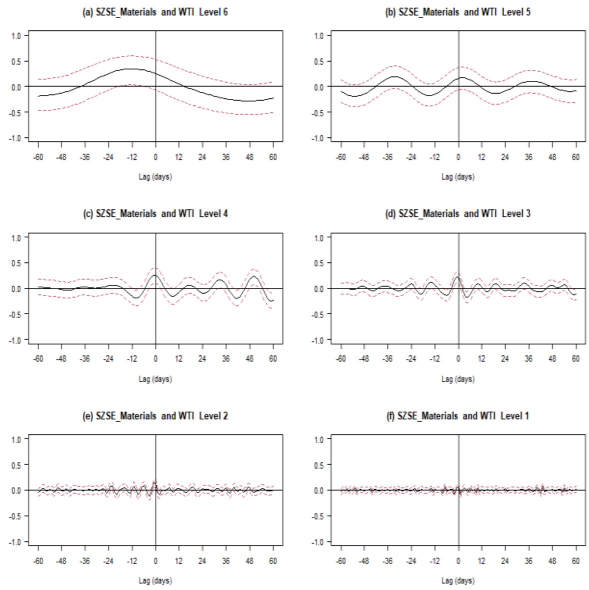

Figure 33: Cross-Correlation between SZSE Materials and WTI at different time scales

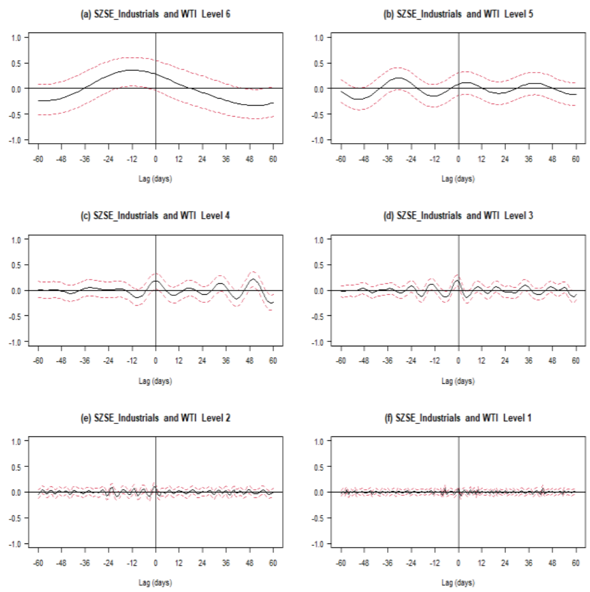

Figure 34 Cross-Correlation between SZSE Industrials and WTI at different time scales

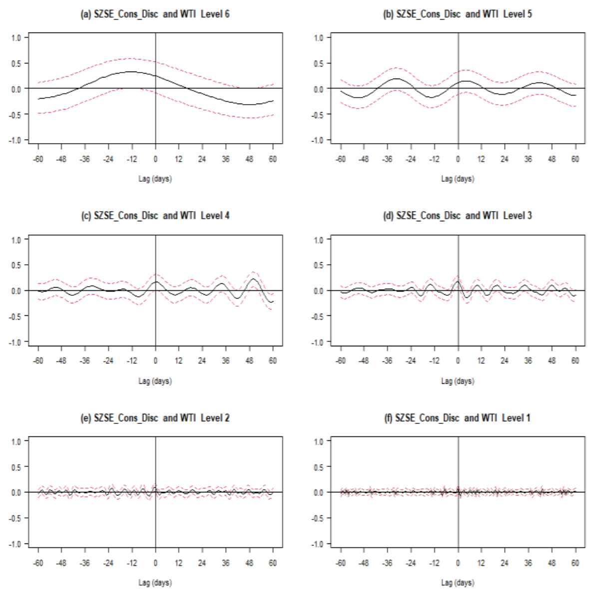

Figure 35 Cross-Correlation between SZSE Cons Disc and WTI at different time scales

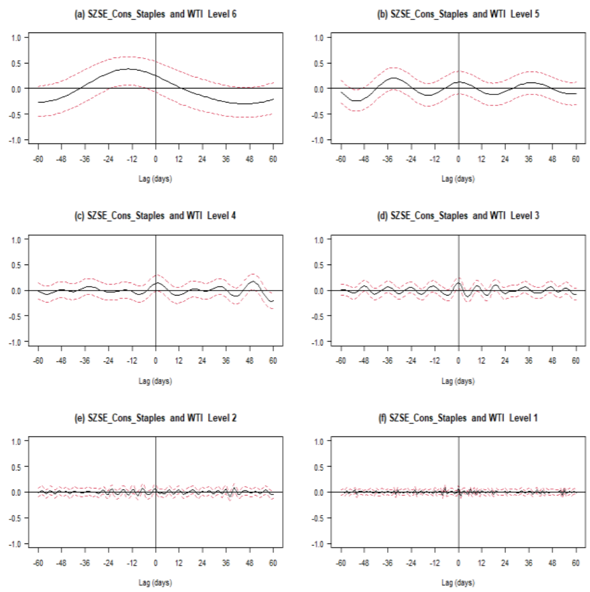

Figure 36 Cross-Correlation between SZSE Cons Staples and WTI at different time scales

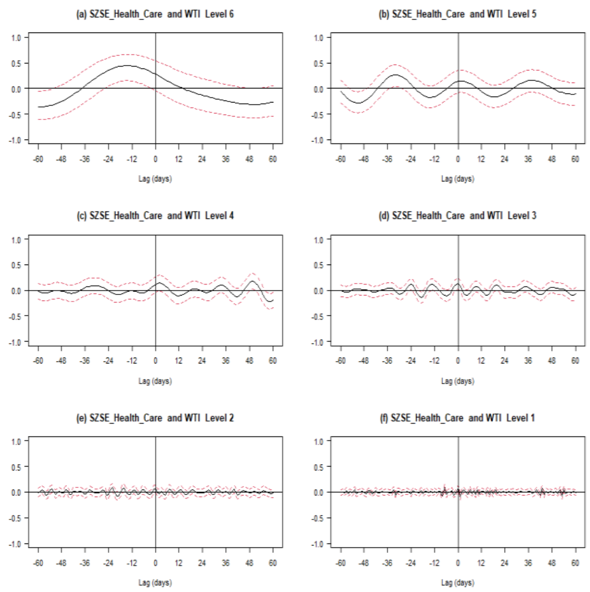

Figure 37 Cross-Correlation between SZSE Health Care and WTI at different time scales

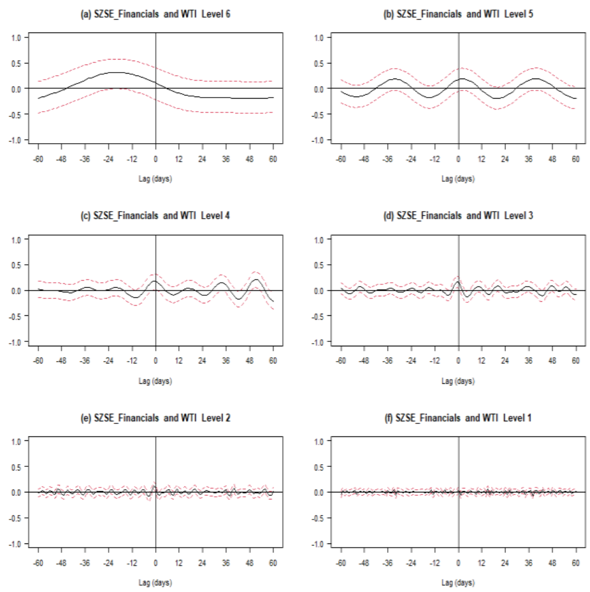

Figure 38 Cross-Correlation between SZSE Financials and WTI at different time scales

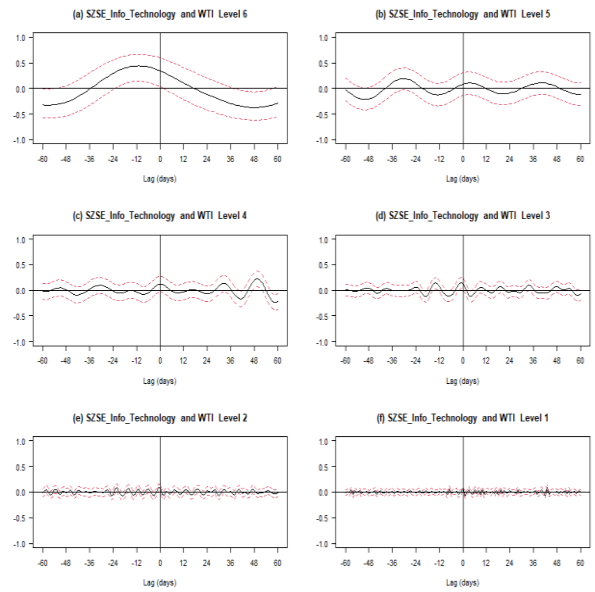

Figure 39 Cross-Correlation between SZSE Info Technology and WTI at different time scales

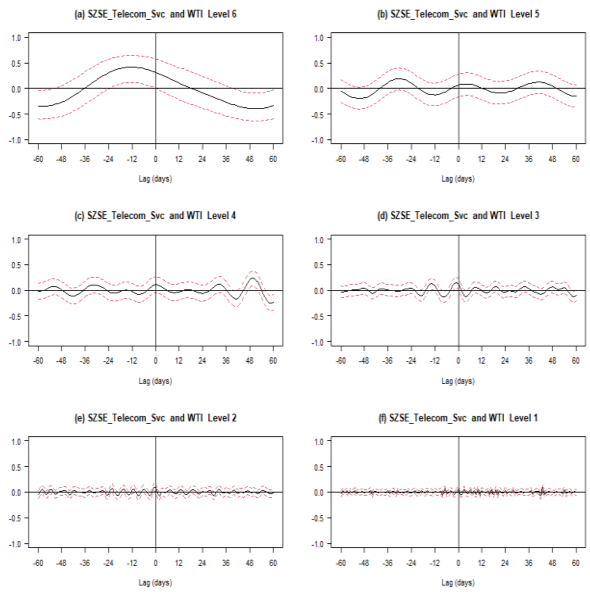

Figure 40 Cross-Correlation between SZSE Telecom Svc and WTI at different time scales

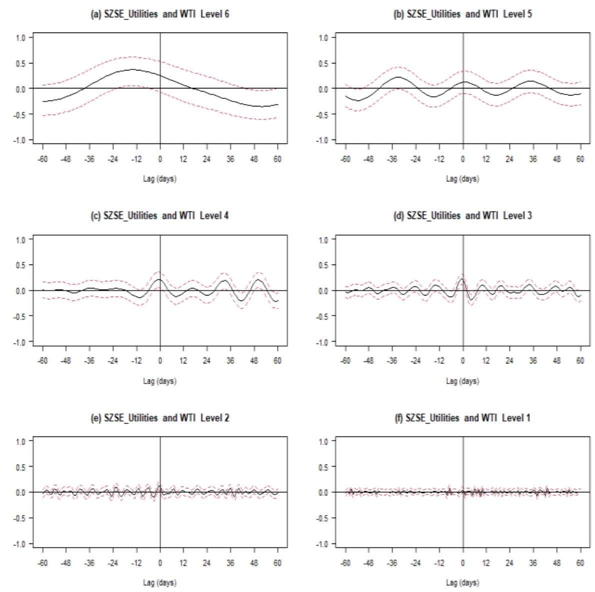

Figure 41 Cross-Correlation between SZSE Utilities and WTI at different time scales

IMPACTS OF ALTERNATIVE ENERGY PRODUCTION INNOVATION ON REDUCTION OF CARBON DIOXIDE EMISSIONS: EVIDENCE FROM CHINA

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ABSTRACT: Though the impacts of green innovation on reduction of carbon dioxide emissions have been an important topic for research on environmental economics, the previous studies ignore heterogeneity of the green innovation and how it might affect the carbon dioxide emissions. This paper identifies the alternative energy production innovation as the main factor from the green innovation which plays a core role in the reduction of CO_2 emissions. It examines how the alternative energy production innovation affects the reduction of the carbon dioxide emission. It further analyzes the effects of the alternative energy production innovation on the CO_2 emissions from different energy resources. Using a sample of 30 provinces in China during the period from the years of 1997-2017, we find the evidences that the alternative energy production innovation is positively related to the deduction of carbon dioxide emissions. In addition, the impacts of the alternative energy production

innovation shows a heterogeneous effects on the deduction effects from different energy sources.. The study contributes to the innovation theory on environmental economics.
Key Words: alternative energy production innovation, carbon dioxide emissions, green innovation, energy structure

INTRODUCTION

The issue of global change has become one of the most severe challenges facing mankind in the 21st century (Rehman et al., 2021; Shen et al., 2020). The increasing in carbon volume leads to global warming, which directly threatens economic and social life and sustainable development of the world(Hansen et al., 2013). Great efforts have been committed to reduce the CO_2 emissions in order to maintain a sustainable development for the human-being (Huisingh et al., 2015). Researches in the area of the impacts of technology innovation on the CO_2 emissions have tended to concentrated on the green technology innovation (Hashmi and Alam, 2019; Khan et al., 2020; Lee and Min, 2015; Shahbaz et al., 2020; Thong et al., 2020). It is widely acknowledged that the green technology innovation facilitates on the deduction of CO_2 emissions (Chen and Lee, 2020; Cheng et al., 2021a; Du et al., 2019a; Fernandez Fernandez et al., 2018; Hashmi and Alam, 2019; Toebelmann and Wendler, 2020; Zhang et al., 2017a), with very few of which focusing on the innovation of the transition to low-carbon energy (Du et al., 2021; Sarkodie and Owusu, 2020; Yao et al., 2021).

Despite of advances in green innovation perspective, little consideration has been given to the divergence of the heterogeneity of the connotation. Green innovation is a broad conception, which includes a wide range of innovations related to environmental improvement. However, these innovations vary according to different objectives, characteristics and functions (Albino et al., 2014; Jiao et al., 2020). Ignoring the heterogeneity of different types of green innovations may lead to inconsistent results (Guan and Yan, 2016). For example, the IPC Committee of Experts divides the patents in the IPC Green Inventory into 7 categories, including both energy substitution and waste treatment, which are different in terms of their impacts on the reduction of CO_2 emission (Gerres et al., 2019; Wendler, 2019). It is obvious that compared with the innovation of energy substitution, the mechanisms for the innovation waste treatment is more focused on the reduction of the pollution, which has limited effects on the CO_2 emissions. The Mixing the effects of these two different types of green innovations on the CO_2 emissions may lead to contradicted conclusions, which might be related to the misinterpretation of the effects of green innovation (Du et al., 2019b; Su and Moaniba, 2017).

It is still far from sufficiency to understand the essential mechanisms on how exactly the green technology innovation leads to the deduction of CO_2 emissions. The question of whether green innovation can facilitate with the reduction of CO_2 emissions by promoting innovation in transition of low-carbon energy has not been clearly answered yet. As the CO_2 emissions generated in energy supply are one of the major resources of the total CO_2 emissions on the earth, researches on how to reduce the CO_2 emissions in energy supply have attracted the attention of the academic community (Danish et al., 2020). There are mainly several measures to reduce CO_2 emissions in the energy supply such as reducing energy demand and energy supply (Li and Yao, 2020), improving energy supply efficiency (Liu et al., 2019) and changing the structure of energy supply (Ji and Zhang, 2019), reducing the usage of the energy generating high-emissions, increasing the usage of energy generating low-emission, and transiting to renewable energy (Ahmed and Shimada, 2019; Kang and Yang, 2020). As reducing the energy usage may inevitably lead to slowing the speed of economic development (Mishra et al., 2019; Yin and Liu, 2021), improving the efficiency of energy is a more positive and practical to deal with this issue, which is believed to be driven by the innovation of the alternative energy production (Hasanbeigi et al., 2014; Liu et al., 2019).

The objective of this study is to enhance the understanding of the impacts of the alternative energy production innovation on the reduction of CO_2 emission, which is separated from the concept of the green innovation. First, we provide a theoretical and empirical extension to the studies of the green innovation and CO_2 emissions. Based on this theoretical framework, we examine the exact effects of the alternative energy production innovation on the CO_2 emissions. We further analyze the impacts of the alternative energy production innovation on the transition of low-carbon energy transition and its impacts on the reduction of CO_2 emissions from different sources of energy.

4. Alternative Energy Production Innovation

1.1. Alternative Energy Production Innovation in Green Innovation

Alternative energy production innovation refers to innovation in the field of alternative energy production, which is actually included within the definition of the green innovation (Dresselhaus and Thomas, 2001; Tabatabaei et al., 2015). In accordance with the existing literatures, there are mainly four indexes commonly used to measure the green innovation, namely: R&D investment/R&D subsidies (Balsalobre-Lorente et al., 2018; Song et al., 2018), complex index of green innovation (Fan et al., 2015; Hao et al., 2021), green innovation efficiency (Song et al., 2020; Zhang et al., 2019) and green patents (Chen and Chen, 2021; Ma et al., 2021). Whereas, as one of the widely used explanatory of the studies on its impact on the CO2 emission, the green innovation suffers some limitations in terms of broad and extensive definition of innovation. Specificly, R&D investment/R&D subsidies can only reflect the input of the innovation while neglect the output of it. The complex index of green innovation may provide more comprehensive information of the innovation; however, the selection of the specific indicators and the setting of weights may not well be targeted to the CO2 emissions. The green innovation efficiency needs to be calculated through the input-output method, which may also be embedded with objectivity issues. In terms of the objectivity and representativeness of data reliability, the green patent is an ideal variable to measure the current level of green innovation. Therefore, to measure the innovation level of alternative energy production, this study chooses to identify the alternative energy product patents from the system of the green patents.

Green patent is normally categorized in the system of industrial technology patent. The IPC Green Inventory developed by the IPC Expert Committee (https://www.wipo.int/classifications/ipc/en/green_inventory/index.html) classifies the green patents into seven major categories and several sub-categories according to functions and objectives of the patent (see Table 1). It is now widely recognized as a comprehensive searching tool for patent information related to green innovation (Fujii and Managi, 2019; Li et al., 2021). As one of an important sub-categories in the IPC Green Inventory category, patents for Alternative Energy Production (AEP) are listed for the innovation on development or promotion of the alternative energy usage.

Table 1 Seven Categories of IPC Green Inventory

Abbreviation	Category Name	Subclasses
AEPP	ALTERNATIVE ENERGY PRODUCTION PATENTS	BIO-FUELS; INTEGRATED GASIFICATION COMBINED CYCLE (IGCC); FUEL CELLS; PYROLYSIS OR GASIFICATION OF BIOMASS; HARNESSING ENERGY FROM MANMADE WASTE; HYDRO ENERGY; OCEAN THERMAL ENERGY CONVERSION (OTEC); WIND ENERGY; SOLAR ENERGY; GEOTHERMAL ENERGY; OTHER PRODUCTION OR USE OF HEAT, NOT DERIVED FROM COMBUSTION, E.G. NATURAL HEAT; USING WASTE HEAT; DEVICES FOR PRODUCING MECHANICAL POWER FROM MUSCLE ENERGY
TSP	TRANSPORTATION PATENTS	VEHICLES IN GENERAL; VEHICLES OTHER THAN RAIL VEHICLES; RAIL VEHICLES; MARINE VESSEL PROPULSION; COSMONAUTIC VEHICLES USING SOLAR ENERGY

ECP	ENERGY CONSERVATION PATENTS	STORAGE OF ELECTRICAL ENERGY; POWER SUPPLY CIRCUITRY; MEASUREMENT OF ELECTRICITY CONSUMPTION; STORAGE OF THERMAL ENERGY; LOW ENERGY LIGHTING; LOW ENERGY LIGHTING; RECOVERING MECHANICAL ENERGY
WMP	WASTE MANAGEMENT PATENTS	WASTE DISPOSAL; TREATMENT OF WASTE; CONSUMING WASTE BY COMBUSTION; REUSE OF WASTE MATERIALS; POLLUTION CONTROL;
A/FP	AGRICULTURE / FORESTRY PATENTS	FORESTRY TECHNIQUES; ALTERNATIVE IRRIGATION TECHNIQUES; PESTICIDE ALTERNATIVES; SOIL IMPROVEMENT
ARDP	ADMINISTRATIVE, REGULATORY OR DESIGN ASPECTS PATENTS	COMMUTING, E.G., HOV, TELEWORKING, ETC.; CARBON/EMISSIONS TRADING, E.G. POLLUTION CREDITS; STATIC STRUCTURE DESIGN
NPGP	NUCLEAR POWER GENERATION PATENTS	NUCLEAR ENGINEERING; NUCLEAR ENGINEERING

AEPI was ranked at the fourth of all innovation in the system of Green Invention Patents in terms of its weighting in China in the year of 2017, following behind Waste Management Invention Patents, Energy Conservation Invention Patents and Administrative Regulatory/ After Design Aspects Invention Patents (Fig. 1). Compared with Waste Management Patents which ranked at the top of the Green Innovation Index, which emphasizes on the reduction of pollution emissions, the Alternative Energy Production Innovation plays a more important role in the input end in terms of the CO2 emissions production.

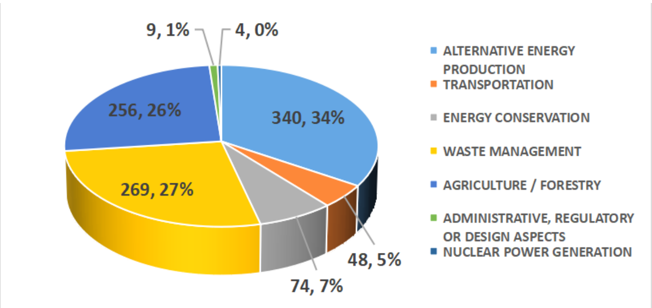

Fig. 1a. Composition of Green Invention Patents-1997

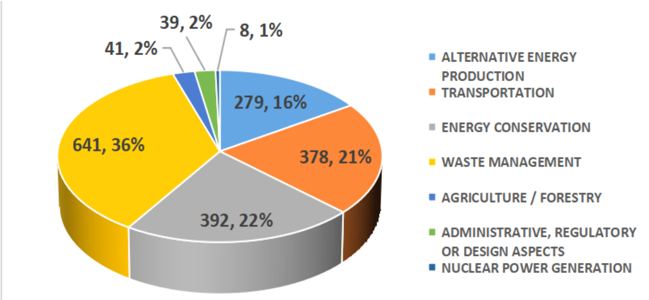

Fig. 1b. Composition of Green Utility Model Patents-1997

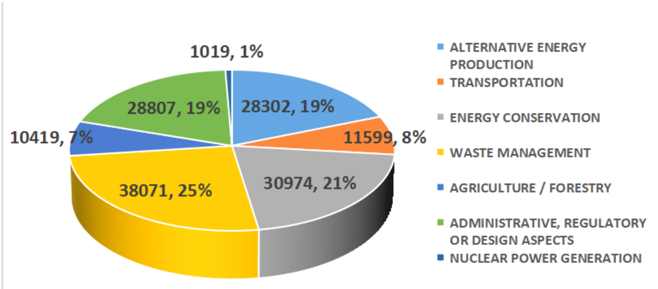

Fig. 1c. Composition of Green Invention Patents-2017

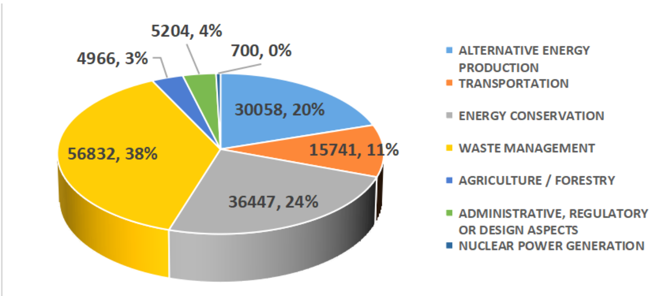

Fig. 1d. Composition of Green Utility Model Patents-2017

1.2. Hypotheses development

1.2.1. Alternative Energy Production Innovation and Carbon Emission Reduction Effect

The driving force for alternative energy innovation is not only motivated by the demand for environmental protection, but more importantly, from the concerning on the depletion of natural resources (Hu et al., 2021). Though the new energy has been actively promoted and developed by all countries, the proportion of fossil energy used in the primary energy demand of the world is still takes account for 80-95%. Since the fossil energy is not renewable in the short term, it is likely to be exhausted in the near future . Therefore, AEPI may contribute on the reduction of CO2 emissions in by seeking for new alternative energy or improving the efficiency of the current usage of the energy (Shao et al., 2021).

AEPI may also contributes to the reduction of CO2 emissions by improving the efficiency of new energy that has been widely used (Xu et al., 2021). The emergence of new alternative energy sources can increase the overall supply of energy and provide the market with richer selectivity (Khurshid and Deng, 2021). The increasing efficiency of the usage of alternative energy sources may reduce the usage cost of the alternative energy sources directly, which may further promote the reduction of the related price of AEP in the market. The decline in the price of AEP could lead to an increase in consumer demand for AEP. These demands are mainly from several aspects as shown in Figure 3. First, it is the power generation link. A major demand for alternative energy comes from electricity production (Chen et al., 2021). According to the *China Renewable Energy Development Report in 2020*, the renewable energy generated more than 2.2 trillion kilowatt-hours, accounting for about 30% of all power generation in the country. The alternative energy sources account for less than 5% of total energy consumption (Fig. 2). The decreasing of the prices for AEP may facilitate its wider usage for the power generation. Second, some alternative energy sources can be directly used in industrial production (Lund, 2009; Taibi et al., 2012). For example, geothermal energy can be directly used in industrial boilers without being converted into electricity. Third, the decline in AEP price has promoted the demand for AEP for daily life usage of the residents (Mohideen, 2013; Turyareeba, 2001). The development of geothermal energy mining technology has been widely used for heating system by residents in winter. During the recent years, roof solar equipment to provide residents with hot water and lighting which has rapidly been popular in China. In addition, due to the increase in the proportion of low-cost AEP in electricity, the electricity may transit to be more popular under the environment regulations on the reduction of CO2 emission. Innovation may contribute to the electric heating (Bamisile et al., 2021; Shyu, 2012; Zahnd and Kimber, 2009), thereby increasing the demand for AEP in production and life which may reduce the CO2 emissions indirectly.

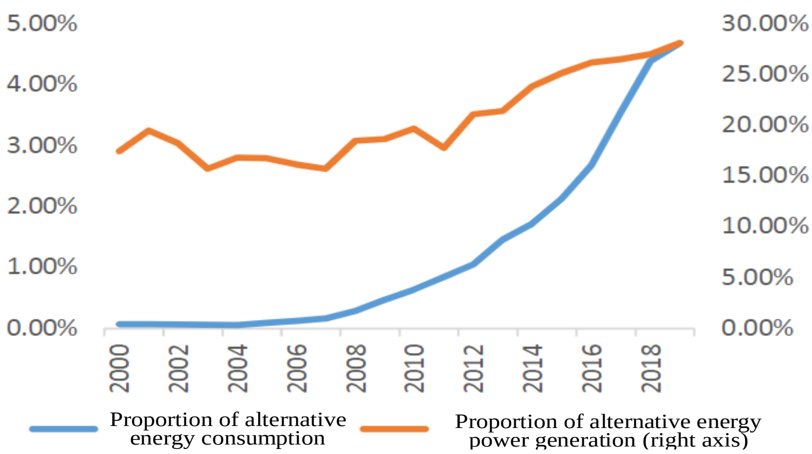

Fig. 2 Consumption of alternative energy in China 2000-2020

It is widely acknowledged that using new energy to replace fossil one is a way to reduce the CO2 emissions while facilitating the economic growth (Boluk and Mert, 2015; Chen et al., 2019; Emir and Bekun, 2019; Lin and Moubarak, 2014; Long et al., 2015; Menyah and Wolde-Rufael, 2010; Pao and Fu, 2013; Riti et al., 2018). This is mainly due to the fact that AEP is mainly composed of solar energy, hydropower, wind energy, biomass energy, wave energy, tidal energy, ocean temperature difference energy, and geothermal energy (Amponsah et al., 2014). Compared with traditional fossil energy sources, alternative energy sources may generate lower CO2 emissions in the power generation/thermal process and can also be recycled technologically, which is described as an inexhaustible "green power" (Wang et al., 2021). AEPI can not only directly improve the production efficiency and diversity of AEP which may facilitate to the decrease of the intensity of CO2 emissions, some types of the innovation are specifically aimed at reducing the efficiency and carbon emissions in the process of AEP factory construction, equipment production and equipment processing. Therefore, though the relationship between AEP consumption and CO2 emissions may be positive (Apergis et al., 2010), it is still believed that the effects of AEPI on carbon emissions is generally negative. Thus, it is proposed that:

Hypothesis 1: The AEPI is negatively related to the CO2 emissions.

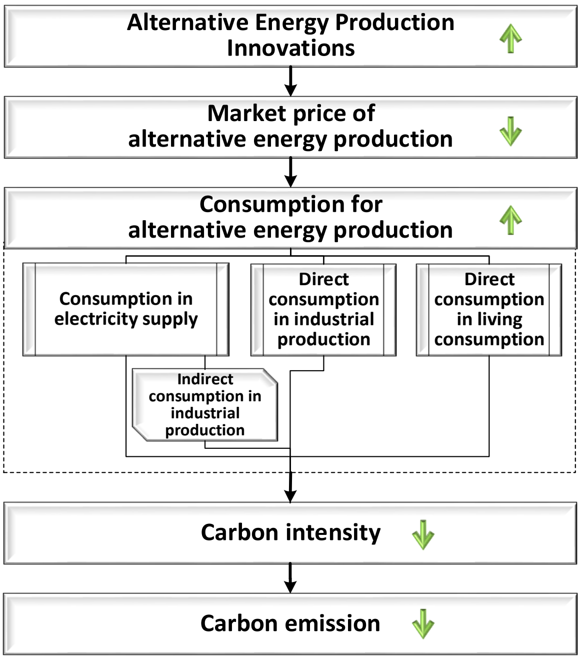

Fig. 3 Impact of AEP price decline on AEP consumer demand

1.1.2. Heterogeneity of Alternative Energy Production Innovation on CO2 emissions from different energy resources

There is also heterogeneity existing in the mechanism of AEPI affecting the CO2 emissions from different types of energy resources. The AEPI does not only include the innovation for the AEP but also for efficiency improvement of existing energy which may generate comparatively low CO2 emissions. As the government normally sets a standard for the total volume of CO_2 emissions without regulating the specific resource/type of the energy usage (Wen and Wang, 2020; Xu and Lin, 2015; Xuan et al., 2020; Zhao et al., 2017), firms may prefers to adopt strategies to respond to the regulations at a lowest cost which may include both the usage of APE, or a type of energy generating comparatively low CO_2 emissions. For the latter choice, the APEI may also include these aiming to improve the efficiency of the usage of energy with lower CO_2 emissions.

As for the positive relativeness between the energy usage and economic growth, it is undesirable to reduce energy consumption to realize the CO_2 emission reduction targets set by the governments (Bloch et al., 2015; Wesseh and Lin, 2016). The adoption of AEP could be one of the best solutions for firms to respond to the environmental regulations. Due to the large differences in energy sources, there is a priority order in the process of energy substitution responding to the environmental regulations. Generally speaking, the low-cost alternative fossil energy is the first to be replaced by other low-emission energy sources (Wang et al., 2015). Taking the amount of energy provided by an energy source to emit one unit of CO_2 as a measure of the cost of energy substitution (Khurshid and Deng, 2021), among the three most commonly used fossil energy sources in China: coal (Shi, 2011; Wang et al., 2019a), oil and natural gas, the replacement cost of coal is the lowest, followed by oil and natural gas subsequently (Guo et al., 2020; Wang and Li, 2016; Zhang et al., 2017b).

The Chinese government sets its CO_2 emission target in the year of 2030 and CO_2 emission neutrality in 2060, which has imposed strong environmental regulation to the market and thus shaped the behavior of firms. The cost of energy substitution varies. When the supply of new energy products cannot fully satisfy the demand for the substitution of traditional fossil energy, the market may firstly choose the fossil energy products with a comparatively lower substitution cost, which may increase the CO_2 emissions from that type of energy (Aune et al., 2004; Lenox and Kaplan, 2016; van Ruijven and van Vuuren, 2009; Waxman et al., 2020)). Compared with the natural gas, the coal and oil are firstly to be substituted by AEP due to its low cost of substation and high CO_2 emissions. Though the AEP has developed rapidly with the past decades, there is still a big gap between the demand the supply in a market, which is still in short of the supply of the APE. Therefore, the natural gas is still taken one of the most important low CO_2 emission energy as equivalent to the APE in the market. The APEI aimed to lower the cost of the usage of the natural gas may further lead to the enlarging of the total consumption of the natural gas, which may increase the CO_2 emissions. Different with the mechanisms that APEI affecting on the substitution of the coal and oil, the APEI may have an opposite effects on the reduction of the CO_2 emissions from the natural gas. Thus, it is proposed that:

Hypothesis 2a. The AEPI is negatively related to the CO_2 emissions for the coal.

Hypothesis 2b. The AEPI is negatively related to the CO_2 emissions from the oil.

Hypothesis 2c. The AEPI is positively related to the CO2 emissions for the natural gas.

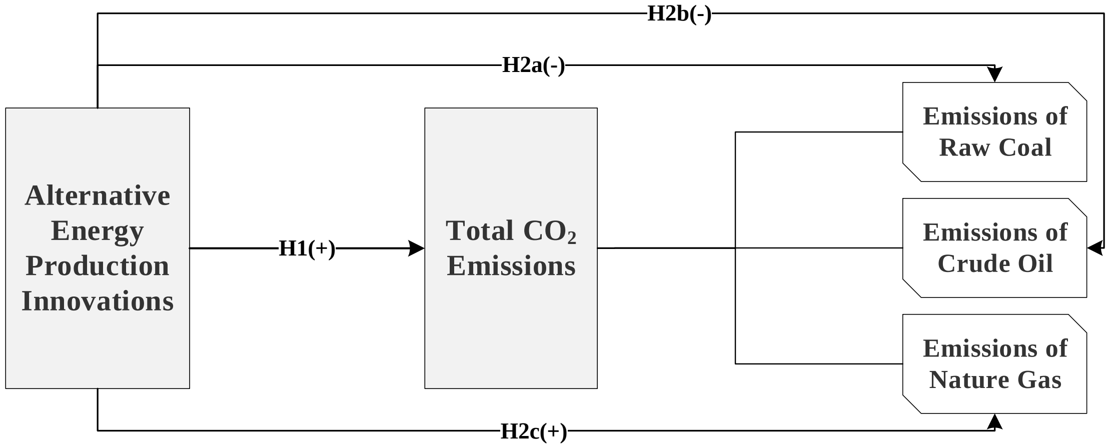

Figure 4. The theoretical framework of the AEPI affecting on the CO2 emissions

5. Research methods

2.1. Sample and Data

Table 3 presents the description of the sample. The panel data involves data from 30 provinces during the period from 1997 to 2017 (Tibet, Hong Kong, Macao and Taiwan are excluded due to the availability of the data). There are 584 samples finally included for the data analysis.

Table 3 Descriptive statistics of the Samples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	N	mean	sd	min	p25	p50	p75	max
ERC	584	187.4	199.7	0	61.11	130.1	235.2	1,527
ECO	584	37.43	46.73	0	4.792	24.50	48.06	353.0
ENG	584	6.088	7.497	0	0.643	3.750	8.552	49.69
TCE	584	245.2	229.8	0.814	92.12	176.4	317.5	1,552
IS	584	46.01	7.887	19.01	42.10	47.40	51.60	61.50
EC	584	1,164	1,082	34.60	449.1	812.2	1,460	5,959
PGDP	584	26,328	22,717	2,048	8,610	19,636	37,312	118,198
POP	584	42.40	26.13	4.960	24.09	37.82	58.08	111.7

FE	584	217.9	227.2	3.363	44.46	128.5	334.6	1,504
ES	584	0.963	0.374	0	0.728	0.902	1.119	2.345
AEPI	584	528.3	1,005	0	37.50	147	551.5	9,170
URB	584	0.489	0.154	0.196	0.381	0.472	0.566	0.896
IER	584	203.9	167.9	28.36	132.0	170.2	235.6	2,368

We set sample period from the years of 1997 to 2017 due to the data availability. The latest provincial-level data of the carbon dioxide emissions as for the dependent variable is updated in the year 2017. The data of main independent variable as the patents of green innovation was published completely from the year of 1997.

The data of carbon dioxide emissions are collected from CEADs (Carbon Emission Accounts & Datasets, https://www.ceads.net/). The data provided by CEADS are from the research findings funded by the National Natural Science Foundation of China, the Ministry of Science and Technology of China and the British Research Council. It is an official website to provide the public with accurate and up-to-date carbon emissions and socio-economic trade data in China. It is also one of most authoritative and reliable databases for researches on climate change and carbon neutrality issues in emerging economies (Shao et al., 2018; Wu et al., 2020; Xu et al., 2018; Yang et al., 2020; Yi et al., 2019). The data of patents are obtained from the database of the State Intellectual Property Office of China. We also use the databases including the *China Statistical Yearbook*, *Energy Statistics Yearbook* and *Financial Statistics Yearbook*. Table 2 presents the description of the measurements and data resources.

Table 2 Measurements and data resources

	Variable	Measurement	Unit	Data source
Dependent variables	TCE	Total CO2 emissions(mt)	Metric tons	CEADs, https://www.ceads.net/
	ERC	Emissions of raw coal(mt)	Metric tons	
	ECO	Emissions of crude oil(mt)	Metric tons	
	ENG	Emissions of nature gas(mt)	Metric tons	
Independent variables	AEPI	Alternative energy production innovation		IPC Green , Inventory"https://www.wipo.int/classifications/ipc/en/green

				_inventory/index.html Incopat, https://www.incopat.com
Control variables	ED	Economic development level		China Statistical Yearbook
	IS	Industry Structure	Percentage	
	POP	Population	Million	
	UR	Urbanization rate	Percentage	
	EC	Electricity consumption	Billion kwh	China Energy Statistical Yearbook
	ES	Energy structure	Percentage	
	FE	Finance express(Billion)	Billion RMB Yuan	Almanac of China's Finance and Banking
	IER	Intensity of environmental regulation	Ten thousands per mt	China Statistical Yearbook on Environment

2.2. Variables and Measurement

Dependent variables

Five dependent variables were included in this study. In examining both the total volume of the emissions and the emission structure, we test five dependent variables including total volume of CO2 emissions, the emissions from the major three channels, and manufacturing process. These five dependent variables are (1) total CO2 emissions (TCE)， (2) CO2 emissions from raw coal (ERC)， (3) CO2 emissions of crude oil (ECO) and (4) CO2 emissions of nature gas (ENG).

Independent variables

There is one independent variable in our analyses, namely, the alternative energy production innovation (AEPI). It was measured using the total number of patents related to alternative energy production.

Control variables

Eight control variables were included in this study: economic development level, industry, population, urbanization, electricity consumption, energy structure, government finance expense and environmental regulation.

The level of economic development level (ED) is measured by gross domestic production per capita. According to the environmental Kuznets curve, environmental pollution has an inverted U-shaped relationship with per capita income and regional development (Ahmad et al., 2021; Alvarez-Herranz et al., 2017; Baloch et al., 2021).

The industrial structure (IS) is measured by proportion of the manufactory industry in GDP. It is believed that the industrial structure has a significant impact on carbon emissions (Ahmad et al., 2021; Alvarez-Herranz et al., 2017; Baloch et al., 2021); However, the results remain inconsistent (Bai et al., 2020; Tian et al., 2014; Wang et al., 2021).

The population (POP) is measured by the number of the population of the province (Ding et al., 2015; Salman et al., 2019). It is generally believed that population is positively correlated with carbon emissions (Jobson, 2004; Yu and Du, 2019).

The urbanization rate (UR) is measured by the ratio of urban population to the total population of the area (Khan et al., 2019a). It is argued that the carbon dioxide emissions are positively related to the urbanization rate (Adebayo et al., 2021; Liu and Bae, 2018).

The electricity consumption (EC) is measured by volume of electricity consumption. Electricity consumption is chosen to substitute the energy consumption as a control variable, which is commonly used by previous studies (Dogan et al., 2021; Khattak et al., 2020).

The energy structure (ES) is measured by the proportion of coal consumption in total energy consumption. It is argued that the energy structure is positively related to the carbon dioxide emissions (Cheng et al., 2021b; Hu et al., 2020).

The government fiscal expenditure (FE) is measured by fiscal expenditure of the provincial government in the year. Government fiscal expenditure reflects the intensity of government environmental regulations (Cheng et al., 2020; Halkos and Paizanos, 2016), which is found to be negatively related to the carbon dioxide emissions (Cheng et al., 2021c).

The intensity of environmental regulations (IER) is measured by the cost of pollutant discharge per unit of emissions. It is believed environmental regulations and carbon emissions are negatively correlated (Khan et al., 2019b; NELSON et al., 1993; Pei et al., 2019; Wang et al., b)

Table 2 presents the measurement of all variables and data sources.

2.3. Empirical Model

Multiple regression models are adopted to analyze a panel data at provincial level of the country during the period between 1997 and 2017. The regressions were analyzed by using the software of STATA version 17.0 MP.

In accordance with the results of Hausman's test, the regressions adopt a fixed-effects models. Due to the reason that there is serious collinearity in sequentially, the fixed effect of time is not included. Models 1is used to test Hypothesis 1. Model 2, model 3 and model 4 are used to test Hypothesis 2a, 2b and 2c. The specific models are presented as follows:

$$TCE_{ij} = \beta_1 AEPI_{ij} + \beta_2 \mathrm{IS}_{ij} + \beta_3 \mathrm{EC}_{ij} + \beta_4 \mathrm{PGDP}_{ij} + \beta_5 \mathrm{FE}_{ij} + \beta_6 \mathrm{POP}_{ij} + \beta_7 \mathrm{ES}_{ij} + \beta_8 \mathrm{IER}_{ij} + \beta_9 \mathrm{URB}_{ij} \quad (1)$$

$$ERC_{ij} = \beta_1 AEPI_{ij} + \beta_2 \mathrm{IS}_{ij} + \beta_3 \mathrm{EC}_{ij} + \beta_4 \mathrm{PGDP}_{ij} + \beta_5 \mathrm{FE}_{ij} + \beta_6 \mathrm{POP}_{ij} + \beta_7 \mathrm{ES}_{ij} + \beta_8 \mathrm{IER}_{ij} + \beta_9 \mathrm{URB}_{ij} \quad (2)$$

$$ECO_{ij} = \beta_1 AEPI_{ij} + \beta_2 \mathrm{IS}_{ij} + \beta_3 \mathrm{EC}_{ij} + \beta_4 \mathrm{PGDP}_{ij} + \beta_5 \mathrm{FE}_{ij} + \beta_6 \mathrm{POP}_{ij} + \beta_7 \mathrm{ES}_{ij} + \beta_8 \mathrm{IER}_{ij} + \beta_9 \mathrm{URB}_{ij} \quad (3)$$

$$ENG_{ij} = \beta_1 AEPI_{ij} + \beta_2 \mathrm{IS}_{ij} + \beta_3 \mathrm{EC}_{ij} + \beta_4 \mathrm{PGDP}_{ij} + \beta_5 \mathrm{FE}_{ij} + \beta_6 \mathrm{POP}_{ij} + \beta_7 \mathrm{ES}_{ij} + \beta_8 \mathrm{IER}_{ij} + \beta_9 \mathrm{URB}_{ij} \quad (4)$$

6. Results

3.1. Descriptive statistics

Prior to running the regression analysis, a VIF test were conducted to test the multicollinearity possibilities (VIF>10). All the models were tested for heteroscedasticity issues and dealt by using a robust standard error method. As can be seen in Table 1.

Table 1: Tests for Model Choice

	Model (1)	Model (2)	Model (3)	Model (4)
VIF Test	3.47	3.47	3.47	3.47
Heteroscedasticity test	196.71***	9353.70***	130.78***	1614.62***
Robustness SD	Yes	Yes	Yes	Yes
Model choice	FE	FE	FE	FE

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 4 reports the results of regression analyses. Models 1 is used to test the hypothesis 1. Models 2, model 3 and model 4 are used to test the hypothesis 2a, 2b and 2c respectively.

Hypothesis 1 is supported. In model (1), the coefficient of AEPI is -0.0653, which is significant at the 1% level, indicating that the alternative energy production innovation is negatively related to the total CO2 emissions.

Hypothesis 2a is supported. The results of Model (2) shows that the coefficient of AEPI to ERC (coal) was significantly negative (β=-0.0607, p<0.01), indicating that the AEPI has a positive impact on the deduction of the CO2 emissions.

Hypothesis 2b is supported. The regression coefficient of AEPI to ECO (oil) is significantly negative (β=-0.00797 p<0.01), see in Model (3).

Hypothesis 2c is supported. The regression coefficient (Model (4)) of AEPI to ENG (natural gas) is significantly positive (β=0.00235, p<0.01), indicating that AEPI increases the carbon emissions via the sources of natural gas, which follows our hypothesis.

Table 4 CO2 emission regression analyses

	Model (1)	Model (2)	Model (3)	Model (4)
VARIABLES	TCE	ERC	ECO	ENG
AEPI	-0.0653***	-0.0607***	-0.00797***	0.00235***
	(0.0122)	(0.0120)	(0.00115)	(0.000317)
IS	-1.575	-2.238**	0.465**	0.00741
	(0.984)	(0.810)	(0.215)	(0.0270)
EC	0.166***	0.129***	0.0324***	0.000306
	(0.00859)	(0.00886)	(0.00371)	(0.000457)
PGDP	0.00121***	0.000949***	0.000417***	4.79e-05***
	(0.000321)	(0.000318)	(0.000102)	(1.12e-05)
FE	-0.0599	-0.0874**	0.00651	0.0152***
	(0.0609)	(0.0419)	(0.0193)	(0.00396)
POP	0.806**	0.726**	-0.0813**	-0.0279***
	(0.328)	(0.299)	(0.0372)	(0.00826)
ES	255.6***	282.6***	-23.85***	-0.434

	(44.53)	(43.65)	(1.405)	(0.641)
IER	-0.0329	-0.000327	-0.0328***	-0.00168*
	(0.0537)	(0.0499)	(0.00924)	(0.000827)
URB	115.7**	88.66*	30.51***	-3.732***
	(54.54)	(48.96)	(9.615)	(1.217)
Constant	-190.0***	-179.6***	-11.74	3.352***
	(41.33)	(43.50)	(7.558)	(0.793)
Observations	584	584	584	584
R-squared	0.672	0.638	0.443	0.424
Number of year	21	21	21	21

Notes: Standard errors in parentheses,* p<0.01, ** p<0.05, * p<0.1**

3.2. Robustness Check and additional test

3.2.1. Robustness check

In check the robustness of the regression model, we conducted a series of robustness tests. First, we removed extreme values and re-regress performing 1% bilateral tailing for all variables. Tailoring is a common robustness test method, which can eliminate the influence of extreme values on the regression (Bieniek, 2016; Wu and Zuo, 2009). Second, the sample period was substituted with the period of 2000-2017, as the year of 2000 is widely used to analyze the CO2 emissions in China. (Du et al., 2018; Lu et al., 2010; Shi et al., 2014; Wang et al., 2005; Zhang et al., 2017c), which also a commonly used robustness test method (Bieniek, 2016; Buckley et al., 2013; Chen et al., 2001; Perez et al., 2008; RIVEST, 1994; Schuler et al., 2021) Third, we substituted the data of the explanatory variables one-year lagging to investigate whether the benchmark model is of endogeneity (Anselin et al., 1996; Kang and Dufour, 2021; Kostakis et al., 2015).

All the results of the robustness check remain consistent with the original measurements. Table 5 and Table 6 present the details of the robustness check results. Table 5 reports the robustness check for hypothesis 1. Table 6 reports the robustness check for hypothesis 2a, 2b and 2c correspondingly. In all the robustness tests, though the values of the coefficients are slightly different, the coefficients are generally consistent with the corresponding coefficients in the original models. It signifies that the original models of this study is relatively robust. There are basically no extreme value biases, sample selection biases and endogenous issues in the analysis process.

3.2.2. Additional test

In accordance with the standard of the Patent Office of China, the general patent could be further divided into three different sub-category ones, namely, invention patent, which signifies the most original innovation in method/technology; utility innovation patent, which signifies the application innovation or technology improvement based on the original innovation; appearance innovation, which signifies the improvement on outlook and appearance of the product. Compared with and appearance patent, the invention patent and utility patent signify essential innovation in terms of the technology and function improvement. Therefore, we further tested the divergent impacts of invention patent and utility innovation of the alternative Energy Production innovation on the CO2 emissions. Compared with the utility patent, the invention patent standards are higher which also signifies greater innovation efficiency (Beneito, 2006; Kim et al., 2012; Prud'Homme, 2017). The results show that both the coefficients of IP and UP are significantly negative, while the UP's negative effects on CO2 emissions is higher than that of IP. The coefficient of IP is -0.0822 ($p<0.01$), and the coefficient of UMP is -0.151 ($p<0.01$).

Table 5 Robust Test of Hypothesis 1

	R1: Tailing	R2：Years	R3：Lagging Effects
	(5)	(6)	(7)
VARIABLES	TCE	TCE	TCE
AEPI	-0.0832***	-0.0607***	-0.0935***
	(0.0108)	(0.0126)	(0.0122)
L1.AEPI			0.00826*
			(0.00400)
IS	-0.925	-1.723	-2.571**
	(0.713)	(1.044)	(1.126)
EC	0.153***	0.159***	0.175***
	(0.00750)	(0.00916)	(0.00883)
PGDP	0.00164***	0.00104**	0.00204***
	(0.000308)	(0.000428)	(0.000390)
FE	0.116***	-0.0567	0.0359
	(0.0339)	(0.0654)	(0.0707)
POP	0.697***	0.988**	0.691**

	(0.231)	(0.435)	(0.265)
ES	226.3***	282.5***	283.1***
	(34.42)	(46.29)	(52.18)
IER	-0.0486	-0.0330	-0.0364
	(0.0430)	(0.0613)	(0.0608)
URB	74.02*	160.4*	163.2***
	(37.37)	(82.49)	(52.91)
Constant	-193.1***	-223.6***	-224.0***
	(30.81)	(50.88)	(45.17)
Observations	584	516	485
R-squared	0.734	0.684	0.657
Number of year	21	18	21

Notes:Standard errors in parentheses,* p<0.01, ** p<0.05, * p<0.1**

Table 6 Robust test of Hypothesis 2 (standard error)

	R1:Tailing			R2：Years			R3：Lagging Effects		
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
VARIABLES	ERC	ECO	ENG	ERC	ECO	ENG	ERC	ECO	ENG
AEPI	-0.0792***	-0.00322*	0.00227***	-0.0562***	-0.00799***	0.00224***	-0.0790***	-0.0154***	0.00161***
	(0.00842)	(0.00164)	(0.000275)	(0.0123)	(0.00126)	(0.000336)	(0.0111)	(0.00278)	(0.000414)
L1.AEPI							0.00770*	0.000966	-0.000968***
							(0.00375)	(0.000561)	(9.31e-05)
IS	-1.096**	0.730***	0.0115	-2.350**	0.410*	0.00293	-3.007***	0.236	0.0182
	(0.387)	(0.178)	(0.0268)	(0.858)	(0.227)	(0.0299)	(0.923)	(0.250)	(0.0268)
EC	0.111***	0.0235***	0.000204	0.122***	0.0331***	0.000339	0.133***	0.0398***	-0.00104***
	(0.00753)	(0.00149)	(0.000466)	(0.00967)	(0.00371)	(0.000465)	(0.00787)	(0.00512)	(0.000332)
PGDP	0.00169***	0.000348**	4.14e-05***	0.000895**	0.000279**	6.26e-05***	0.00121***	0.000899***	8.38e-05***
	(0.000259)	(0.000150	(1.11e-05)	(0.000422)	(0.000129)	(1.31e-05)	(0.000331)	(0.000167)	(1.98e-05)

		)							
FE	0.114***	-0.00379	0.0202***	-0.0854*	0.00988	0.0162***	-0.0256	0.0293	0.0174***
	(0.0241)	(0.0225)	(0.00325)	(0.0448)	(0.0205)	(0.00415)	(0.0511)	(0.0266)	(0.00244)
POP	0.624***	0.00480	-0.0368***	0.921**	-0.121***	-0.0339***	0.710**	-0.230***	0.0129*
	(0.183)	(0.0582)	(0.00819)	(0.397)	(0.0379)	(0.0102)	(0.257)	(0.0543)	(0.00676)
ES	229.1***	-21.51***	-0.472	309.5***	-23.92***	-0.372	297.5***	-11.12***	0.0726
	(26.99)	(1.608)	(0.617)	(45.15)	(1.570)	(0.710)	(49.67)	(2.840)	(0.783)
IER	-0.0163	-0.0351*	-0.00198**	-0.00137	-0.0318***	-0.00168*	-0.00624	-0.0298***	-0.000936
	(0.0335)	(0.0173)	(0.000723)	(0.0575)	(0.00871)	(0.000868)	(0.0550)	(0.00962)	(0.000675)
URB	9.146	37.15**	-3.782***	119.3	47.22***	-5.870***	141.0**	22.89**	0.170
	(19.58)	(13.98)	(1.218)	(73.92)	(15.06)	(1.786)	(49.67)	(8.895)	(0.629)
Constant	-174.6***	-21.99***	2.960***	-209.6***	-15.55*	4.202***	-196.5***	-24.82***	-0.673
	(26.06)	(7.116)	(0.767)	(52.39)	(8.049)	(1.015)	(46.69)	(8.620)	(0.534)
Observations	584	526	584	516	516	516	485	485	485
R-squared	0.758	0.349	0.416	0.653	0.445	0.431	0.611	0.476	0.471
Number of year	21	21	21	18	18	18	21	21	21

Notes:Standard errors in parentheses,* p<0.01, ** p<0.05, * p<0.1**

7. Discussion and Conclusions

4.1. Discussions

Hypothesis 1 supported which signifies that the reduction effect of CO2 emissions by the AEPI significant. It is further found that the deduction effects of CO2 emission by the utility patent innovation are stronger than the invention patent innovation. According to the innovation theory, a high extent of innovation of the technology normally leads to a strong impact (Johnstone et al., 2017; Zhang and Gallagher, 2016). Invention patent innovation is normally regarded as more innovative than utility patent one; however, our empirical results show an opposite way in terms of their impact intensity on the CO2 emissions. One of the possible reasons lies on the fact that the utility patents are normally more directly related to the application circle, which generates a faster and efficient effects in terms of impacts on the deduction of CO2 emissions in the real world, while the application of the technology related by the invention patent innovation may takes much longer time.

The supported hypothesis 2a, 2b and2c demonstrate that the mechanisms of the AEPI reducing the CO2 emissions are through different sources of energy types. It further implies that the AEPI may lead to low-carbon energy transition. It signifies that the AEPI may well respond to the environmental regulations. Further, the results of Hypothesis 2 also implies that the current new energy supply cannot fully bear the task of energy substitution in the country. Theoretically speaking, with the development of AEPI, the emissions of traditional petrochemical energy sources should be reduced. Although its impact on the emissions of various traditional petrochemical energy sources might be heterogeneous, it is still supposed to lead to the deduction of the CO2 emission; However, our empirical results show that the AEPI is positively related to the carbon emissions from the source of natural gas. It implies that the new energy has not yet filled the shortage gap caused by the reduction of coal and crude oil. There is still a demand for traditional petrochemical energy with low carbon emissions represented by natural gas in the market. The AEPI may include some innovation related to improving the efficiency the of natural gas usage. As a result, though AEPI reduces the emission intensity of the natural gas, it may increase the demand for natural gas, which ultimately leads to a positive correlation between AEPI and the CO2 emissions of the natural gas.

4.2. Conclusions, limitations and implications

This paper studies the relationship between AEPI and CO2 emissions by using a multiple regression analysis on the provincial panel data of China during the period during the years from 1997-2017. Our results suggest that the AEPI has a positive impact on the deduction of CO2 emissions. Compared with the innovation of the invention patent type, the innovation of utility patent shows a stronger impact on the deduction of CO2 emissions. Further, our results show that the deduction mechanism further varies in accordance with different sources of energy consumption types which implies that the innovation could be active response to the environmental regulations.

This paper contributes to the current studies in the research areas of technology innovation and environmental economics in the following two aspects. First, the AEPI is identified from the green innovation which is hybrid with other green innovation including consuming of the energy. Compared with the green innovation, the AEPI can explain the mechanisms on its effects on the deduction of CO2 emissions in a more essential way. Second, the study explores the heterogeneity of the effects on the CO2 emission from different energy resources. It further clarifies the role of AEPI in promoting the energy low-carbon transition.

Based on the conclusions of this paper, the study provides at least two possible practical implications for the government. First, the government may need to pay full attention to support the AEPI when it publish specific policies targeting in the CO2 emissions via encouraging green innovation. Second, it is important to improve efficiency of the system for patent application reviewing and approval. By shortening the application circle for invention patent may have a direct positive effect on the deduction of the CO2 emissions.

There are mainly two limitations for this study. First, since this study sets the research context in China, the findings may not applicable to advanced economies or some small and medium sized ones. Further similar studies should be carried-out in other countries to expand the applicability of the findings. Second, in terms of the patent data adopted for the study, due to the data availability we use the number of patent applications, which may cause the deviation of the results. Different sub-types of patents vary in terms of the criteria for the application terms. Though the number of the application can still reflect the activeness of the innovation, this heterogeneity in application circle may lead to statistical discrepancies. The future studies may adopt the data of authorized patents to examine the similar mechanisms.

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THE NEXUS BETWEEN ENVIRONMENTAL INNOVATION AND CARBON EMISSION FROM POWER SECTOR FOR OECD COUNTRIES

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Abstract

This paper empirically investigates the impact of environmental innovation on energy sector-based CO_2 emissions using a large dataset for 32 OECD countries covering the period 1997-2018. To detect the nonlinear relationship between variables, this paper adopts a panel smooth transition regression (PSTR) model, which can estimate both the threshold level endogenously and the smoothness of the transition from one regime to another. The findings indicate that environmental innovation has a reducing effect on CO2 emissions from the energy sector up to a certain level of innovation is insignificant (1st regime), then it has a reducing effect (2nd regime), and above this level environmental innovation has an increasing effect on carbon emissions (3rd regime), suggesting the existence of a rebound effect. These findings point out that environmental innovations alone are not a solution to struggle environmental problems. This paper not only makes an important contribution to the empirical literature, but also reveals important policy implications, particularly to achieve climate change targets.

Keywords: Environmental innovation, CO_2 emissions, Energy sector, Panel smooth transition regression, OECD.

1. Introduction

Liberalization movements, which gained momentum at the global level in the 1980s, put countries in an intense competitive environment today (Aydin et al., 2019). The increasing level of competition accelerates research and development (R&D) activities and assigns a key role to innovation. As innovation increases, the level of competition and trade volume, industrial activities, and economic growth of countries are positively affected (Akyol, 2020). However, excessive consumption of natural resources by increasing economic activities in this process leads to the accumulation of waste and pollution on a global scale. These progresses bring about that economic growth is increasingly dependent on natural capital and that the economy-environment relationship needs to be addressed more (Temelli and Sahin, 2019). In this respect, it is an important issue whether innovation is an encouraging factor to ensure sustainable development.

The aim of this paper is to empirically examine the effect of environmental innovation on energy sector-based CO_2 emissions by using a large dataset for the 32 OECD countries — Australia, Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Sweden, Switzerland, Turkey, United Kingdom and United States— covering the period 1997-2018. This paper adopts a panel smooth regression (PSTR) model, which allows smooth transition of the coefficient of the threshold variable between regimes depending on the threshold level and slope parameter outputs to analyze the asymmetric linkage between variables.

This paper is expected to contribute to the emerging literature in three aspects. First, this paper is expected to contribute to ongoing debate on the issues by considering the energy sector-based CO_2 emissions, as the link between environmental innovation activities and environmental quality is controversial. To the best of our knowledge, this paper is the first to examine the possible impacts of environmental innovation activities specifically on energy sector-based CO_2 emissions rather than total CO_2 emissions. Second, most of the studies investigating the environmental innovation-environmental quality nexus in the literature have generally used either linear models or reduced-form models (quadratic or cubic form), which are basically linear models, which may not be flexible enough to determine the true form of the relationship. However, the fact that nature has the capacity to absorb the human-induced waste up to a certain level indicates that the response of nature to human activities is non-linear (Esen et al., 2020). To capture the true form of the relationship between environmental innovative activities and energy sector-based CO_2 emissions, unlike traditional parametric approaches, this paper adopts the PSTR model, which can estimate the threshold level endogenously and also predict the smoothness of the transition from a low-level regime to a high-level regime. The third is that the majority of OECD economies, which have a large share of the world's production of goods and services, set important targets to reduce CO_2 emissions, and that investments and incentives in environmental innovative activities are at the core of OECD energy and environmental policies. However, empirical studies investigating the role of environmental innovations in shaping environmental quality are quite limited. To achieve this aim, this paper tackles OECD economies as a sample of the “innovation-environmental quality” link.

2. Data & Methodology

In this study, the non-linear relationship between environmental innovation and carbon emission from power sector are investigated using the panel smooth transition regression for OECD countries. According to data availability we use data of 32 OECD countries (Australia, Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Sweden, Switzerland, Turkey, United Kingdom and United States) for 1997-2018 period.

3. Empirical Results

The stationarity of the series is important for regression models. Analysis performed with non-stationary series may cause spurious regression problem. On the other hand, cross-section dependency is important in determining stationarity of series. Thus, the cross-sectional dependency and the stationarity test results can be seen in Table 2.

After determining nonlinearity and the number of regimes, the effects of environmental patent on pollution from power industry can be investigated. PSTR model results can be seen in Table 1.

Table1: Results of PSTR Models

Variables		PSTR			Panel OLS	DFE
		First Regime	Second Regime	Third Regime		
lnpat	Coeff.	-0.005	-1.688***	1.233***	-0.010	-0.067
	Std. Err.	0.031	0.307	0.276	0.022	0.130
lnec	Coeff.	1.647***	0.164***	-0.054	1.102***	2.220***
	Std. Err.	0.133	0.042	0.048	0.043	0.724
lngdppcur	Coeff.	-0.141***	0.422***	-0.170**	-0.233***	-0.376
	Std. Err.	0.044	0.090	0.085	0.052	0.240
lntrade	Coeff.	-0.208**	0.197	-0.327***	-0.152**	-0.018
	Std. Err.	0.089	0.121	0.096	0.069	0.373
fd	Coeff.	0.503***	-1.376***	0.237	0.234	0.801
	Std. Err.	0.181	0.363	0.356	0.175	0.632
d.lnurban	Coeff.	-8.669**	-20.076	-3.110	-11.556**	-0.845
	Std. Err.	3.754	13.009	10.317	4.948	1.132
Location parameters		*12.781*	*13.315*			
Slope parameters		*6.227*				

Note: ***, ** and * show stationarity at 1%, 5% and 10% significance levels, respectively.

In table 1, PSTR model as well as Panel OLS and DFE model results are presented for comparison. The nonlinear PSTR model provides powerful predictors for cross-sectional dependence, heterogeneity, and heteroscedasticity problems. The panel OLS model, on the other hand, presents the results of the Beck Katz Estimator, which provides powerful estimators for cross-sectional dependence, heterogeneity and heteroscedasticity problems. Finally, the results of the DEF model, which considers cross-sectional dependence, heterogeneity and dynamic effects, are included.

When the panel OLS and DFE results are examined, it is seen that environmental patent does not have a significant effect on the carbon emission from power sector. On the other hand, according to Panel OLS test results, while energy use increases the pollution from the power sector, income, openness and urban population decrease the pollution. According to DEF test results, only energy use increases pollution.

Within the scope of our study, the PSTR model provides more reliable results due to the nonlinear structure of the estimation model. For the PSTR model, 3 regimes with low, medium and high innovation are estimated. In the low regime, the annual number of patents is less than 12.7. In the second regime it is between 12.7 and 13.3. In the 3rd regime, it is higher than 13.3. The effect of the environmental patent on the carbon emission from power sector is insignificant in the low regime. The effect is negative (between 12.7 and 13.3) in the medium regime and positive in the high regime.

According to the results of the PSTR model, energy use increases pollution in the first two regimes. After this level (in the 3rd regime), the effect of energy use becomes insignificant. The effect of per capita income and openness is negative in low and high innovation regimes and positive in the 2nd regime. The effect of financial development has positive effects in the low and high regimes and a negative effect in the 2nd regime. Finally, the urban population has a negative and significant effect only in the 1st regime. In the 2nd and 3rd regimens, the effect is insignificant.

4. Conclusion

While the emergence of easily accessible market structures as a result of technological and industrial developments with globalization creates an increase in the competition process, on the other hand, it causes a decrease in natural resources and environmental values. The CO_2 emissions resulting from human activities have increased considerably in recent years and this is seen as the primary cause of climate change and global warming. The negative impact of human-industrial activities on the environment causes concerns about the future. The tendency to increase environmental awareness at the national and international levels allows the environment to be at the center of economic policies.

Increasing the efficiency in resource use or taking measures only at the point where the pollution mixes with the nature is not sufficient for the required environmental development. To cope with issues such as resource scarcity, global warming and climate change, corporations should put sustainability at the center of all decisions and produce innovative solutions. However, corporations can avoid this responsibility by considering sustainable environmental-based investments as a cost element. This approach, which reflects a short-term perspective, prevents the transformations expected from corporations. The fact that environmental innovations are relatively less market-oriented than other innovations shows that the fate of innovative activities that take into account the environment should not be left to the initiative of enterprises alone. For this reason, environmental innovations should be supported and encouraged by government policies to increase the environmental impacts expected from them.

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THE IMPACT OF INCLUSIVE FINANCE ON CARBON DIOXIDE EMISSIONS: EVIDENCE FROM CHINA'S PROVINCIAL REGIONS

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ABSTRACT: Previous studies have not paid close attention to the effects of inclusive finance on carbon dioxide emissions. Setting research context in China with its rapid development in inclusive finance and pressing target of carbon dioxide neutrality, this paper adopts fixed effects model, moderating effect model, instrumental variable method and quantile regression method to analyze the effects of inclusive financial on carbon dioxide emissions in China. The results show that the inclusive finance is negatively related to the carbon dioxide emissions. This impact is particularly significant in the deep usage of the inclusive finance. It is also found that the inclusive finance can promote enterprise innovation in the region, and reduce carbon emissions by stimulating enterprise innovation to increase productivity. The quantile regression results further show that the effects only exist in the regions within a certain degree of the usage of the inclusive finance. In addition, the results of cross-section analysis signify that compared with manufacturing industry, the effects are only significant in non-manufacturing industry. Moreover, the effects can only be found in inland regions of the country whilst the coastal areas are insignificant. The research contributes to the understanding in development of inclusive finance and relativeness to the carbon dioxide emission issues.

Key Words: inclusive finance, deep usage, carbon dioxide emissions, technology innovation

INTRODUCTION

Carbon dioxide emissions have had a major impact on global climate change and human social and economic development, and have become a hot issue worldwide. The recent empirical studies have paid considerable attention to the role of finance on the deduction of carbon dioxide emission (Tamazian et al., 2009; Tamazian & Rao, 2010; Shahbaz et al., 2013; Ozturk and Acaravci, 2013; Salahuddin et al., 2015). These researches indicate that finance plays a vital role in the development of a low-carbon society. However, as a new type of finance, financial inclusion in reducing carbon dioxide emissions has not been recognized yet. Financial inclusion was first put forward as the opposite of financial exclusion (Chakravarty & Pal, 2013). It refers to the availability of financial resources and service supplies at an acceptable cost, which emphasizes the general availability by a broad audience, including the government, enterprises, consumers, and other economic entities (Chakravarty & Pal, 2013). Furthermore, finance inclusion may lead to technology innovation that enhances energy efficiency, reducing carbon dioxide emissions (Zhou et al., 2010; Wang et al., 2012). This paper intends to enrich and develop the existing literature research on how inclusive finance may affect carbon dioxide emissions in an emerging economy setting as China as the research context for this study.

We choose digital financial inclusion to address its impact on reducing carbon dioxide emissions for mainly two reasons. First, digital financial inclusion can reduce information asymmetry, reduce the cost of financial intermediaries to obtain investment information, and improve the efficiency in reviewing investment projects. Second, digital financial inclusion can help promote the transfer of funds from low-efficiency and high-emission investment projects to high-efficiency and low-emission investment projects and realize the rational allocation of financial capital (Buera et al., 2011). The reasonable allocation of financial capital means that more money flows to high-efficiency and low emission industries. In addition, by effectively supporting the material recycling of physical enterprises from raw materials, intermediate products, waste to products, it can optimize the industrial structure and improve energy-saving efficiency, which has become an important means to achieve green development (Farla et al., 1998).

China is chosen as the empirical context for our study. In the past few decades, China has made remarkable achievements in economic construction, and its total economic volume has ranked second in the world. However, China's economic development is an extensive economic growth model. Long-term high-speed economic growth is based on high pollution and high energy consumption. A major problem is a rapid increase in China's carbon dioxide emissions. According to data released by the International Energy Agency (IEA), China’s carbon dioxide emissions in 2007 were 6.16 billion tons, surpassing the United States to become the world’s largest carbon dioxide emissions country. In recent years, China's carbon dioxide intensity (carbon dioxide per unit of GDP) has declined year by year, but it is still much higher than in other countries. According to data released by the International Energy Agency, China's carbon dioxide intensity in 2019 was 0.7 kg/USD, equivalent to 1/3 of that in 1990. At the Copenhagen Climate Summit in 2009, the Chinese government announced that by 2020, China's carbon dioxide emissions per unit of GDP would drop by 40%-45% compared to 2005. The significant participation of its carbon dioxide emission reduction and its emerging economy status allows us to capture the effects of its financial inclusion on carbon dioxide emissions.

The study sheds some light on the current literature on the relationship between finance and environmental economics. The existing studies mainly examine the finance on carbon dioxide emissions with its participation in urbanization, trade, and industrial structure. Instead, we focus on the role of digital financial inclusion as a new emerging means of finance and examine its effects on carbon dioxide emissions. It is particularly meaningful in developing emerging countries with developing economic development and high carbon dioxide emissions. This paper intends to enrich and expand the existing literature research from empirical analysis and provide a policy basis for developing countries to achieve low-carbon development by developing financial inclusion.

The rest of this paper is organized as follows. Section 1 briefly reviews existing research. Section 2 describes the methodology, including the econometric models, data, and estimation strategies used in the current study. In section 3, we discuss the research method and discuss the data and results. Finally, in section 4, we provide a conclusion and implications of the study.

8. THEORETICAL BACKGROUND

There are has been extensive literature exploring the relationship between financial development and environmental management. Claessens (2007) confirms that financial development can help reduce transaction costs and information costs and facilitate loans and investment, including investment in environmentally friendly projects, which impact the environment. Tamazian et al. (2010) pioneered the study of the relationship between financial development and environmental quality, using the total stock market and total deposits and loans as indicators to measure financial development, confirming that financial development is conducive to reducing pollutant emissions and improving the environment. Jalil & Feridum (2011) demonstrated that China's financial development could reduce pollution emissions and improve the environment.

In recent years, the focus of environmental pollution literature has shifted to analyzing determinants of carbon dioxide emissions (Tamazian et al., 2009; Tamazian & Rao, 2010; Shahbaz et al., 2013; Ozturk and Acaravci, 2013; Salahuddin et al.). Tamazian et al. (2009) used the data of Brazil, Russia, India, and China from 1992 to 2004 to investigate the impact of financial development on carbon dioxide emissions. The study found that financial development reduced per capita carbon dioxide emissions. The growth of the capital market and banking sector had a more significant impact on carbon dioxide emissions. Shahbaz et al. (2013) used Malaysian data from 1971 to 2011. They found through cointegration tests that there is a long-term equilibrium relationship between financial development and carbon dioxide emissions, and financial development is conducive to reducing carbon dioxide emissions. The studies mentioned above mainly use time series analysis methods to take a specific country as the research object. These studies show that economic growth, urbanization, trade opening, and financial development. They are all crucial factors affecting carbon dioxide emissions.

On the other hand, financial development has a significant impact on energy consumption efficiency. Financial development can promote the diversification of financial services and improve financial efficiency, which will help drive economic growth and industrial structure adjustment, thereby changing energy consumption structure and energy consumption efficiency. On the whole, financial development help reduce the consumption of fossil fuel, increase the consumption of clean energy, improve energy consumption structure, improve energy consumption efficiency, and reduce environmental pollution and carbon emissions. Sadorsky (2010) uses panel data of 22 emerging countries from 1990 to 2006 and uses the generalized moment system estimation method to conduct empirical analysis and finds that financial development can improve energy consumption efficiency.

Furthermore, Sadorsky (2011) analyzed nine countries, including Central and Eastern Europe and South Africa, and found that financial development can help improve energy consumption efficiency and reduce carbon emissions. Brunnschweiler (2017) used panel data from 119 non-economic cooperation organizations from 1980 to 2006 and found that financial intermediaries represented by commercial banks can effectively increase renewable energy production, thereby reducing carbon emissions caused by traditional energy consumption. Zhang (2011) found that financial development is an important driving factor for China's carbon emission growth, and the impact of the development scale of financial intermediaries on carbon emission far exceeds other financial development indicators. It is further found that though the size of the stock market has a great impact on carbon emissions, it has a limited impact on improving energy consumption efficiency.

A large number of studies (Sinton and Levine, 1994; Lin and Polenske, 1995; Garbaccio et al., 1999) believe that technological progress can improve energy efficiency, and technological innovation is the core driving force for China's energy efficiency improvement (Fisher Vanden et al., 2004). However, it is also argued that though technological progress can directly improve energy efficiency, under the effect of return effect, technological progress may stimulate economic growth and indirectly drive the rise of energy consumption, which makes the energy-saving effect of technological progress uncertain (Einhorn, 1982).

In light of the discussion above, based on a framework of digital financial inclusion (Huang and Chen, 2016), we adopted the fixed effects model, the mediation effect, and the instrumental variable method to analyze the mechanism of the impact of digital financial inclusion on regional carbon emissions in China.

9. METHODOLOGY AND DATA

2.1 Data resource

Industrial carbon emissions. At present, China does not have an official statistical agency to publish CO2 emissions data for various provinces, and various academic institutions or scholars have different results of China's CO2 emissions calculations. The reasons for this difference can be summarized into three points: First, some studies only consider the carbon emissions generated by energy consumption without analyzing the carbon emissions caused by non-energy combustion in cement production. Second, the default emission factors of the United Nations Intergovernmental Panel on climate change (IPCC, 2006) are generally used to estimate China's CO2 emissions. However, according to the field investigation of the research team of the China carbon emissions database (CEADS), it is found that the default emission factors of IPCC are 40% higher than China's actual emission factors. It results in the estimated results being higher than the actual emissions (Shan et al., 2020). Third, most studies have not considered the industry heterogeneity of fossil fuel oxidation rates. Given this consideration, we use the province's carbon dioxide emissions provided by CEADS (Shan et al., 2016; 2018;2020) for research. The error between this data and the World Bank's data is less than 6%, indicating reliable information.

Digital Financial Inclusion Development Index. The Digital Finance Research Center of Peking University and Ant Financial Group formed a collaborative research group. The digital financial inclusion index was scientifically and accurately calculated using Ant Financial's massive data on digital financial inclusion. The spatial span of the index includes three levels: province, city, and district/county, and the period cover data from 2011 to 2018. In addition, in addition to the overall index, the index also depicts different dimensions of digital Inclusive Finance, such as coverage, depth of use, and digitization, as well as business sub-indexes such as payment, insurance, monetary fund, credit services, investment and credit (Huang and Chen, 2016). Therefore, the database has been widely used in China's financial Inclusion Research (Xie et al. 2018; Guo et al., 2020).

The digital financial inclusion development index in this article adopts the multi-dimensional financial inclusion index calculated by the Institute of Digital Finance of Peking University from 2011 to 2018, namely, the digital financial inclusion development index, the coverage breadth index, the usage depth, and the digitalization level index.

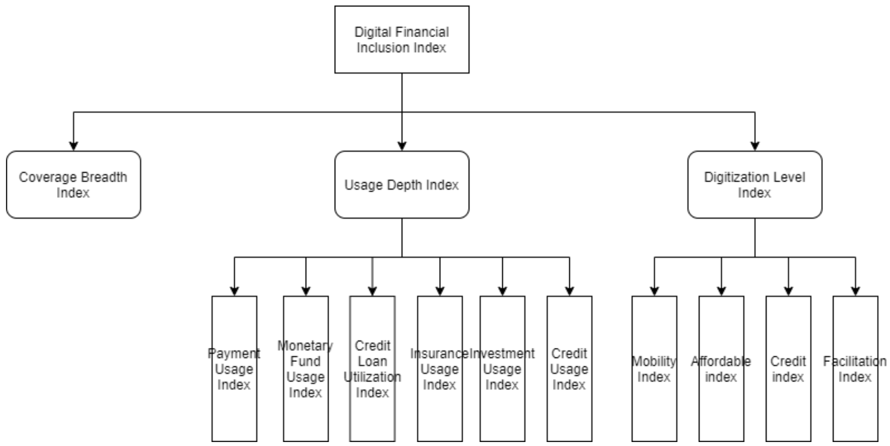

Figure 1: Digital financial inclusion effect on carbon dioxide emissions

3.2 Empirical model

The baseline model is built as follows:

$$CO2_{it} = \beta_0 + \beta_1 \text{Index\_aggr}_{\text{it}} + \beta_2 Urban_{it} + \beta_3 Infrastructure_{it} + \beta_4 FDI_{it} + \beta_5 Open_{it} + \beta_6 Structure_{it} + \beta_7 Fiscal_{it} + \beta_8 Energy_{it} + \beta_9 GDP_{it} + \beta_{10} Industry_{it} + province_i + year_t + \varepsilon_{it} \quad (1)$$

The explanatory variable is industrial carbon emissions (CO_2) and the core explanatory variable is the Digital Inclusive Financial Development Index (Index_aggr). According to the general literature, the control variables of this article are:

i. Urbanization rate ($Urban$). On the one hand, the transfer of labor with low education and low skill levels in the process of urbanization may increase economic efficiency; on the other hand, the waste generated in urbanization may hinder the improvement of energy efficiency. This paper uses the ratio of urban population to total population to express the urbanization rate, reflecting the impact of each region's urbanization level on carbon emissions.

ii. Infrastructure ($Infrastructure$). Regional infrastructure improvement can provide a convenient external environment for economic development and promote regional economic development. Infrastructure has two impacts on carbon emissions: on the one hand, it may increase the energy demand, increasing carbon emissions; On the other hand, the improvement of infrastructure has reduced the transaction costs between enterprises and external, accelerated the transformation and upgrading of traditional industries, improved energy efficiency, and reduced carbon emissions. This article selects the province's per capita road area to represent the infrastructure.

iii. Dependence on foreign investment (FDI). Opening to the outside world can increase regional economic output by introducing advanced foreign technology and management experience. Still, when the region's ability to absorb technology spillovers is insufficient, opening to the outside world may have an uncertain impact on urban economic efficiency. This study selects the province's annual actual foreign investment (which is converted into RMB based on the average exchange rate of RMB in that year) as a percentage of the local GDP to indicate the degree of foreign investment dependence.

iv. Open degree ($Open$). To avoid green export barriers, domestic export companies often choose to learn relevant green management techniques and management concepts through a cooperation with foreign companies to help companies achieve technological innovation and improve green economic efficiency. This article uses the ratio of total import and export trade to GDP to express the degree of openness, which reflects the impact of market openness on carbon emissions.

v. Industrial structure ($Structure$). On average, China's energy consumption demand for the secondary industry is higher than that of the tertiary sector. Therefore, with the continuous development of the tertiary industry, energy consumption will gradually decrease. However, China is currently at a critical stage of industrial transformation and upgrading; the long-standing extensive growth model may also cause economic inefficiency. In this paper, the ratio of the tertiary industry's output value to the secondary industry's output value is used to express the industrial structure to reflect the impact of the optimization and upgrading of the industrial structure on the efficiency of the green economy.

vi. Financial scale ($Fiscal$). Fiscal expenditure can affect the efficiency of the green economy in two ways. On the one hand, the government can encourage SMEs to carry out technological innovation through financial subsidies, thereby improving the efficiency of the green economy; on the other hand, if there are blind and repeated financial subsidies, resources may be wasted instead, which is not in line with the concept of green economic development. This article uses the ratio of government fiscal expenditure to GDP to represent the fiscal scale to reflect the impact of fiscal expenditure on the efficiency of the green economy.

vii. Energy consumption intensity ($Energy$). Due to the obvious heavy industrialization in the development of the Chinese economy, energy consumption per unit of GDP can be a good measure of the energy efficiency of the Chinese economy. Therefore, energy consumption data is estimated using energy consumption after conversion to standard coal.

viii. Gross Regional Product (GDP). Finally, control the impact of regional GDP on regional carbon emissions.

This paper uses 30 provinces (Tibet was excluded from the sample due to the lack of data), autonomous regions, and municipalities in China from 2011 to 2018 as the research sample, with 240 observations. The data of urban population, total population, provincial road area, GDP, total import and export trade, the output value of manufacturing industry, the output value of servicing industry, and government financial expenditure are from China's National Bureau of statistics. The data of actual foreign investment and energy consumption are from the statistical yearbooks of various provinces in China. The descriptive statistics of each variable are shown in Table 1 below.

Table 1: Descriptive statistics

variables	N	mean	sd	p50	min	max
CO2	240	271.415	185.573	206.800	23.800	842.079
Index_aggr	240	188.186	84.980	204.136	18.330	377.734
Coverage_breadth	240	167.934	82.722	175.530	1.960	353.867
Usage_depth	240	183.526	84.883	178.175	6.760	400.397

Digitization_level	240	263.529	116.651	294.333	7.580	453.660
Urban	240	0.571	0.124	0.555	0.344	0.938
Infrastructure	240	5.150	2.015	4.869	1.100	10.941
FDI	240	0.022	0.020	0.019	0.000	0.120
Open	240	0.284	0.304	0.146	0.018	1.464
Structure	240	1.256	0.692	1.106	0.527	5.022
Fiscal	240	0.264	0.116	0.236	0.121	0.758
Energy	240	0.868	0.488	0.687	0.220	2.327
GDP	240	2276.401	1846.909	1790.825	137.040	9994.520
Industry	240	0.348	0.080	0.362	0.117	0.574

10. Results and discussions

3.1 Baseline regression results

Column (1) of Table 2 presents the regression results based on equation (1). The marginal effect of the digital financial inclusion index on regional industrial carbon emissions is -1.1931, and it is significant at the 5% level (t=-2.14), which shows that the development of digital financial inclusion can significantly reduce regional industrial carbon emissions. Every increase of 1 unit in the financial inclusion index will reduce regional carbon emissions by 1.1931 units. As mentioned above, the higher the inclusive finance index, the better the development of Inclusive Finance. Inclusive finance can help SMEs upgrade technology by reducing the credit constraints faced by SMEs and increasing financial services for SMEs, which allows to improve the energy efficiency of SMEs and reduce carbon emissions.

Further examination of the control variables shows that the increase in energy consumption intensity will directly lead to increased carbon emissions. In addition, the rise in energy consumption intensity may also hinder the improvement of energy efficiency. The possible reason is that the more energy consumption per unit of output is required, the lower the energy efficiency. The remaining control variables are not significant, which may be caused by the endogeneity between the variables.

It can be seen from the above analysis that the development of digital financial inclusion can significantly reduce regional industrial carbon emissions. To explore the digital finance inclusion affects regional industrial carbon emissions, this paper regresses the carbon emissions to each dimension of the development of digital financial inclusion, and the regression results are presented in columns (2), (3), and (4) of Table 2. It can be seen that the depth of use in digital financial inclusion has a significant negative impact on carbon emissions (t=-2.25), and the impact of coverage and the degree of digitalization on carbon emissions is negative but not significant. This shows that the development of digital financial inclusion to reduce regional carbon emissions is mainly driven by depth dimensions. Therefore, the remaining analysis of this article focuses on the analysis from the perspective of using the depth dimension.

Table 2: The impact of the development of digital financial inclusion on regional carbon emissions

Dependent	(1)	(2)	(3)	(4)
	CO2	**CO2**	**CO2**	**CO2**
Index_aggregate	-1.1931**			
	(-2.14)			
Coverage_breadth		-0.2629		
		(-0.31)		
Usage_depth			-0.6773**	
			(-2.25)	
Digitization_level				-0.1964
				(-1.47)
Urban	137.5299	219.4233	120.7152	168.8776
	(0.54)	(0.85)	(0.50)	(0.66)
Infrastructure	12.6059	10.1234	11.1001	12.6633
	(1.57)	(1.38)	(1.58)	(1.43)
FDI	257.3608	185.1429	197.5904	138.2626
	(1.26)	(0.97)	(1.11)	(0.69)
Open	-34.5799	-43.1474	-57.6160	-28.5337
	(-0.64)	(-0.77)	(-1.13)	(-0.49)
Structure	-38.6473	-55.5422	-53.0022	-43.6591
	(-0.84)	(-1.16)	(-1.29)	(-0.93)
Fiscal	-192.1687	-143.4943	-197.5875	-136.4025
	(-1.28)	(-0.94)	(-1.37)	(-0.92)
Energy	143.3596***	141.5289***	153.3541***	139.5943***
	(3.05)	(2.97)	(3.29)	(3.01)
GDP	-0.0014	-0.0060	-0.0053	-0.0026

	(-0.13)	(-0.51)	(-0.53)	(-0.24)
Industry	-16.5014 (-0.08)	-49.5398 (-0.23)	-82.1326 (-0.45)	-10.9540 (-0.05)
Constant	133.8083 (0.66)	93.7788 (0.47)	179.5024 (0.92)	73.5901 (0.36)
Year Fixed effect	Yes	Yes	Yes	Yes
Province Fixed effect	Yes	Yes	Yes	Yes
N	240	240	240	240
Adjusted R^2	0.259	0.219	0.267	0.231

Note: All regressions use heteroscedasticity adjustment and province clustering adjustment to obtain robust standard errors. The t statistic is in parentheses. *, **, * represent the significance level of 10%, 5%, and 1%, respectively. The following tables are the same.**

4.2 Channel analysis

Next, this article examines the channel through which the development of digital financial inclusion affects regional carbon emissions—regional energy consumption intensity. Energy consumption intensity (energy consumption per unit of GDP) can be a good measure of the energy efficiency of the Chinese economy, so energy consumption intensity has a direct relationship with carbon emissions. The higher the energy consumption intensity of a region, the lower the energy efficiency of the region. For those regions with low energy efficiency, the development of digital financial inclusion helps improve the financing of small and micro enterprises, improve energy efficiency and reduce carbon emissions.

To verify the channel function of regional energy consumption intensity, we set the virtual variable intensity of high energy consumption intensity according to the median ratio of energy consumption to GDP of each province, in which the value is 1 when the energy consumption intensity is higher than the median, otherwise, it is 0. Table 3 shows the corresponding regression results. It can be seen from columns (1) and (2) that the development of digital financial inclusion has significantly reduced regional carbon emissions, and the regression coefficients of the interaction terms between dummy variables and digital financial inclusion (HIntensity*Index_aggregate and Hintensity*Usage_depth) are 0.2695 and 0.2819, respectively. Significantly positive at the levels of 5% (t=2.45) and 1% (t=3.32). It shows that the higher the energy consumption intensity, the smaller the effect of digital financial inclusion in reducing carbon emissions. This result provides empirical evidence supporting regional energy consumption intensity as a channel for digital financial inclusion to influence regional carbon emissions.

Table 3: Channel test-regional energy consumption intensity

Dependent	(1)	Dependent	(2)
	CO2		**CO2**
Index_aggregate	-0.8482*	Usage_depth	-0.4856*
	(-1.79)		(-1.83)
HIntensity	-29.2206	HIntensity	-30.0236
	(-1.29)		(-1.69)
HIntensity*Index_aggregate	0.2695**	HIntensity* Usage_depth	0.2819***
	(2.45)		(3.32)
Control variables	Yes	Control variables	Yes
Year Fixed effect	Yes	Year Fixed effect	Yes
Province Fixed effect	Yes	Province Fixed effect	Yes
N	240	N	240
Adjusted R^2	0.338	Adjusted R^2	0.353

4.3 Cross-section difference

4.3.1 Influence of industrial structure

The manufacturing industry occupies a dominant position in developing the national economy and determines the speed, scale, and level of national economic modernization. China's industrial production mainly consumes fossil energy, which generates a large number of carbon emissions. From the above analysis, we have found that digital financial inclusion can reduce regional carbon emissions. Given the critical position of the manufacturing industry in China's economic development, this paper further investigates whether digital financial inclusion minimizes the carbon emissions of manufacturing or non-manufacturing industries.

In order to investigate whether the development of digital Inclusive Finance reduces the carbon emissions of manufacturing industries or non-manufacturing industries, according to the industrial classification of national economy issued in 2017, the carbon emissions of CEADs industries are divided into manufacturing carbon emissions and non-manufacturing carbon emissions, and the grouping test is carried out. Table 4 presents the corresponding regression results. In the manufacturing group in columns (1) and (3), the regression coefficients of the Digital Financial Inclusion Index and the Depth of Use Index are -0.3262 and -0.1712, respectively, which fail the significance test. However, in the non-manufacturing groups in columns (2) and (4), the regression coefficients of the total digital inclusive finance index and the depth of use index are -0.8496 and -0.5007, respectively, both of which pass the significance test at the level of 5%. It shows that the development of digital financial inclusion only reduces the carbon emissions of non-manufacturing industries in China but has no effect on the carbon emissions of manufacturing industries.

Table 4: The impact of industrial structure-whether it is manufacturing

Dependent	(1)	(2)	(3)	(4)
	manufacturing	**Non-manufacturing**	**manufacturing**	**Non-manufacturing**
Index_aggregate	-0.3262 (-1.44)	-0.8496** (-2.15)		
Usage_depth			-0.1712 (-1.45)	-0.5007** (-2.05)
Control variables	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes
Province Fixed effect	Yes	Yes	Yes	Yes
N	240	240	240	240
Adjusted R^2	0.096	0.384	0.097	0.393

4.3.2 Influence of regional development level

The level of regional economic development constrains the impact of digital financial inclusion on regional carbon emissions. In developed regions, local governments have more capital for R&D, energy-saving and emission-reduction technology innovation, etc., to promote the upgrading of low-efficiency, high-energy-consumption technologies to high-efficiency, low-energy-consumption green technologies. As economic development reaches a certain level, people pay more attention to living conditions and environmental quality. At this time, increase environmental investment and emission reduction investment, eliminate or transfer high-polluting industries to reduce pollution. The development of inclusive finance can reduce information asymmetry, reduce the cost of financial intermediaries to obtain investment information, and improve the efficiency of reviewing various investment projects. The development of inclusive finance can help promote the transfer of funds from low-efficiency and high-emission investment projects to high-efficiency and low-emission investment projects and realize the rational allocation of financial capital (Buera et al., 2011). The reasonable allocation of financial capital means that more capital flows to high-efficiency and low emission industries. By effectively supporting the material recycling of physical enterprises from raw materials, intermediate products, waste to products, it can optimize the industrial structure and improve the energy utilization efficiency, which has become an important means to realize green development (Farla et al., 1998). Due to the lower degree of information asymmetry and lower information cost in areas with better economic development, the development of inclusive finance may have a weaker impact on carbon emissions.

As far as China is concerned, since the reform and opening up, the economic development of the eastern region has generally been higher than that of the central and western regions, and the economic development level of the coastal areas has generally been higher than that of the inland areas. To analyze the impact of digital financial inclusion in areas with different economic development levels on carbon emissions, we divide the 30 provinces in mainland China (excluding Tibet) into eastern, central, and western regions. Columns (1)-(3) of Table 5 show digital financial inclusion regression results in the eastern, central, and western regions on regional carbon emissions. The development of digital financial inclusion in the eastern and western regions has reduced regional carbon emissions, but the significance level has not been passed. The development of digital financial inclusion in the central region has significantly reduced regional carbon emissions at a level of 10%. Every increase in digital financial inclusion by 1 unit will reduce carbon emissions by an average of 0.9530. In addition, since China's reform and opening up, the development level of coastal areas is generally higher than that of inland areas. Therefore, this article further explores the heterogeneity of the impact of the development of digital financial inclusion in coastal and inland areas on regional carbon emissions4. Columns (4) and (5) respectively report digital financial inclusion regression results in coastal and inland areas on regional carbon emissions. The development of digital financial inclusion in coastal areas reduced regional carbon emissions but did not pass the significance level. The development of digital financial inclusion in the inland areas has significantly reduced regional carbon emissions at a level of 10%. Every increase in digital financial inclusion by 1 unit will reduce carbon emissions by an average of 0.9227. Based on the above results, it can be seen that the development of digital financial inclusion has mainly reduced the carbon emission levels of the central and inland regions where the level of economic development is low.

Table 5: Regional heterogeneity

Dependent	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
	east	**middle**	**west**	**coast**	**inland**
Usage_depth	-0.4671	-0.9530*	-0.0726	-0.2359	-0.9227*
	(-1.41)	(-1.86)	(-0.20)	(-0.78)	(-2.09)
Control variables	Yes	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes	Yes
Province Fixed effect	Yes	Yes	Yes	Yes	Yes
N	88	80	72	88	152

Adjusted R^2	0.445	0.594	0.691	0.444	0.396

4.4 Mechanism analysis

In order to empirically investigate whether digital financial inclusion affects regional carbon emissions through the transmission mechanism of stimulating innovation, we use the mediation effect test method to analyze. It should be pointed out that there are many test methods for mediating effects, and each has its own advantages and disadvantages in statistical test error and test power. The applicability of a single method is low (Mackinnon et al., 2002). Yan et al. (2021) constructed a comprehensive mediation effect test program based on different test methods proposed by Judd and Kenny (1981), Sobel (1982), Baron and Kenny (1986), which can control the probability of type I and type II errors on the basis of high statistical power. Therefore, this article will use the test procedure to test the mediation effect. Specifically, the equations are shown in equations (2), (3), and (4), and the verification procedure is shown in Figure 2.

$$CO2_{it} = a_0 + a_1 usage\_depth_{it} + a_2 X_{it} + province_i + year_t + e_{it}^1 \quad (2)$$

$$Innovation_{it} = b_0 + b_1 usage\_depth_{it} + b_2 X_{it} + province_i + year_t + e_{it}^2 \quad (3)$$

$$CO2_{it} = c_0 + c_1 usage\_depth_{it} + c_2 Innovation_{it} + c_3 X_{it} + province_i + year_t + e_{it}^3 \quad (4)$$

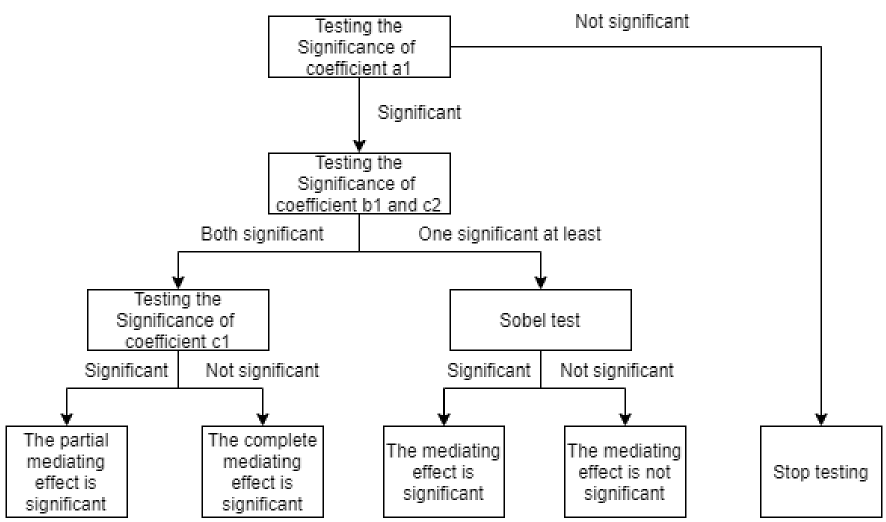

Figure 2: Mediating effect test process

where $Innovation_{it}$ represents the total number of patent applications per capita in province I in year t, the degree of regional technological innovation. Other variables are defined as described above. The mediating effect is measured by $b_1 \times c_2 = a_1 - c_1$, and the Sobel test statistic is $Z = \widehat{b_1}\widehat{c_2}/S_{b_1c_2}$ ($\widehat{b_1}$ and $\widehat{c_2}$ are the estimators of b_1 and c_2, respectively, $S_{b_1c_2} = \sqrt{\widehat{b_1}^2 {S_{c_2}}^2 + \widehat{c_2}^2 {S_{b_1}}^2}$, and S_{b_1} and S_{c_2} are the standard errors of $\widehat{b_1}$ and $\widehat{c_2}$, respectively).

Columns (1)-(3) of Table 6 report the results of the above-mentioned mediation effect test. Column (1) reflects the result of the model (2). It can be seen that, similar to the previous article, the development of digital financial inclusion has a significant negative impact on regional carbon emissions. The results in column (2) show that the development of digital financial inclusion has a significant positive impact on regional technological innovation, which shows that the development of digital financial inclusion can promote more R&D and technological innovation in the region. The Z statistic in the Sobel test is -1.673, which indicates that the mediating effect is significant, so there is a mediating effect with regional technological innovation as the mediating variable. The mediating effect accounts for 12.3% of the total effect.

These results show that regional technological innovation has played an important role in developing digital financial inclusion affecting regional carbon emissions. Specifically, suppose the development level of digital financial inclusion in a certain region rises. In that case, this will encourage R&D and innovation in the region, thereby improving energy efficiency and reducing regional carbon emissions.

Table 6: Mediating Effect Test-Regional Technological Innovation

Dependent	**(1)** **CO2**	**(2)** **Innovation**	**(3)** **CO2**	**(4)** **CO2**	**(5)** **Innovation**	**(6)** **CO2**
Index_aggregate	-1.1931** (-2.14)	0.1435** (2.35)	-1.0469* (-2.02)			
Usage_depth				-0.6773** (-2.25)	0.1052** (2.20)	-0.5818** (-2.15)
Innovation			-1.0191 (-1.58)			-0.9082 (-1.44)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Province Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	240	240	240	240	240	240
Adjusted R^2	0.259	0.751	0.276	0.267	0.759	0.280
Sobel Z	-1.673*			-1.763*		
Sobel Z-p value	(0.094)			(0.078)		
Proportion	0.123			0.141		

4.5 Robustness test

4.5.1 Endogenous problems

When identifying the impact of the development of digital Inclusive Finance on regional carbon emissions, there may be interference from endogenous problems. There are two main reasons for endogenous problems: first, the reverse causality problem, that is, digital Inclusive Finance reduces regional carbon emissions, but the activities related to carbon emissions in a region may also promote the development of digital Inclusive Finance in turn. Second, the problem of missing variables. Although the model has controlled a series of related characteristic variables that affect regional carbon emissions, it still cannot effectively solve the missing variable bias caused by other unobservable factors in theory. Therefore, to better identify the relationship between digital financial inclusion and urban innovation, this paper further constructs instrumental variables to re-estimate the model. This paper selects the spherical distance from the provincial capital of the province to Hangzhou, Zhejiang Province as the instrumental variable, and mainly considers three levels: first, the distance will affect through economic behavior, but will not change with economic development; Secondly, "the distance between the surveyed city and Hangzhou" is not only directly related to the development level of digital finance in the city, but also will not affect the financial needs of residents through the development of digital finance, meeting the two conditions of instrumental variables.

Columns (1) and (2) in Table 7 are the regression results of instrumental variables 2SLS and GMM methods. It can be seen that in the correlation test of instrumental variables, the P values of Kleibergen-Paap rk LM statistics are less than 0.1, rejecting the original hypothesis of insufficient identification of instrumental variables; The Cragg-Donald Wald F statistic is greater than the empirical judgment value of 10, rejecting the original hypothesis of weak instrumental variables, indicating that the selection of instrumental variables is appropriate. The regression coefficient of the depth index is consistent with the benchmark regression result, and it is still significantly negative, which further shows that the conclusion of this paper is reliable. Considering that the Kleibergen-Paap RK Wald F statistic is slightly less than 10, there may be weak instrumental variables affecting the regression results. The LIML method, which is insensitive to weak instrumental variables, is used for the robustness test. The regression results are shown in Table 5. The results show that the regression results of instrumental variable regression using the LIML method are similar to the original regression results, indicating that there is no influence of weak instrumental variables. In summary, it can be seen that the regression results of the article are relatively robust.

Table 7: Robustness test-endogenous problems

Dependent variables	(1) 2SLS	(2) GMM	(3) LIML
Usage_depth	-2.5652**	-2.5652**	-2.5652**
	(-2.54)	(-2.54)	(-2.54)

Control variables	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes
Province Fixed effect	Yes	Yes	Yes
Kleibergen-Paap rk LM statistic	5.672		
P-value	(0.0172)		
Cragg-Donald Wald F statistic	11.522		
Kleibergen-Paap rk Wald F statistic	9.377		
N	240	240	240
Adjusted R^2	0.974	0.974	0.974

4.5.2 Substitution of main variables

The carbon emission data of each province in China in the above analysis comes from the CEADs database. In this section, this article draws on Liu et al. (2021) and uses the following formula to calculate carbon emissions:

$$CO_2 = \sum_{i=1}^{7} E_i \times CF_i \times CC_i \times COF_i \times \frac{44}{12} + m_0 \times Q \quad (5)$$

Where E_i is the energy consumption in i; CF_i is the heating value corresponding to the i-th energy source; CC_i is the carbon content of the i-th energy; COF_i is the oxidation factor of the i-th energy; $44/12$ is the relative molecular weight ratio of CO_2 to C. Q is the cement production volume, and m_0 is the carbon emission coefficient during the cement production process. According to the carbon content (CC) and other related values, the carbon dioxide emission coefficient of the i-th energy can be calculated. Specifically, the CO_2 emission coefficients of CF_i, CC_i, COF_i and cement production of coke, coal, kerosene, diesel, gasoline, fuel oil and natural gas are 2.8481, 1.6470, 3.1742.3, 3.1500, 3.0451, 3.0642, 21.6704 and 0.5271 respectively.

Table 8 shows the regression results of replacing the explained variables. It can be seen that when the carbon dioxide emissions released by various energy uses are used as the replacement of the above carbon emissions, the impact of Inclusive Financial Development on regional carbon emissions is still significantly negative, and this impact is still driven by the depth of use dimension in the inclusive financial index.

11. CONCLUSION AND PRACTICAL IMPLICATIONS

This paper uses the panel data of 30 province-level administrative regions in China from 2011 to 2018. It uses the fixed effects model, the mediation effect test, and the instrumental variable method to analyze the degree and mechanism of the development of inclusive finance on regional carbon emissions. The study found that the development of digital financial inclusion has significantly reduced regional carbon emissions, and this impact is mainly driven by the depth of use dimension in the financial inclusion index. The instrumental variable method and robustness analysis also confirmed that the development of inclusive finance is conducive to reducing regional carbon emissions. Through channel inspection, it is found that the development of inclusive finance reduces carbon emissions by improving the efficiency of regional energy use.

Furthermore, this paper examines the cross-sectional differences of the impact of the development of digital Inclusive Finance on regional carbon emissions from the perspectives of industrial structure and regional development level. It is found that the impact of the development of digital financial inclusion on regional carbon emissions is mainly to reduce the carbon emissions of non-manufacturing industries, and the impact on the carbon emissions of manufacturing industries is not significant. Moreover, the digital financial inclusion mainly reduces carbon emissions in the central and inland regions and has no significant impact on the eastern and coastal regions. Finally, through the intermediary effect test, it is found that the development of inclusive finance can promote technological innovation in the area and reduce carbon emissions by stimulating enterprise innovation to increase productivity.

It is concluded that advancing the development of digital financial inclusion and improving the construction of an inclusive financial system can help improve energy utilization efficiency and reduce carbon emissions, thereby improving the efficiency of the green economy and promoting green and sustainable economic development.

Based on the above conclusions, this article proposes policy recommendations from the following two aspects: First, give full play to the role of inclusive financial development in promoting the development of a green and low-carbon economy. The research in this paper shows that the current development of inclusive finance in China is conducive to reducing carbon emissions. Therefore, local governments should promote bank credit to favor green and low-carbon enterprises, encourage and support resource-saving and environmentally friendly enterprises, and accelerate the green transformation and upgrading of industries through financial development.

Second, it is also suggested that the government should intensify the construction of an inclusive financial system in the central and inland regions. At this stage, the marginal effect of the development of digital financial inclusion, particularly in the central and inland regions driving the improvement of green economic efficiency, is the strongest. To make up for the shortcomings of financial services in the central and western regions, active policies, commercial and cooperative financial institutions are encouraged in these regions.

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THE RESPONSE OF CARBON INTENSITIES OF TECHNOLOGICAL SHOCKS IN INDONESIA: DECOMPOSED ANALYSIS

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ABSTRACT: Environmental damage is mainly caused by the use of various energy resources for economic growth. This study investigated the impact of technological shocks on carbon Intensities (coal emission, oil emission, gas emission) in Indonesia. This study uses a newly developed methodological ARDL dynamic simulation to show the actual impact of positive and negative changes in the Economic Complexity Index and GDP for the emission of coal, oil and, gas. Dynamic ARDL findings show that Economic Complexity Index and GDP have a positive impact on carbon intensities, both short-term and long-term. It has been suggested that environmental damage can be reduced by promoting renewable energy sources.
Key Words: Carbon Intensities, Technological Shock, GDP, Economic Complexity Index

1)INTRODUCTION

Technological shocks in economic terms are related to macroeconomic models, which change the production function, and are modelled with aggregate production functions that have a scaling factor. Besides GDP, one model that can represent technology shock is the Economic Complexity Index. The Economic Complexity Index (ECI) was developed by Cesar Hidalgo and Ricardo Hausmann - Harvard University's Center for International Development. ECI sees that the measure of a country's success is the product it produces. Products produced from a country are the right indicator to see the advantages of a country compared to other countries. An economic system that produces products has a complex set of knowledge from the production process, quality control, to the residue of the production process. In short, a country with many product variants, rich in a set of applicable and productive knowledge to produce it (Nababan 2013). ECI indicates the intense application of technical knowledge in product diversification to encompass it in the domestic consumer markets on the one hand and foreign markets on the other. Industry in a country plays an important role in increasing ECI. Industrial activities have an unavoidable environmental impact. The use of energy produces emissions that affect environmental stability. Environmental degradation is the most complex problem faced by developing countries that are spurring economic growth through the industrial sector. High greenhouse gas (GHG) emissions affect industrial and non-industrial countries around the world. To achieve maximum economic growth Countries are using energy and other natural resources and increasing greenhouse gas emissions. Carbon intensities are one of the major factors that cause environmental damage (Khan, Teng, and Khan 2019)

2)Review of Literature

Carbon Intensity (CI) is the amount of carbon by weight emitted per unit of energy consumed. in the last three decades, increasing carbon intensity has led to climate change, which has been recognized as a critical issue for national governments for decades, researchers and the international community because of its detrimental impact on humanity. This is related to the release of GHG into the atmosphere, especially carbon dioxide (CO2) emissions. Carbon intensity is a side effect of the use of energy intended for the production process of various commodity products from a country. Several previous studies have proven that there is a positive correlation between an increase in CI and an increase in GDP (Malzi et al., 2021)(Mendonça et al., 2020) (Begum et al., 2015)) where the higher a country is GDP, the higher the CI. While CI has negative side effects on the environment. This results in technological shocks that have a negative impact on state conditions if they are not responded to properly and correctly. From previous research (Wang & Wang, 2020), they found that carbon intensity can coordinate carbon performance and economic performance. In general, China's industrial carbon intensity has decreased and contributed to the decline in the national carbon intensity. In addition, Industries with low initial carbon intensity show greater potential to reduce carbon intensity. In addition, energy intensity effects are considered a major contributor to carbon intensity reduction in almost all industries. Moreover, their research also found that industries with high initial carbon intensity experienced a surprising increase in carbon intensity in India.

Overview about Indonesia in 2019 by the Observatory of Economic Complexity (OEC). It was the number 16 economy in the world in terms of GDP (current US$), the number 30 in total exports, the number 30 in total imports, the number 68 most complex economy according to the

Economic Complexity Index (ECI), and the number 117 economy in terms of GDP per capita (current US$). The three top exports of Indonesia are Coal Briquettes ($20.3B), Palm Oil ($15.3B), Petroleum Gas ($8.32B), exporting mostly to China ($28.6B), the United States ($19.2B), Japan ($16.8B). In the same year 2019, Indonesia was also the world's biggest exporter of Palm Oil ($15.3B), Lignite ($2.91B), and Stearic Acid ($2.76B). The three top imports of Indonesia are Refined Petroleum ($12.3B), Crude Petroleum ($5.11B), and Vehicle Parts ($3.25B), importing mostly from China ($45B), Singapore ($19.8B), Japan ($13.9B).

By looking at Indonesia's general profile aforementioned, several traded commodities are categorized as having a "significant impact on the environment and climate change". However, Indonesia has made strong progress in energy access and security in the last decade both in terms of access and in terms of reliability. The Indonesian government is optimistic about fulfilling its commitment to the energy transition, as a response to technological shocks to adapt to climate change under the Paris Agreement, by taking bold measures for environmental sustainability of energy system, especially by reducing the carbon intensity of energy supply, which has increased substantially over the past decade. The energy system is critical for economic growth in Indonesia, both as a source of export revenue, a significant source of employment, and a source of competitiveness. As the largest energy consumer in Southeast Asia and a source of rising demand, Indonesia is the key to effective CI reduction in the region. A robust plans enabling environment for CI reduction, characterized by increased political commitment for energy transition, and mechanisms to attract capital and investment, and just transition pathways to ensure equitable distribution of costs and benefits from CI reduction are critical for accelerated progress in Indonesia.

From this profile, it is shown how coal, oil, and natural gas are the main trading commodities from Indonesia. Several previous studies related to gas, oil, and coal emissions, have negative and significant interactions for fossil energy and GDP. the study shows that non-renewable energy coupled with technological inefficiency has a detrimental impact on economic growth. (Malzi et al., 2021). Changes in energy use from fossil to non-fossil, if implemented in the short term, can have an impact on oil, gas and coal price shocks, because the transformation of changes in energy use from fossil to non-fossil requires the readiness of the funding system, infrastructure and operational system. It takes a long time. As stated by (Amiri et al., 2021), Their findings imply that oil price shocks coupled with rising oil revenues result in an expansion of the monetary base, and ultimately lead to higher liquidity growth and inflation. The same is true for other non-fossil energy commodities. In addition, such energy commodity price shocks, its lead to a depreciation of the real exchange rate and a decline in economic competitiveness.

To be able to realize a low-carbon energy system that is in line with the targets of the Paris Agreement; electricity and transportation in Indonesia are two priority sectors to carry out the CI reduction process. This process has consequences and impacts on other industrial sectors.

For the CI reduction process to be carried out fairly, impacts need to be anticipated and responses prepared.

Looking at the current reality and developments in Indonesia, the projection of the renewable energy mix in primary energy and power generation will not be in line with the target of the General National Energy Plan (RUEN). The targeted renewable energy mix of 23% is projected to only reach 15%. The renewable energy target of 23% can only be achieved in 2050. The fossil energy mix is also projected not to match the RUEN target.

The projected power plant in the RUEN is planned at 136 GW with 45 GW renewable energy, only 95 GW with RE generators of 23 GW. For this reason, the 2015-2050 RUEN needs to be reviewed, by updating the parameters and assumptions, in particular the assumptions of economic growth, the rate of energy demand, the economy, renewable energy, as well as the development of global CI reduction trends.

Increase the installed capacity of renewable energy plants from 10.3 GW in 2019 to a minimum of 23.7 GW in 2025 and 407.9 GW in 2050. In a more aggressive scenario, the capacity of renewable energy generation in 2025 and 2050 will reach 36,0 GW and 450.6 GW respectively.

In the CI reduction scenario, although it is not close to zero, the total GHG emissions can be held in the range of 703-750 MtCO2e in the primary energy mix and may decrease to 82 MtCO2e in the electricity system in 2050. In the realization scenario, the energy sector GHG emissions will reach 1.6 GtCO2e in 2050. The current policy scenario is limited to reducing emissions by 18% from the baseline GHG emissions in the realization scenario. CI reduction scenario, reducing GHG emissions from the baseline in the realization scenario between 857-909 MtCO2e. GHG emissions in the electricity sector may reach 82 MtCO2e and further support the Paris Agreement target (net-zero emissions by 2050). If the CI reduction scenario, combined with the renewable CI reduction phenomenon in export destination countries, is implemented, it will suppress coal demand.

From an economic perspective, this decline in coal demand in Indonesia will have a negative impact on at least five districts in three coal-producing provinces, including three coal mines in East Kalimantan (average coal production capacity of 34-86 million metric tons of coal in 2018), 1 coal mine in East Kalimantan. South Kalimantan (28 million tons of coal) and the smallest in South Sumatra (19 million metric tons of coal), with the contribution of mining and research to the district's GRDP (Gross Regional Domestic Product) in 2018 ranging from 55% to 81%. From a workforce perspective, this decline in coal demand may arise from the 100 thousand direct workers in the coal industry. However, currently, Indonesia is still planning to use coal to meet its energy needs through the construction of steam power plants and downstream. Clean coal development is not an environmentally friendly option; the use of CCS (Carbon Capture Storage) technology requires a large investment and is not economical when using renewable energy generation. If these policies and plans are carried out, coal-based infrastructure (and other fossil energy in general) has the potential to cause losses (in the form of stranded assets) in the future.

The Indonesian transportation sector, as the largest share of fossil energy users, also needs to be a priority to be able to transform. As the economy grows, the transportation sector will continue to grow, as will its GHG emissions. However, various e-carbonization options could bring GHG emissions to near zero by 2050. To be able to decarbonize the transportation sector, vehicle electrification and the use of biofuels/synthesis/hydrogen are steps to improve technology. In the transport sector, the development and utilization of biofuels may become a technology lockout if not planned comprehensively. Careful and careful planning that pays attention to developments in technology will be the key to the transition of the transportation sector. The negative impacts of the CI reduction need to be managed properly so that the transformation process can run fairly.

This study was conducted through a decomposition analysis of the Indonesian's response in dealing with technological shocks caused by CI escalation by using the ARDL method.

3)Methodology

3.1. Data & Model Specification

This study uses annual time-series data from 1966 to 2019 taken from the WDI (World Bank 2020) and BP Statistics Review of World Energy 2020 to determine Carbon Intensities to Indonesian Technological Shocks. Carbon emissions were measured in tons per capita of Oil emission, Coal emission, and Gas emission. The technological shock was measured as Economic Complexity Index. These two variable data were collected by WDI (World Bank 2020). In this paper, we applied a dynamic autoregressive distribution lag simulation method to examine the actual changes caused by the independent variables of the dependent variable Jordan and Philips (2018). Before using the dynamic ARDL simulation, you need to perform a unit root test to find out the stationarity of each variable and the order of integration of the associated variables. If the variables are not stationary, they can lead to false regression results. We used the level and the first difference to confirm the stationarity of each variable. If a variable is not stationary in its level term, it has a unit root, but if the first difference in the time series is stationary, it means that the time series is linear or I (1) integrated. increase. Only variables that are stationary at I (0) or I (I) can be used to apply a dynamic ARDL simulation.

To examine the association among the study variables, the following general equation is proposed:

$$EMOil_t = \beta_0 + \beta_1 GDPC_1 + \beta_2 ECI + \varepsilon_t \quad (1)$$

$$EMGas_t = \beta_0 + \beta_1 GDPC_1 + \beta_2 ECI + \varepsilon_t \quad (2)$$

$$EMCoal_t = \beta_0 + \beta_1 GDPC_1 + \beta_2 ECI + \varepsilon_t \quad (3)$$

In the above equation, β0 is constant, β1 to β3 are the coefficients of independent variables, and εt is the error term. The bound test was utilized to scrutinize the long-run association among the study variables. Based on the hypothesis, the following ARDL bound test model was applied to examine the long-run association among the study variables:

$$\Delta EMOil_t = \varphi_0 + \varphi_1 EMOil_{t-i} + \varphi_2 GDPC_{t-i} + \varphi_3 ECI_{t-i} + \sum_{i=1}^{q} \beta_1 \Delta EOil_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varepsilon_t \quad (4)$$

$$\Delta EMGas_t = \varphi_0 + \varphi_1 EMGas_{t-i} + \varphi_2 GDPC_{t-i} + \varphi_3 ECI_{t-i} + \sum_{i=1}^{q} \beta_1 \Delta EMGas_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varepsilon_t \quad (5)$$

$$\Delta EMCoal_t = \varphi_0 + \varphi_1 EMCoal_{t-i} + \varphi_2 GDPC_{t-i} + \varphi_3 ECI_{t-i} + \sum_{i=1}^{q} \beta_1 \Delta EMCoal_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varepsilon_t \quad (6)$$

In Equation 4,5,6, Δ represents the first difference, Technological shock, emissions per capita, EMOil is the oil emission, EMCoal is the coal emission, and EMGas is the gas emission. and t-i represents the optimal lags selection based on the Akaike information criterion. φ and β are variables that will be examined for checking long-run association among the study variables. Long-run associations exist among the study variables so we estimate the short-run and long-run ARDL model. The null and alternative hypotheses of the bound test are the following:

$H_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$

$H_1 \neq \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq 0$

The null hypothesis can be accepted or rejected based on the examined value of F-statistics. the long-run association presents among the study variables if the calculated F-statistics values are greater than the value of the upper bound; no long-run association exists if the calculated F-statistics value is less than the lower bounds value and the decision is inconclusive if the calculated F-statistics value be- tween the value of the lower and upper bound (Pesaran et al., 1999).

3.2 ARDL model

The ARDL model was suggested by (Pesaran et al., 1999); (Pesaran, et al 2001). The ARDL model has different advantages as compared to other time series models. The ARDL model can be utilized with short-time data. ARDL model can be utilized if the series is stationary at I(0), I(I), or both of them (Haug, 2002). Different lags can be used for dependent and independent variables. As the estimated results ofARDL bound test indicate that cointegration exists among the study variables. This is the long-run ARDL model:

$$EMOil_t = \alpha_0 + \sum_{i=1}^{q} \sigma_1 \Delta EMOil_{t-i} + \sum_{i=1}^{q} \sigma_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \sigma_3 \Delta ECI_{t-i} + \varepsilon_t \quad (7)$$

$$EMGas_t = \alpha_0 + \sum_{i=1}^{q} \sigma_1 \Delta EMGas_{t-i} + \sum_{i=1}^{q} \sigma_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \sigma_3 \Delta ECI_{t-i} + \varepsilon_t \quad (8)$$

$$EMCoal_t = \alpha_0 + \sum_{i=1}^{q} \sigma_1 \Delta EMCoal_{t-i} + \sum_{i=1}^{q} \sigma_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \sigma_3 \Delta ECI_{t-i} + \varepsilon_t \quad (9)$$

In the above equation, σ represents the long-run variation in the study variables. Akaike information criterion was applied to select suitable lags for each variable. For the short-run ARDL model, the following error correction model was applied:

$$EMOil_t + \alpha_0 + \sum_{i=1}^{q} \beta_1 \Delta EMOil_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varphi ECT_{t-i} + \varepsilon_t \quad (10)$$

$$EMGas_t + \alpha_0 + \sum_{i=1}^{q} \beta_1 \Delta EMGas_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varphi ECT_{t-i} + \varepsilon_t \quad (11)$$

$$EMCoal_t + \alpha_0 + \sum_{i=1}^{q} \beta_1 \Delta EMCoal_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta GDPC_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta ECI_{t-i} + \varphi ECT_{t-i} + \varepsilon_t \quad (12)$$

In the above equation, β shows the short-run variation while ECT indicates the error correction term that estimates the speed of adjustment from disequilibrium; the normal range of error correction term is from − 1 to 0. Error correction term should be negative and statistically significant which means that any shock is adjusted to equilibrium in the next period. The stability of the model was checked through CUSUM and CUSMSQ (Brown et al. 1975. A serial correlation was checked by Breusch–Godfrey Lagrange Multiplier (LM). Heteroscedasticity was checked through Breusch-Pagan- Godfrey (BG), and autoregressive conditional heteroscedasticity (ARCH); Jarque–Bera was used to check the residual normality. The model specification was checked through Ramsey reset test among the study variables.

3.3 Dynamic Autoregressive Distributed Lag Simulations

Jordan and Philips (2018) proposed the dynamic ARDL model to remove the complications of the existing ARDL for investigation of the short-run and the long-run association among the study variables. Dynamic ARDL simulations method is efficient to estimate, stimulate, and predict the graph automatically of the actual change in the regressor and its impact on the regressand while the remaining variables in the equation remain constant. To use the dynamic ARDL simulations method, the variables would be stationary at I(I) and cointegration among the study variables (Jordan and Philips 2018; Sarkodie and Strezov 2019). Dynamic ARDL error correction term algorithm used 5000 replications for the vector of variables from a multivariate normal distribution. The graphs are used to examine the actual change in the regressor and its impact on the regressand. This is the error correction term forms of ARDL bound test (Jordan & Philips, 2018); (Sarkodie & Strezov, 2019):

$$\Delta EMOil_y = \alpha_0 + \Theta_0 EMOil_{t-1} + \beta_1 \Delta GDP_t + \Theta_1 GDP_{t-1} + \beta_1 \Delta ECI_t + \Theta_1 ECI_{t-1} \quad (13)$$

$$\Delta EMGas_y = \alpha_0 + \Theta_0 EMGas_{t-1} + \beta_1 \Delta GDP_t + \Theta_1 GDP_{t-1} + \beta_1 \Delta ECI_t + \Theta_1 ECI_{t-1} \quad (14)$$

$$\Delta EMCoal_y = \alpha_0 + \Theta_0 EMCoal_{t-1} + \beta_1 \Delta GDP_t + \Theta_1 GDP_{t-1} + \beta_1 \Delta ECI_t + \Theta_1 ECI_{t-1} \quad (15)$$

a. Description of Variables

Table 1 shows the description of each variable.

Table 1 Description of Variables

Variable	Description	Unit	Source
Emission of Gas (EG)	As the carbon footprint of greenhouse gas (GHG) emission standard unit measurement using gas tonnes carbon dioxide equivalent tCO_2e or tCO_2eq	tCO_2eq	BP Statistics Review of World Energy
Emission of Oil (EO)	The carbon footprint for crude oil standard unit measurement using tonnes carbon dioxide equivalent per megajoule tCO_2eq/mJ	tCO_2eq/mJ	BP Statistics Review of World Energy /
Emission of Coal (EC)	This unit of measurement of coal emissions does not use kilotons (amount of coal) but uses the tonnes of carbon dioxide equivalent to knowing the equivalent of coal emissions.	tCO_2eq	BP Statistics Review of World Energy
GDPC4			Word Bank Index 2020

The results of the Dynamic Decomposed Carbon Intensities and ARDL analysis are explained and discussed in the following sections.

4)Results and Discussion

4.1 Descriptive Statistic Result

Table 2 Descriptive Statistic Result

Variable	Min	Max	Mean	Std. Dev
EMIOIL	12356359.00	1284979975.00	1099032401.5741	392752795.68815
EMIGAS	124857971.00	1397494479.00	1204534136.4074	156854156.01577
EMICOAL	126664616.00	1331545185.00	1228498168.8148	220157650.55514
ECI	-242460165.00	-6918.00	-29174547.5556	55490026.45050
GDPC	31132968.00	3648422547.00	2861391597.7963	1047840578.73735

Source: data processing

Table 2 presents a summary of descriptive statistics for each variable. The other descriptive statistics are consistent to the economic information in Indonesia

4.2. Dynamic Decomposed Carbon Intensities

The energy sector has a GHG emission reduction target of 314 million tonnes of CO_2e or the equivalent of 11% under scenario conditions without unconditional reduction requirements (countermeasure / CM1). The goal of reducing greenhouse gas emissions is achieved through energy sector-based mitigation measures implemented by the central government (Ministry of Industry and Ministry of Transport) referred to as the contribution of RAN GRK, various programs, and local government policies related to energy procurement and use that Role of active private parties and the public who have taken various measures to contain the energy sector.

The contribution to reduction other than RAN GRK has not been fully identified. In 2018, the actual emissions level of 207.69 Mt CO2e was below the construction emissions

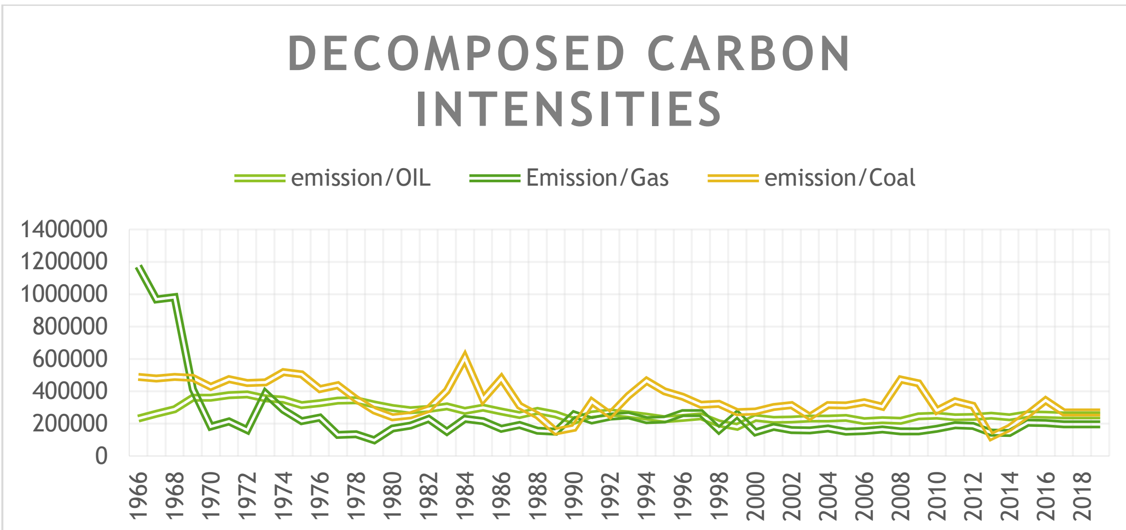

Figure 1: Decomposed Carbon Intensities 1966 - 2018

level this year, so that GHG emissions were reduced by 7.28% compared to the 11% contribution target set for the energy sector in 2030. From 207 The 0.69 MTon CO_2e, 61.30 MTon CO_2e originate from the mitigation measures that are contained in the RAN GRK and are claimed by the respective industry. Thus, there are approximately 146.40 million tonnes of CO_2e to reduce greenhouse gas emissions due to the impact of other measures 114 implemented by various parties, both government and non-government, as well as the effects of certain ones Policies that have not been properly disclosed / recorded.

Table 3: Order of Integration

UNIT ROOT TEST RESULTS TABLE (ADF)					
			At Level		
	ECI	CO_2-COAL	CO_2-GAS	CO_2-OIL	LGDPC
With Constant	-0.7319	-3.4965**	-4.4321***	-1.3248	-0.9082
With Constant & Trend	-1.2996	-4.0482**	-4.2119***	-2.3463	-2.5858

Without Constant & Trend	-1.3710	-0.3716	-1.0299	-0.2338	8.5307
			At First Difference		
	ΔECI	Δ CO_2-COAL	Δ CO_2-GAS	Δ CO_2-OIL	ΔLGDPC
With Constant	-6.7694***	-6.8102***	-9.0735***	-6.5150***	-5.3876***
With Constant & Trend	-6.7015***	-6.7290***	-9.3290***	-6.4325***	-5.3621***
		UNIT ROOT TEST RESULTS TABLE (PP)			
	ECI	CO_2-COAL	CO_2-GAS	CO_2-OIL	LGDPC
With Constant	-0.7683	-3.5208	-5.0371***	-1.9041	-0.8566
With Constant & Trend	-1.4018	-4.0482	-4.3583**	-3.4552*	-2.2731
Without Constant & Trend	-1.3452	-0.4842	-1.0545	0.0959	7.3160
			At First Difference		
	ΔECI	Δ CO_2-COAL	Δ CO_2-GAS	Δ CO_2-OIL	ΔLGDPC
With Constant	-6.7748***	-8.4697***	-9.0751	-7.9185***	-5.3540***
With Constant & Trend	-6.7075	-8.3821	-9.9195	-7.7858	-5.3276
Without Constant & Trend	-6.7164	-8.5360	-9.0313	-7.9691	-2.9084

Table 3 summarizes that before applying dynamic ARDL simulations, it is essential to check that any series are not I(2); otherwise, the results will not be valid. Three different unit root tests ADF and PP, were applied to check unit root of each series. The examined results show that none of the series are stationary at I(2). The estimated results of the above three unit root tests show that dynamic ARDL model can be applied with the used series.

Table 4: Dynamic Impact of Technology on Decomposed Emission Intensity

Regressor	Emission -Oil Intensity	Emission -Gas Intensity	Emission -Coal Intensity
	Long Run Coefficients		
$LGDPC_{t-1}$	-8.9457***	7.2446***	8.6534***
	1.8670	1.0915	0.76504
$LGDPC_{t-1}^2$	1.3212***	-1.0808***	-1.4502***
	0.2825	0.3130	0.2191
ECI_{t-1}	-0.1037**	-0.0681	0.0500
	0.0450	0.3158	0.2484
	Short Run Coefficients		
$\Delta LGDPC$	-6.1061***	2.7744***	3.7394***
	1.3273	0.9778	1.0498
$\Delta LGDPC^2$	1.1132***	-.41392**	-0.6266***
	0.2176	0.1935	0.1898
ΔECI	-0.0708***	-0.0261	0.0216
	0.0376	0.1191	0.1069

ECM_{t-1}	-0.6825***	-0.3829***	-0.4321***
	0.1184	0.0981	0.1175

Technological shock is measured by GDP and ECI. GDP and ECI has positive and negative significant effect on the Emissions of Gas, Emission of Oil and Emission of Coal. The examined results of GDP indicated that in the long run and short run has positive impact on carbon intensities

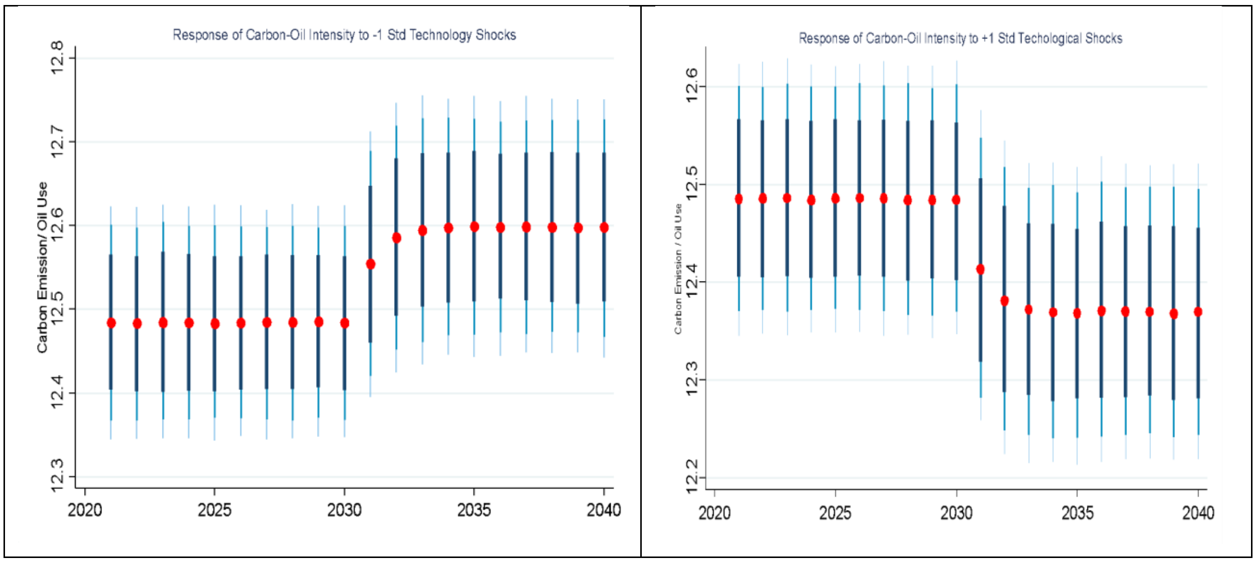

Figure 2: Dynamic Simulated ARDL under different Scenario

Figure 2 shows the impulse response plot of oil consumption for energy and CO_2 emissions in Indonesia. Results of the impulse response plot indicate that 10% increase in oil consumption for energy consumption positively influences the CO_2 emissions in Indonesia both in the short run and the long run while 12%.

5)Conclusion

Environmental degradations are mainly caused by the use of energy for economic growth, and ECI growth. The purpose of this research was to scrutinize the effect of technological shock on emissions gas, oil, and coal in Indonesia from 1966 to 2019. Dynamic ARDL simulation model was utilized to scrutinize the short-run and the long-run influence of GDP and ECI on emissions energy in Indonesia. Simple ARDL model in literature is applied again and again to examine the short- run and long-run association among study variables, but this study utilized dynamic ARDL simulations to examine the actual change (positive and negative) in GDP and ECI and its impact on emissions gas, oil, and coal. Before utilizing dynamic ARDL simulations, it is necessary to check the stationarity ofeach series that none ofthe series are I(2); otherwise, the results will not be valid. Three differ- ent unit root tests (ADF and PP) were applied to examine the stationarity of each series. The examined unit root tests indicate that none ofthe series are stationary at I(2) which confirm that dynamic ARDL simulations can be applied. Results of dynamic ARDL simulations model indicate that technological shock boost the environmental degradations in Indonesia both in the short run and the long run. Based on the examined results, it is observed that environmental degradations in Indonesiaare caused by the use of traditional energy resources for energy consumption. It is recommended that policy makers in Indonesia should adopt such polices that help to reduce the environmental degradations by motivating industrial and household to use renewable energy resources for energy consumption

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YENİLENEBİLİR ENERJİ VE TEKNOLOJİK İNOVASYONUN ÇEVRESEL BOZULMAYA ETKİSİ: RALS BİRİM KÖK VE RALS ENGLE-GRANGER EŞ-BÜTÜNLEŞME YAKLAŞIMI

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ÖZET: Sürdürülebilir kalkınma hedeflerinin gerçekleştirilmesinde enerji kaynaklarına erişimin sağlanması ve dünya çapında yenilenebilir enerjinin payının artırılması önemlidir. Yenilenebilir enerji kaynaklarının kullanımı ve sürdürülebilirliği için çevre dostu inovatif teknolojilere gereksinim duyulmaktadır. Yenilenebilir enerji fosil yakıtların çevre ile iklim değişikliği üzerindeki olumsuz etkilerinin azaltılmasına, sera gazı emisyonlarını azaltarak hava kalitesinin artırılmasına, insan sağlığının iyileştirilmesine, istihdam yaratılmasına ve enerji arz güvenliğinin sağlanmasına katkıda bulunur. İnovasyon faktörü, araştırma ve yenilik faaliyetlerini ve kaynak verimliliğini artırmaya, yenilenemeyen enerji kaynaklarının daha verimli kullanılmasını sağlamaya yönelik ileri teknoloji kullanımını amaçlayan yeşil yatırımlara ve yenilenebilir enerji kullanımının yaygınlaşmasına odaklanarak ekonomik kalkınmanın sürdürülmesine ve ekolojik ayak izinin azaltılmasına yardımcı olabilir. Bu bağlamda sürdürülebilir kalkınma açısından hem yenilenebilir enerji kaynaklarının kullanımı hem de inovatif faaliyetlerin artması ekolojik ayak izinin azalmasına katkıda bulunacaktır. Bu çalışmada yenilenebilir enerji ile teknolojik inovasyonun ABD'deki ekolojik ayak izi üzerindeki etkisinin RALS birim kök ve RALS Engle-Granger eş-bütünleşme testleri yapılarak incelenmesi amaçlanmıştır. Çalışmada değişkenler arasında uzun dönemli bir ilişki olduğu sonucuna ulaşılmıştır. Ayrıca yenilenebilir enerjinin ve teknolojik inovasyonun ekolojik ayak izini azalttığı bulgusuna da ulaşılmıştır.

Anahtar Kelimeler: Yenilenebilir Enerji, Teknolojik İnovasyon, Çevresel Bozulma, RALS-EG Yaklaşımı
Jel Sınıflandırması: Q55, Q43,Q20,C32

ABSTRACT: Ensuring access to energy resources and increasing the share of renewable energy worldwide are important in achieving sustainable development goals. Environmentally friendly innovative technologies are needed for the use and sustainability of renewable energy sources. Renewable energy contributes to reducing the negative effects of fossil fuels on the environment and climate change, increasing air quality by reducing greenhouse gas emissions, improving human health, creating employment, and ensuring energy supply security. The innovation factor can help sustain economic development and reduce the ecological footprint by focusing on increasing research and innovation activities and resource efficiency, green investments that aim to use advanced technology to ensure more efficient use of non-renewable energy resources, and the widespread use of renewable energy. In this context, both the use of renewable energy sources and the increase in innovative activities will contribute to the reduction of the ecological footprint in terms of sustainable development. In this study, it is aimed to examine the effect of renewable energy and technological innovation on the ecological footprint in the USA by performing RALS unit root and RALS Engle-Granger cointegration tests. In the study, it was concluded that there is a long-term relationship between the variables. It has also been found that renewable energy and technological innovation reduce the ecological footprint.
Keywords: Renewable Energy, Technological Innovation, Environmental Degradation, RALS-EG Approach
Jel Classification: Q55, Q43, Q20, C32

GİRİŞ

Sanayi devriminden sonra sera gazlarında meydana gelen artışla birlikte doğal denge bozulmaya başlamıştır. Eğer önlem alınmazsa okyanus seviyelerinin yükselmesi, buzulların daha fazla erimesi, aşırı sıcaklık, kuraklaşma, bitki ve hayvan çeşitliliğinin azalması gibi sonuçlara yol açacak iklim değişmeleri ile karşı karşıya kalınacaktır (Tekin, 2020: 274-275). 2015 yılında Birleşmiş Milletler Genel Kurulu, sürdürülebilir bir geleceği güvence altına almak için 2030 yılında tamamlanacak bir yol haritası olarak "2030 Gündemi" adıyla Sürdürülebilir Kalkınma Amaçlarını (SKA) kabul etmiştir. Enerji ve çevre politikalarının yeniden düzenlenmesi ve ekolojik ayak izi yoluyla çevresel bozulma üzerinde kontrol sahibi olunması, sürdürülebilir kalkınma hedeflerine ulaşılmasına yardımcı olacaktır.

Dünya çapında sürdürülebilir kalkınma hedeflerinin gerçekleştirilmesinde, enerji kaynaklarına erişimin ve enerjinin sürdürülebilirliğinin sağlanması ve toplam enerji kaynakları içerisinde yenilenebilir enerjinin payının artırılması önemlidir. Yenilenebilir enerjinin kullanımı ve sürdürülebilir gelişimi için çevre dostu inovatif teknolojilere ve bu teknolojileri ortaya çıkartacak Ar-Ge faaliyetlerine ihtiyaç vardır. Fosil yakıtlara alternatif olarak yenilenebilir enerjilerin keşfedilmesi ve kullanımı karbon yoğun yenilemeyen enerji kaynaklarına olan bağımlılığın ve ekolojik ayak izinin azalmasını da sağlayacaktır. Teknolojik inovasyon, endüstriyel dönüşüm ve yenilenebilir enerjinin geliştirilmesi yoluyla sürdürülebilir kalkınma, ekonomik ve sosyal kalkınmanın sağlanmasına yardımcı olacaktır.

Literatürde son zamanlarda sürdürülebilirlik kavramı ile yenilenebilir enerji, teknolojik inovasyon ve çevresel bozulma konularında çalışmaların yoğunlaştığı görülmektedir. Bu çalışmada çevresel bozulma göstergesi olarak ekolojik ayak izi verisi kullanılmış ve yenilenebilir enerji ile teknolojik inovasyonun ABD'deki ekolojik ayak izi üzerindeki etkisinin RALS birim kök ve RALS Engle-Granger eş-bütünleşme testleri yapılarak incelenmesi amaçlanmıştır. Kişi başına düşen ekolojik ayak izi sıralamasında ilk on ülke arasında yer alan ABD'nin ekolojik açığı -1,416.05 kişi başına düşen ekolojik ayak izi 8,22 hektar ve biyokapasitesi 3,76 hektardır. Dolayısıyla ABD'de ekolojik ayak izi üzerinde yenilenebilir enerjinin ve teknolojik inovasyonun etkisinin test edilmesi çevresel sürdürülebilirlik açısından önemli rol oynayacaktır. Girişten sonraki ilk bölümde konuyla ilgili teorik çerçeve ortaya konmuştur. İkinci bölümde bu alanda yapılan önceki çalışmalar gözden geçirilerek literatür özetlenmiştir. Üçüncü bölümde veri kaynakları ve metodolojiye yer verilmiştir. Dördüncü bölümde ise ampirik bulgular sunulmuştur. Son olarak, sonuç ve politika önerilerine yer verilmiştir.

1.TEORİK ÇERÇEVE

Uluslararası Enerji Ajansı (IEA, 2018) raporuna göre hem gelişmiş hem de gelişmekte olan ülkelerde karbon yoğun enerji kaynaklarının kullanımı ekolojik ayak izinin yükselmesinde etkili olmaktadır. Çevresel bozulma göstergesi olarak bilinen ekolojik ayak izi terimi, ne kadar doğaya sahip olduğumuzu ve doğayı ne kadar kullandığımızı hesaplayan bir ölçüttür (Ullah vd., 2021).

Sürdürülebilirliği sağlamanın ve çevresel bozulmanın önüne geçebilmenin yollarından biri, enerji kullanımın yenilenemeyen enerji kaynaklarından yenilenebilir enerji kaynaklarına yönlendirilmesidir. Diğeri ise enerjinin çevresel kalite üzerindeki olumsuz etkisini minimize edebilmek için üretim aşamasında yenilenemeyen enerji kaynaklarının marjinal tüketiminin azaltılmasıdır (Sharma vd., 2021: 2). Bu bağlamda hem yenilenebilir enerjilerin kullanımı hem de sera gazı salınımına neden olan faaliyetlerin durdurulması, minimuma indirilmesi veya karbonsuz olanlarla değiştirilmesine neden olabilecek enerji verimliliği sağlayacak teknolojilerin üretim ve kullanımının yaygınlaştırılması önem arz etmektedir (Tekin, 2020). Dolayısıyla sürdürülebilir kalkınma açısından hem yenilenebilir enerji kaynaklarının kullanımı hem de inovatif faaliyetlerin artması ekolojik ayak izinin azalmasına katkıda bulunacaktır.

Ülkeler sürdürülebilir kalkınma hedeflerini gerçekleştirmek için temiz ve yenilenebilir enerji kaynaklarına yönelmeye başlamıştır. Yenilenemeyen enerji kaynaklarının kullanımı, ithalata bağımlılık, fiyat dalgalanmaları, yüksek maliyetler ve ekolojik dengesizlik gibi olumsuzluklara yol açabilmektedir (Sharma vd., 2021). Yenilenebilir enerji fosil yakıtların çevre ile iklim değişikliği üzerindeki olumsuz etkilerinin azaltılmasına, sera gazı emisyonlarını azaltarak hava kalitesinin artırılmasına, insan sağlığının iyileştirilmesine, istihdam yaratılmasına ve enerji arz güvenliğinin sağlanmasına katkıda bulunur. Ayrıca, yerli yenilenebilir enerji kaynaklarının kullanımı enerji ithalatından kaynaklanan maliyetleri de azaltır (Pata, 2021:

198). Sürekli artan enerji talebi nedeniyle yenilenebilir enerjinin geleceğin en önemli enerji kaynağı olduğu ve aynı zamanda çevre dostu bir enerji kaynağı olduğu bilinen bir gerçektir (Chien vd., 2021: 308).

Sürdürülebilir ekonomik kalkınmanın sağlanmasında ve ekolojik ayak izinin azaltılmasında etkili olan diğer bir faktör de inovasyondur. İnovasyon faktörü, araştırma ve yenilik faaliyetlerini ve kaynak verimliliğini artırmaya, yenilenemeyen enerji kaynaklarının daha verimli kullanılmasını sağlamaya yönelik ileri teknoloji kullanımını amaçlayan yeşil yatırımlara ve yenilenebilir enerji kullanımının yaygınlaşmasına odaklanarak ekonomik kalkınmanın sürdürülmesine ve ekolojik ayak izinin azaltılmasına yardımcı olabilir (Ghita vd., 2018: 21).

Her türlü inovasyon faaliyeti sürdürülebilir kalkınma için önemli olmakla birlikte, doğrudan enerji sektörüne yönelik inovatif faaliyetler çevresel sorunları önemli ölçüde iyileştirebilir ve daha temiz enerjinin yayılmasını teşvik edebilir. Enerji sektörüne yönelik inovatif faaliyetler yoluyla daha az karbon yoğun teknolojinin uygulanması, geleneksel fosil yakıtlardan, özellikle petrol, doğal gaz ve kömürden birincil enerji üretimini azaltarak atmosferdeki sera gazı yoğunluğunu önemli ölçüde azaltabilir (Altıntaş ve Kassouri, 2020).

2.LİTERATÜR TARAMASI

Ekonomik kalkınma amacıyla birçok ülke enerji talebinin önemli bir bölümünü fosil yakıtlardan yana kullanmaktadır. Fosil yakıtların kullanımı ise karbon salınımı meydana getirmesi sebebiyle çevre kirliliğine yol açmaktadır. Son zamanlarda politika yapıcılar enerji tüketimine bağlı olarak çevreye verilen tahribatın farkına vararak, çevresel bozulmanın ortadan kaldırılmasına yönelik politikalar oluşturmaya başlamışlardır. Bu bağlamda son zamanlarda ekolojik sürdürülebilirlik kavramı ile yenilenebilir enerji, teknolojik inovasyon ve çevresel bozulma konularında çalışmalar yoğunlaşmıştır. Tablo 1'de teknolojik inovasyon ve çevresel bozulma alanındaki uygulamalı literatüre yer verilmiştir.

Tablo 1: Teknolojk inovasyon ve çevresel bozulma ile ilgili yapılan çalışmalar

Yazar	Ülke	Dönem	Yöntem	Sonuç
Hang ve Yuan-Sheng (2011)	Çin	1980-2006	Regresyon Analizi	Yeni teknolojinin ilk aşamada çevresel bozulmaya etkisi pozitif iken, sonraki aşamalarda, teknolojinin gelişmesiyle etki negatif olmuştur.
Fei vd. (2014)	Norveç, Yeni Zelanda	1971-2010	ARDL Granger nedensellik testi	Norveç'te çevresel bozulma ile teknolojik inovasyon arasında çift yönlü bir nedensellik ilişkisi varken Yeni Zelanda'da ilişki tespit edilememiştir.
Ali vd. (2016)	Malezya	1985-2012	ARDL	Teknolojik inovasyonun çevre kirliliğine etkisi yok denilecek kadar azdır.
Ahmed vd. (2016)	24 Avrupa Ülkesi	1980-2010	ARDL	Teknolojik inovasyonun çevre kirliliğini azalttığı tespit edilmiştir.
Irandoust (2016)	Danimarka, Finlandiya, İsveç ve Norveç	1975-2012	VAR analizi Granger nedensellik testi	İncelenen ülkelerde teknolojik inovasyondan yenilenebilir enerjiye doğru tek yönlü bir nedensellik ilişkisi bulunmuştur.
Yii ve Geetha (2017)	Malezya	1971-2013	VECM'ye dayalı Granger nedensellik testi	Teknolojik inovasyon ve çevresel bozulma arasında bir ilişki bulunmamaktadır.
Samargandi (2017)	Suudi Arabistan	1970-2014	ARDL	Teknolojik gelişmenin çevresel bozulma üzerinde önemli bir etkisi bulunmamaktadır.
Fan ve Hossain (2018)	Çin, Hindistan	1974-2016	Toda-Yamamoto nedensellik testi	Çin'de teknolojik inovasyon ile çevresel bozulma arasında çift yönlü bir nedensellik ilişkisi tespit edilirken, Hindistan'da teknolojik yenilikten teknolojik bozulmaya doğru tek yönlü bir nedensellik ilişkisi bulunmuştur.
Ibrahiem (2020)	Mısır	1971-2014	Toda-Yamamoto nedensellik testi	Teknolojik inovasyon ve alternatif enerji kaynaklarının çevreyi iyileştirdiği, ancak finansal gelişme ve ekonomik büyümeyi bozduğu bulunmuştur.
Danish vd. (2020)	BRICS ülkeleri	1992-2016	Westerlund panel eş-bütünleşme testi Panel nedensellik testi	Doğal kaynak rantı, yenilenebilir enerji ve kentleşme ekolojik ayak izini azaltır.
Khattak vd. (2020)	BRICS ülkeleri	1980-2016	Panel eş-bütünleşme testi	Teknolojik inovasyon faaliyetlerinin Brezilya dışındaki BRICS ülkeleri için çevre kirliliğini azaltmada başarısızdır.

Tablo 1'in devamı

Ali vd. (2020)	33 Avrupa Ülkesi	1996-2017	Westerlund panel eş-bütünleşme testi Panel nedensellik testi	Teknolojik inovasyonun çevresel bozulma üzerinde negatif etkisi vardır.
Wang vd (2020)	N-11 ülkeleri	1990-2017	Westerlund panel eş-bütünleşme testi	Teknolojik inovasyon ve yenilenebilir enerji tüketimi ile çevre kirliliği arasında negatif bir ilişki bulunmaktadır.
Destek ve Manga (2021)	Yükselen büyük piyasa (BEM) ülkeleri	1995-2016	Westerlund panel eş-bütünleşme testi	Teknolojik yenilik karbon emisyonlarını azaltmada etkili iken, ekolojik ayak izi üzerinde önemli bir etkisi bulunmamaktadır
Chien vd. (2021)	Pakistan	1980-2018	Kantil ARDL Granger nedensellik testi	Teknolojik inovasyon ve yenilenebilir enerji çevresel bozulma ile negatif ilişkilidir.
Khan vd. (2021)	69 ülke	2000-2014	Panel GMM	Teknolojik inovasyon, ekonomik büyüme ve doğrudan yabancı yatırım yenilenebilir enerji üzerinde negatif etkilidir.
Shao vd (2021)	N-11 ülkeleri	1980-2018	Kesitsel artırılmış otoregresif dağıtılmış gecikmeler (CS-ARDL) modeli	Yeşil teknolojik inovasyonu ve yenilenebilir enerji çevre kirliliğini uzun dönemde negatif etkiler.
Shan vd. (2021)	Türkiye	1990-2018	Bootstrap ARDL Granger nedensellik testi	Yeşil teknoloji inovasyonu ve yenilenebilir enerji, çevre kirliliğini azaltır.
Danish ve Ulucak (2021)	ABD, Çin	1980-2016	Dinamik ARDL	Teknolojik inovasyon ABD'de çevre kirliliğini azaltırken, Çin'de istatistiksel olarak anlamlı bir ilişki bulunamamıştır. Her iki ülkede de yenilenebilir enerji çevre kirliliğini azaltmaktadır.
Haldar ve Sethi (2022)	16 gelişmekte olan ülke	2000- 2018	Westerlund panel eş-bütünleşme testi Bootstrap panel kantil regresyon testi	Artan internet kullanımı, yenilenebilir enerji tüketimi ve uluslararası ticaret çevre kirliliğini azaltırken, yenilenemeyen enerji tüketimindeki artış ise emisyonu önemli ölçüde artırmıştır.
Suki vd. (2022a)	Malezya	1971-2017	Bootstrap ARDL	Teknolojik inovasyon hem CO2 emisyonunu hem de ekolojik ayak izini azaltır.
Suki vd. (2022b)	Malezya	1971-2017	Bootstrap ARDL Granger nedensellik testi	Yeşil inovasyon hem kısa hem de uzun dönemde büyüme ile pozitif ve çevresel bozulma ile negatif ilişkilidir.

Kaynak: Tablo yazarlar tarafından oluşturulmuştur.

3. VERİ VE METODOLOJİ

Bu çalışmada ABD'de çevresel bozulma üzerinde yenilenebilir enerji tüketimi ve teknolojik inovasyonun etkisini test etmek için 1980-2016 dönemi verileri kullanılmıştır. Çalışmada çevresel bozulma göstergesi olarak ekolojik ayak izi, teknolojik inovasyon göstergesi olarak da patent sayısı kullanılmıştır. Ayrıca çevresel bozulma üzerinde hem yenilenebilir hem de yenilenemeyen enerji tüketiminin etkisini görebilmek amacıyla her iki enerji tüketimi verisi de analize dâhil edilmiştir. Analize dâhil edilen tüm değişkenlerin logaritmik dönüşümleri yapılmıştır**.** Ekolojik ayak izi (LEF) verisi Küresel Ayak izi Ağı (Global Footprint Network), patent sayısı (LPT), Dünya Bankası Dünya Kalkınma Göstergeleri (WB-WDI), yenilenebilir (LREN) ve yenilemeyen enerji tüketimi (LNREN) verileri ise Uluslararası Enerji Ajansı (IEA)'dan temin edilmiştir.

Bu çalışmada değişkenlerin durağanlık özelliklerinin belirlenmesinde RALS-ADF birim kök testi, değişkenler arasında uzun dönemli bir ilişki olup olmadığının ortaya konulmasında ise RALS Engle-Granger (RALS-EG) eş-bütünleşme testinden yararlanılacaktır. Bu testler modelin kalıntılarının normal dağılmadığı durumda geleneksel ADF ve Engle-Granger testlerine göre daha güçlü kanıtlar sunmaktadır.

4. EKONOMETRİK ANALİZ VE SONUÇLARI

Çalışmada ilk olarak modelin kalıntılarının normal dağılıma sahip olup olmadığını belirlemek amacıyla Jarque-Bera testi yapılmıştır. Tablo 2'de Jarque-Bera test sonuçlarına yer verilmiştir.

Tablo 2: Jarque-Bera test sonuçları

Değişkenler	Jarque-Bera Test İstatistiği	Olasılık Değeri
LEF	5.708563	0.057597
LPT	2.870189	0.238093
LREN	3.769308	0.151882
LNREN	1.460048	0.481897

Tablo 2'de yer alan Jarque-Bera test sonuçlarına göre teknolojik inovasyon, yenilenebilir enerji ve yenilenemeyen enerji tüketimi normal dağılıma sahip iken ekolojik ayak izi verisi %10 anlam düzeyinde normal dağılıma sahip değildir.

4.1. RALS-ADF Birim Kök Testi ve Sonuçları

Bu çalışmada ekolojik ayak izi, teknolojik inovasyon, yenilenebilir ve yenilenemeyen enerji tüketimi değişkenlerinin durağan olup olmadıklarının belirlenmesinde Im ve Schmidt (2008) tarafından geliştirilen RALS (Residual Augmented Least Squares-Kalıntılarla Genişletilmiş En Küçük Kareler) tekniğinin ADF testine uyarlanmış hali olan ve Im vd.(2014) tarafından geliştirilen RALS-ADF birim kök testi kullanılmıştır.

Tablo 3: Birim kök testi sonuçları

Değişkenler	ADF	RALS-ADF	rho	k
LEF	-0.637523	-0.540408	0.9	0
LPT	-0.285772	-0.603842	0.7	0
LREN	-1.306965	- 0.143963	0.6	3
LNREN	-1.460512	-2.651151	0.7	0
Δ LEF	-6.228877	-5.604653	0.9	0
ΔLPT	-5.232982	-5.669676	0.6	0
ΔLREN	-5.546370	-7.936513	0.6	1
ΔLNREN	-5.414320	-5.690470	0.9	0

Değişkenler için hesaplanan test istatistikleri Im vd. (2014)’te yer alan asimptotik kritik değerler ile karşılaştırıldığında serilerin birim kök içerdiği görülmektedir. Başka bir ifadeyle temel hipotez reddedilememekte ve değişkenler birinci farkı alındığında durağan hale gelmektedir.

4.2. RALS-EG Eş-bütünleşme Testi ve Sonuçları

Birim kök testi sonrasında eş-bütünleşme testinin uygulanması araştırmacıların değişkenler arasındaki ilişkileri incelemesine olanak tanıdığından önem arz etmektedir. Eş-bütünleşme ilişkisinin varlığı, uzun dönemde modelin değişkenleri arasında bir denge olduğunu göstermektedir. Bu çalışmada değişkenler arasında bir eş-bütünleşme ilişkisinin var olup olmadığı Lee vd. (2015) tarafından geliştirilen ve Im ve Schmidt (2008) tarafından önerilen RALS tekniğinin Engle-Granger testine uyarlanmış hali olan RALS-EG yaklaşımı kullanılarak test edilmiştir. Analiz sonuçlarına Tablo 4’te yer verilmiştir.

Tablo 4: Eş-bütünleşme testi sonuçları

Test	t istatistiği	rho	k
EG	-3.190074	-	0
RALS-EG	-4.480988	0.8	0
RALS-EG kritik değerler	%1	%5	%10
	-4.23082	-3.61044	-3.29201

Hesaplanan RALS-EG test istatistiği, kritik değerlerden büyük olduğu için sıfır hipotezi reddedilmektedir. Buna göre ele alınan dönemde ABD'de ekolojik ayak izi, yenilenebilir enerji tüketimi, teknolojik inovasyon ve yenilenemeyen enerji tüketimi değişkenleri arasında uzun dönemli ilişki bulunmaktadır.

4.3.Uzun Dönem Katsayıların Belirlenmesi

Bu çalışmada son olarak RALS-EG eş-bütünleşme testi sonrasında uzun dönem katsayı tahmininde Phillips ve Hansen tarafından geliştirilmiş olan FMOLS (Fully Modified Ordinary Least Squares-1990) ve Park tarafından geliştirilen CCR (Canonical Cointegrating Regression-1992) yöntemleri kullanılmıştır. Analiz Sonuçları Tablo 5'te sunulmuştur.

Tablo 5: Uzun dönem katsayıları

Bağımlı Değişken: LEF				
	FMOLS		CCR	
Bağımsız Değişken	Katsayı	Olasılık Değeri	Katsayı	Olasılık Değeri
LPT	-0.1163	0.0000	-0.1176	0.0000
LREN	-0.0549	0.0024	-0.0556	0.0018
LNREN	1.0806	0.0000	1.0906	0.0000
C	3.1131	0.0000	3.1325	0.0000

Tablo 5'ten de görüleceği üzere FMOLS ve CCR yöntemleri kullanılarak elde edilen uzun dönem katsayıları birbirine oldukça yakındır. Başka bir ifadeyle her iki testin sonucu birbirini desteklemektedir. Elde edilen sonuçlara göre ekolojik ayak izi üzerinde yenilenebilir enerji tüketimi ve teknolojik inovasyon negatif, yenilenemeyen enerji tüketimi ise pozitif bir etkiye sahiptir. Buna göre ABD'nin yenilenebilir enerji tüketimindeki ve teknolojik inovasyondaki %1'lik artış, ekolojik ayak izini sırasıyla %0,05 ve %0.11 azaltırken, yenilenemeyen enerji tüketimindeki artış ekolojik ayak izini yaklaşık olarak %1.09 artırmaktadır. Bununla birlikte elde edilen uzun dönem katsayıları %5 önem düzeyinde istatistiksel olarak anlamlıdır.

SONUÇ

Sürdürülebilir kalkınma hedeflerine ulaşabilmek ve karbon yoğun yenilemeyen enerji kaynaklarının doğa, insan ve ekonomi üzerindeki olumsuz etkilerini azaltabilmek için ülkeler, bir taraftan daha az karbon yoğun olan yenilenebilir enerji kaynaklarını kullanmayı tercih ederler. Diğer taraftan yenilenebilir enerjinin kullanımını artırmak ve sürdürülebilir gelişimini sağlamak için çevre dostu inovatif teknolojilere ve bu teknolojileri ortaya çıkartacak Ar-Ge faaliyetlerine yönelirler.

Yenilenebilir enerji ile teknolojik inovasyonun ABD'deki ekolojik ayak izi üzerindeki etkisinin test edildiği bu çalışmada, analize dahil edilen değişkenler (çevresel bozulma, yenilenebilir enerji, inovasyon ve yenilenemeyen enerji tüketimi) arasında uzun dönemli bir ilişki tespit edilmiştir. Bununla birlikte elde edilen bulgular, yenilenebilir enerjinin ve teknolojik inovasyonun ekolojik ayak izini azalttığını göstermektedir.

Sera gazı salınımına neden olan faaliyetlerin azaltılmasını veya bu faaliyetlerin daha az karbon yoğun olanlarla değiştirilmesini sağlayacak enerji verimliliği yüksek teknolojilerin teşvik edilmesi, enerji sektörüne ilişkin inovatif faaliyetlerin arttırılması ve yenilenebilir enerji kaynaklarının geliştirilmesi önem arz etmektedir. Bu bağlamda ekolojik ayak izini azaltmaya yönelik olarak yeşil enerji politikalarının oluşturulması çevresel tahribatla mücadelede kilit rol oynayacaktır.

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COVID-19 PANDEMİSİ DÖNEMİNDE ENERJİ TÜKETİMİ VE ÇEVRESEL KALİTE

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ÖZET

Covid 19 Pandemisi bütün ülkelerin iktisadi büyüme performansını zayıflattığı gibi işsiz sayısının artmasına da yol açmıştır. Pandeminin daraltıcı etkileri bütün sektörler üzerinde aynı düzeyde değildir. Bazı sektörlerdeki üretimde daralma ve işsiz sayısındaki artış çok belirgin iken, bazılarında daraltıcı etkiler daha hafiftir. İşsizlik artışı ve büyüme performansı üzerindeki negatif etkilerine rağmen, Pandeminin yegane pozitif yönünün çevresel tahribattaki azalma olduğu söylenebilir. İktisadi faaliyetlerdeki yavaşlama ve kapanmanın doğal sonucu olarak enerji tüketiminde bir azalma beklenmektedir.

Bu çalışmada Covid 19 Pandemisinin enerji tüketimi ve çevresel tahribat üzerindeki etkileri ele alınmaktadır. Öncelikle söz konusu değişkenler arasındaki ilişkiyi araştıran çalışmaların bulguları değerlendirilecek ardından enerji tüketiminde etkinlik ve çevresel kalitenin artırılmasına ilişkin politika önerileri sunulacaktır.

ENERGY CONSUMPTION AND ENVIRONMENTAL QUALITY DURING THE COVID-19 PANDEMIC PERIOD

ABSTRACT

The Covid-19 Pandemic negatively impacted the economic growth performance globally, and led to a sharp incline in the unemployment rates. The contractionary effects of the pandemic varied in different industries and sectors. While there has been a severe contraction in production and increase in unemployment due to job losses, the contractionary effects are milder in others. The only positive effect of the Pandemic is the alleviation of environmental degradation since there has been a decline in energy consumption as a consequence of the slowdown in economic activities, and even shutdowns in many industries.

In this study, the impacts of the Covid-19 Pandemic on energy consumption and environmental degradation are discussed. Firstly, the findings of studies investigating the relationship between these variables will be discussed. Then, policy recommendations will be put forth to improve efficiency in energy consumption and environmental quality.