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Relationships between Energy Technology Patents and CO_2 Emissions in China: An Empirical Study

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Abstract This paper explores dynamic relationships between energy technology patents and CO_2 emissions in China during 1985-2009. Based on vector autoregression (VAR), cointegration and vector error correction model (VECM) are adopted to uncover relationships in both long-run and short-run; also dynamic interactions are identified to establish these relationships between variables through impulse response functions and variance decomposition methods. Results show that: (1) the increase of energy technology patents does not reduce CO_2 emissions in both long-run and short-run; (2) in the long-run, the increase of energy technology patents helps to reduce CO_2 emissions intensity; while it does not for the short term. The present empirical study clearly indicates that Chinese government should attach more importance to investigating and improving energy technology patent system and formulating related energy technology policies for CO_2 emissions reduction.

Key words CO_2 emissions, CO_2 emission intensity, energy technology patents, GDP, VAR/VECM

I. INTRODUCTION

With the severe situation of global warming and resource restrictions, the importance of

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reducing carbon emissions and mitigating climate change has drawn great attention worldwide. So far that is aware of, China will be or is already the largest CO_2 emitter around the world. And its emissions will increase along with rapid population growth, accelerated industrialization and urbanization. Meanwhile, Chinese government made the commitment to reduce CO_2 emissions per unit of GDP in 2020 by 40 to 45 percent compared with the level of 2005 in Copenhagen Climate Change Conference 2009. Therefore, China is facing serious pressure to reduce emissions.

Both the government and academic circles believe that technology innovation is crucial for reducing CO_2 emissions (IPCC, 2007; Sun et al., 2008). Attributed to the government efforts on related supporting policies, Chinese energy technology patents have experienced a great increase after the patent system established in 1985, and it went up at a very high speed especially after the year of 2000 (Fig. 1). However, it seems there are some puzzles with respect to the interaction of energy technology patents and CO_2 emissions over the last few decades and little research has been conducted so far as we know. In this paper we aim to investigate the relationship between energy technology patents and CO_2 emissions as well as CO_2 emissions intensity in China and conclude recommendations for China's future energy technology policies.

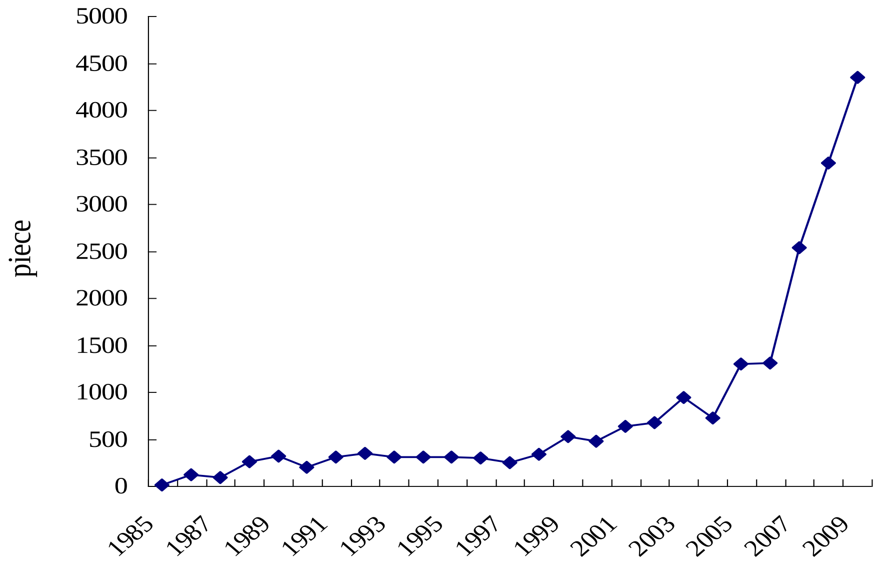

FIG.1. Domestic energy technology patents granted in China from 1985 to 2009

Most previous scholars have studied the interactions between technology innovation and carbon emissions mainly from two perspectives. Some researchers studied the impact of technology advance on carbon emissions. According to Fan et al. (2006), the impact was different in countries with different development levels. Similarly, Bernstein et al. (2006) argued that developing countries had vast potential in reducing carbon emissions by technology advances in the next fifteen years. James (2009) found CO_2 emissions were negatively influenced by R&D intensity, technology transformation and technology absorption in China. On the other hand, other researchers recently focused on the technology innovation input. Fisher-Vanden and Wing (2008) claimed that improvement of R&D efficiency and quality had reverse effects on energy and emission intensities. Garrone and Grilli (2010) concluded that energy R&D public expenditure had no significant influence on carbon emission factors and intensity, yet energy R&D budget was significantly affected by carbon trend in developed countries. Li and Lu (2010) found R&D investment in China's manufacturing industry had no effect on reducing CO_2 emissions.

To the best of our knowledge, the existing literature mainly focused on the relationship between energy technology innovation and carbon emissions by analyzing the effect of technology advance and innovation input, while ignored the relationship between energy technology patents and CO_2 emissions in the meantime. Energy technology patents, being regarded as the core index to indicate the output of energy technology innovation (Liu and Sun, 2008) , would directly reflect the output of R&D expenditure and innovation capabilities. Therefore, in order to enrich innovation theories and provide recommendations for policy making of energy technology, this paper deals with relationships between energy technology patents and CO_2 emissions as well as emissions intensity in China based on the VAR (vector autoregression)/VECM (vector error correction model) framework and studies long-run and short-run relationships and the dynamic influence mechanism among variables.

The paper proceeds as follows: Part 2 briefly introduces VAR/VECM framework; Part 3 elaborates data sources and descriptions; Part 4 lists the empirical results and discussions; Part 5 drafts main conclusion and provides policy recommendations.

II. METHODOLOGY

Following established procedures, the dynamic relationships between energy technology patents and CO_2 emissions in China are analyzed under the frame of VAR and VECM. Both methods are especially efficient for identifying interactions among variables when endogenous variables exist in both sides of equations. The steps of analyzing time series using VAR and VECM can be stated as follows:

First, stationarity of time series should be examined. Unit root test is the standard method of testing stationarity. In the paper, the ADF and KPSS test approaches are adopted to identify the unit root. Second, the existence of cointegration is tested. Cointegration test is used to identify the existence of long-run equilibrium among nonstationary series. In this paper, AIC

(Akaike information criterion) is used to get the optimal lag order of VAR model and the trace statistic will be adopted to test cointegration according to Johansen cointegration test. Third, an attempt is made to estimate VECM. VECM is actually a VAR model under the restriction of cointegration, and it incorporates short-run dynamic elements within the framework of long-run equilibrium relationships established by the cointegration among variables. Fourth, Impulse Response Function (IRF) and Variance Decomposition analysis needs to be conducted. The IRF traces the effect that a one-standard-deviation-shock to one of endogenous variables has on current and future values of all variables in the system. Generalized IRF will be used in this paper. Variance decomposition analyzes the contribution of each structural shock to the variation of endogenous variables for the evaluation of each shock.

III. DATA DESCRIPTION

Data of energy technology patents, CO_2 emission and GDP from the year 1985 to 2009 are used in this paper.

Energy technology patents include invention and utility model in this paper (SIPO, 2008). State Intellectual Property Office of P. R. C. patent bibliographic database was used. Besides, key words of energy technology patents[b)] have been designed to get patent set of energy technology (Margolis and Kammen, 1999). All the data have been cataloged yearly from 1985 to 2009.

Since there are no direct official monitoring data of CO_2 emissions in China, equivalent data from EIA (EIA, 2010) were adopted as an alternative. As is shown in Fig. 2, Chinese CO_2 emissions have been rising since 1985, but not fiercely until 1997. It dropped a little

[b)] The keywords of energy technology patents in this study:(oil or natural gas or coal or photovoltaic or hydroelectric or hydropower or nuclear or geothermal or solar or wind) and (electric* or energy or power or generat* or turbine) between 1998 and 2000 and has grown fast since 2001, mainly due to the rapid growth of Chinese economy and the mass burning of fossil-fuels. The CO_2 emissions intensity refers to CO_2 emissions per unit of GDP, and it has kept decreasing since 1985, expect for a rebound during 2002 and 2005.

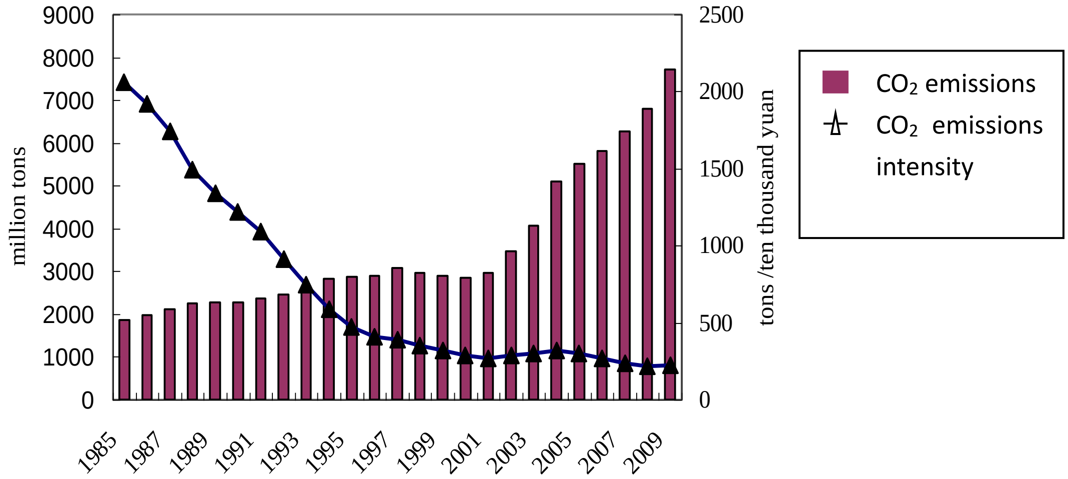

FIG.2 CO_2 emissions and the CO_2 emissions intensity in China from 1985 to 2009

GDP data comes from 1986-2010 China Statistical Yearbooks. Nominal GDP were used for data analysis.

The logarithm of sample data was used to eliminate fluctuation and alleviate the possible heteroscedasticity. In the paper, Lpatent represents the logarithm of energy technology patents, LCO_2 is the logarithm of CO_2 emissions, LCI is the logarithm of CO_2 emissions intensity and LGDP stands for the logarithm of gross domestic product.

IV. RESULTS AND DISCUSSION

A. Unit Root Tests

TABLE I. ADF and KPSS tests for stationarity of Lpatent, LCO_2, LGDP and LCI

Methods	Variables							
	Lpatent	LCO_2	LGDP	LCI	ΔLpatent	ΔLCO_2	ΔLGDP	ΔLCI

ADF*	-1.3899	-1.4247	-1.4361	-2.2316	-10.9959 [a]	-4.6354 [a]	-3.8831 [b]	-3.7453 [b]
KPSS	0.7086 [b]	0.6781 [b]	0.7271 [b]	0.6859 [b]	0.2377	0.2830	0.1536	0.3369

*The lag order of the augmented term was chosen by the Akaike Information Criterion (AIC).

[a] Denotes significance at the 1% level.

[b] Denotes significance at the 5% level.

The stationarity of variables were examined using ADF and KPSS tests. Results are shown in TABLE I, including those in levels and after one differentiation (prefixed by Δ). ADF tests indicate that the null hypothesis of a unit root is accepted for all the level series. While KPSS tests prove that the null hypothesis of stationarity is rejected for the level series at the 5% significance level. Therefore, none of the level series is stationary. For all the differentiated series, the ADF tests show that the null hypothesis of a unit root is rejected at the 1% or 5% significance levels, and KPSS tests suggest stationarity. According to the analysis, all series are stationary after one differentiation.

B. Cointegration Tests

TABLE II. Johansen cointegration tests

Hypothesized No. of CE(s)	CO_2 emissions			CO_2 emissions intensity		
	Trace statistic	0.05 Critical value	Prob.**	Trace statistic	0.05 Critical value	Prob.**
None*	36.07436	29.79707	0.0083	22.2118	15.4947	0.0042
At most 1	8.154318	15.49471	0.4491	0.0132	3.8415	0.9082

*Denotes rejection of the null hypothesis at the 5% significance level.

**MacKinnon-Haug-Michelis (1999) p-values

Given the existence of non-stationarity of level series, the possibility of cointegration among variables was tested. A VAR model was applied to analyze the data, using the AIC criterion to derive the optimal lag length p. Results suggest p=3 for CO_2 emissions, and p=4 for the CO_2 emissions intensity. TABLE II shows the results of Johansen cointegration, considering that the data series have deterministic trends and cointegration equations have intercepts. The results suggest the existence of 1 cointegration equation among Lpatent, LCO_2 and LGDP for CO_2 emissions, and also the existence of 1 cointegration equation between Lpatent and LCI for the CO_2 emissions intensity at the 5% significance level. The resulting normalized parameters estimates are:

CO_2 emissions:

$$Lpatent = -16.44605 + 3.270114LCO_2 - 0.34402LGDP + u_t \qquad (1)$$

（-7.66573）*　　　（2.29469）*

CO_2 emissions intensity:

$$LCI = -4.0975 - 0.3243Lpatent + u_t \qquad (2)$$

（-1.4151）**

Where the numbers in brackets are the t-statistics (*statistical significance at the 5% level, **statistical significance at the 10% level).

Eq. (1) reflects a positive long-run relationship between energy technology patents and CO_2 emissions and between CO_2 emissions and GDP, which confirms that energy technology patents have failed to reduce CO_2 emissions as CO_2 emissions will increase as energy technology patents increase. A possible reason could be that the rapid growth of GDP in China excessively depends on coal and other fossil-fuels which leads to the fast increase of CO_2 emissions. In order to promote energy-saving and emissions reduction, the Chinese government attaches great importance to energy technology innovation, hence as we can see from Fig.1, the number of energy technology patents raise rapidly recently. However, the patents have not been widely adopted, which could limit their role in reducing CO_2 emissions to some extent. Eq. (1) also reflects the negative long-run relationship between energy technology patents and GDP which shows that GDP has not done very well to promote energy technology patents. The possible reason might be the lack of energy technology innovation policies, e.g. the percentage of Chinese public energy R&D in GDP is far lower than that of developed countries, and the actual time for a patent to be granted is too long (Ma et al., 2003; Liu and Zheng, 2008).

Eq. (2) reflects a negative long-run relationship between energy technology patents and CO_2 emissions intensity, implying that increase of energy technology patents helps to reduce CO_2 emissions intensity. When energy technology patents increase by 1%, the emissions intensity will decrease by 0.3243%. The reason may be that CO_2 emissions intensity is an effective indicator to measure the effects of greenhouse gas emission reduction (Garrone and Grilli, 2010). For that matter, the government has making great efforts to improve energy efficiency of fossil-fuels, promote energy structure adjustment, and develop carbon-free energy technologies (e.g. wind and solar etc.) to reduce the CO_2 emission intensity.

C. VECM Estimation

Cointegration reflects the long-run equilibrium relationship among variables, which may deviate from the long-run equilibrium in the short-run, but would gradually adjust to the equilibrium. This paper employs VECM to detect the short-run error-correction mechanism among energy technology patents, CO_2 emissions and GDP, as well as between energy technology patents and CO_2 emissions intensity.

Results of VECM estimation are shown in TABLE III, which reflect the short-run adjustments. We firstly analyzed the short-run relationship among energy technology patents, CO_2 emissions and GDP. The coefficient of ECT -0.71 in the Lpatent equation, implies that energy technology patents will converge towards its long-run equilibrium level at a fast speed.

The results of short-run parameters suggest that energy technology patents are significantly affected by CO_2 emissions and GDP. CO_2 emissions are not affected by energy technology patents in the LCO_2 equation; and GDP is significantly affected by energy technology patents and CO_2 emissions in the LGDP equation.

TABLE III. VECM results*

	CO_2 emissions				CO_2 emissions intensity	
	ΔLpatent	ΔLCO_2	ΔLGDP		ΔLpatent	ΔLCI
ECT	-0.71	0.11	0.021	ECT	-0.15	-0.05
	(-3.90)	(2.80)	(0.71)		(-1.65)	(3.59)
ΔLpatent(-1)	0.03	-0.03	-0.08	ΔLpatent(-1)	-0.55	0.07
	(0.17)	(-0.78)	(-2.28)		(-2.54)	(1.76)
ΔLpatent(-2)	0.07	0.02	0.01	ΔLpatent(-2)	-0.18	0.08
	(0.92)	(1.21)	(0.78)		(-0.79)	(2.09)
$\Delta LCO_2(-1)$	0.004	0.68	-0.31	ΔLpatent(-3)	0.21	0.04
	(0.004)	(2.82)	(-1.50)		(1.92)	(2.17)
$\Delta LCO_2(-2)$	-1.91	0.29	0.35	ΔLCI(-1)	0.08	0.77
	(-1.46)	(1.02)	(1.49)		(0.06)	(3.62)
ΔLGDP(-1)	0.83	0.03	1.32	ΔLCI (-2)	-0.18	-0.02
	(0.69)	(0.13)	(6.05)		(0.06)	(-0.07)
ΔLGDP(-2)	-2.97	-0.11	-0.80	ΔLCI (-3)	1.27	-0.57
	(-2.40)	(-0.43)	(-3.56)		(0.94)	(-2.53)
C	0.58	0.02	0.08	C	0.32	-0.10
	(3.69)	(0.48)	(2.62)		(2.18)	(-4.30)

* t-statistics in brackets

Then we analyzed the short-run relationship between energy technology patents and CO_2 emissions intensity. The coefficient of ECT is -0.05 in the LCI equation, consistent with the reverse correction mechanism which means that ECT will make it return to equilibrium when a deviation from long-run equilibrium does occur. The results of short-run parameters suggest that energy technology patents have a significantly positive effect on CO_2 emissions intensity. The reason may be as follows. The number of energy technology patents raise rapidly in the short-run. However, the patents may not be widely and quickly adopted, which could limit their role in reducing CO_2 emissions to some extent. The CO_2 emissions intensity refers to CO_2 emissions per unit of GDP. The growth of GDP is relatively stable. Therefore, energy technology patents are difficult to reduce CO_2 emissions intensity in the short-run. The coefficient of ECT is -0.15 in the Lpatent equation, which is consistent with the reverse correction mechanism. The above results suggest that energy technology patents are not affected by the CO_2 emissions intensity.

D. Impulse Response Function and Variance Decomposition

The long-run equilibrium and VECM reflects the long-run and short-run relationships among variables respectively. IRF and variance decomposition on VECM are analyzed in order to draw conclusions of dynamic interactions among variables.

The IRF results of Lpatent, LCO_2 and LGDP on CO_2 emissions are shown in Fig. 3. All the variables respond to their own shocks. Energy technology patents significantly respond to CO_2 emissions and GDP shocks; CO_2 emissions have a positive effect on energy technology patents and GDP has a negative effect in the long-run. The signs of the IRFs are in accordance with Eq. (1). The response of CO_2 emissions to energy technology patents shocks is significantly positive. The negative effect of GDP shocks on CO_2 emissions increases significantly after the fourth year. The response of GDP to energy technology patents and CO_2 emissions shocks shows a persistent negative effect.

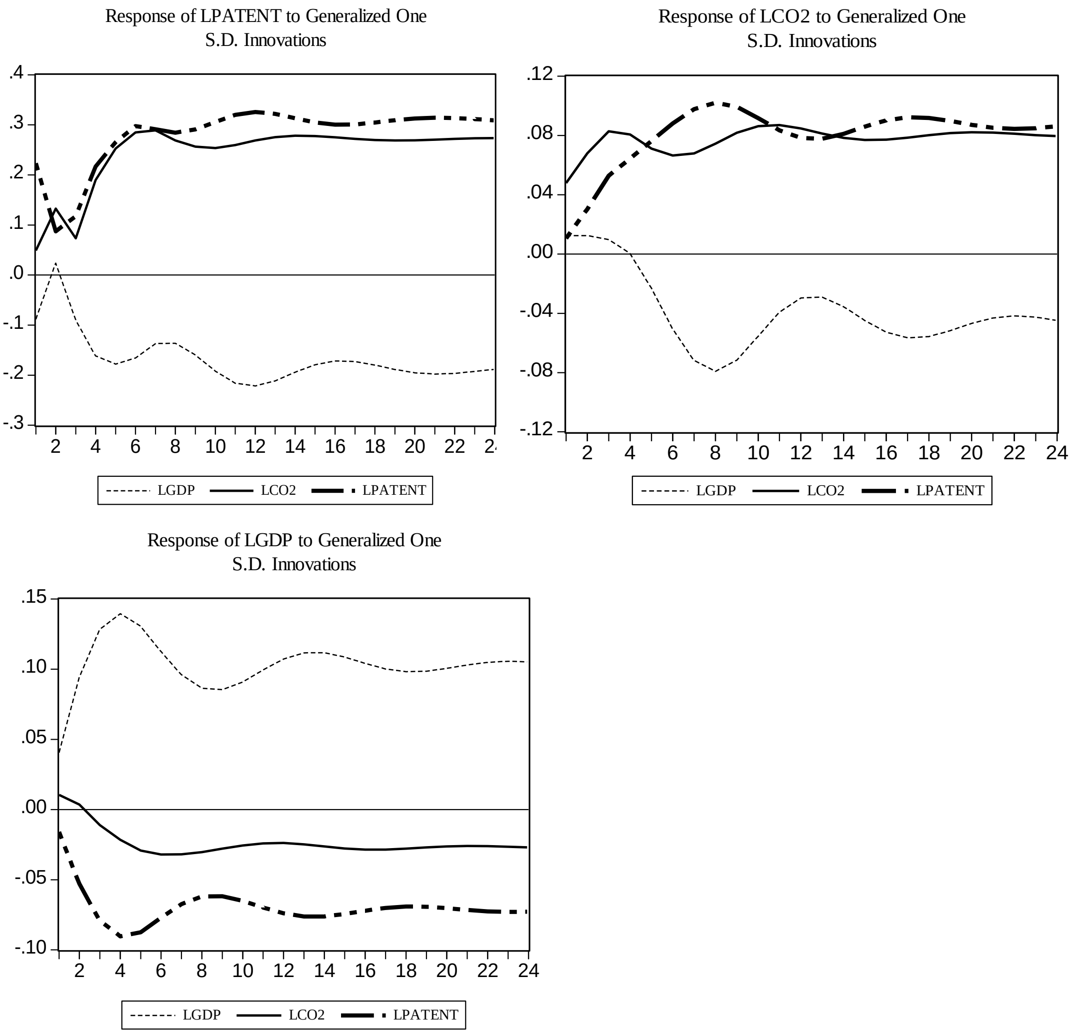

FIG. 3 IRF results of Lpatent, LCO_2 and LGDP on CO_2 emissions

Figure 4 shows the IRF results of Lpatent and LCI on the CO_2 emissions intensity. The response of energy technology patents is significantly affected by CO_2 emissions intensity and its own shocks. The latter has a persistent negative effect on energy technology patents, which is in accordance with Eq. (2). The response of the CO_2 emissions intensity to energy technology patents shocks shows statistical significance since the second year and remains a positive oscillating. The response of CO_2 emission intensity to its own shock tends to fluctuate near zero during the first12 years, and then remains a negative oscillating.

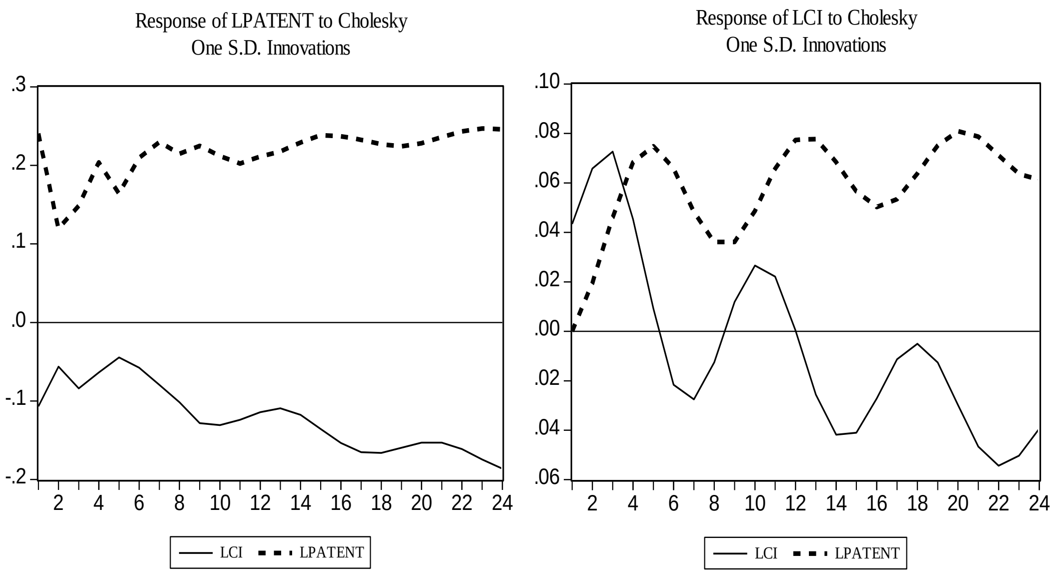

FIG. 4 IRF results of Lpatent, LCI on the CO_2 emissions intensity

The variance decomposition of Lpatent, LCO_2 and LGDP on CO_2 emissions is shown in TABLE IV. According to the variance decomposition of Lpatent, LCO_2 has a very significant effect on Lpatent, and LGDP explained about 20% of the variance of Lpatent. The percentage error variance of LCO_2 mainly originates from itself, while LGDP and Lpatent respectively explained less than 20% of the variance of LCO_2. The percentage error variance of LGDP is mainly determined by itself. LCO_2 explained about 20% of the variance of LGDP, and Lpatent has a very small effect on LGDP.

The variance decomposition of Lpatent, LCI on the CO_2 emissions intensity is shown in TABLE IV. The percentage error variance of Lpatent mainly originates from itself and LCI explains about 20% variance of Lpatent after the twelfth year. The percentage error variance of LCI is influenced by Lpatent and LCI, the effect of Lpatent becomes progressively stronger and the effect of LCI becomes progressively weaker.

TABLE IV. Variance decomposition

	CO_2 emissions	CO_2 emissions intensity

	period	Lpatent	LCO_2	LGDP		period	Lpatent	LCI
Lpatent	6	16.92	17.22	1.23	Lpatent	6	86.97	54.83
	12	14.68	13.61	1.39		12	81.63	67.99
	24	13.41	13.93	1.46		24	74.30	73.88
LCO_2	6	62.12	75.03	15.68	LCI	6	13.03	45.17
	12	64.61	67.63	19.29		12	18.37	32.01
	24	65.50	68.56	20.60		24	25.70	26.12
LGDP	6	20.96	7.75	83.09				
	12	20.71	18.76	79.32				
	24	21.09	17.51	77.94				

V. CONCLUSIONS AND POLICY IMPLICATIONS

Based on the framework of VAR / VECM, this paper deals with the existence of dynamic relations between energy technology patents, CO_2 emissions and CO_2 emissions intensity in China during 1985-2009. The long-run and short-run relationships among variables were examined using cointegration theory and VECM, and the dynamic mechanism among variables was analyzed using IRF and variance decomposition.

Results show that: (1) There is a significantly positive long-run relationship between energy technology patent and CO_2 emissions, implying that energy technology patents would not reduce CO_2 emissions. And neither is the case with for the short-run. (2) There is a significantly negative long-run relationship between energy technology patents and CO_2 emissions intensity, indicating that the increase of energy technology patents could help to reduce the CO_2 emissions intensity. While for the short-run, energy technology patents have a significantly positive effect on the CO_2 emissions intensity. (3) There is a negative relationship between energy technology patents and GDP in both long-run and short-run. (4) There exists a positive long-run relationship between CO_2 emissions and GDP, but CO_2 emissions have a significant negative influence on GDP in the short-run.

Our empirical results provide some implications for the design of energy technology policy. First, the government should formulate more market creation policies (e.g. procurement policies for energy-efficient technologies; expand customers for energy-efficient technologies, either through subsidies or through mandates/standards) to further improve the transformation of energy technology patents, especially in key energy-consuming industries enterprises. Meanwhile, we suggest reforming the current system of energy technology patents, and trying to make the approval of application for energy technology patents faster. Secondly, more technology-push policies need to be taken into consideration (e.g. government sponsored R&D, tax credits for companies to invest in R&D, and funding demonstration projects) to intensify the investment of energy-efficient technologies, get more energy technology patents, and further advance energy technology patents. Third, as rapid economic growth is at the cost of high emissions in China, it is necessary to promote energy structure adjustment, develop low carbon and energy-efficient industries, and further promote the development of new energy industry.

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