Research on the coordinated development of green innovation, environmental pollution and energy consumption

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Abstract. The article from the environmental benefits of green innovation, respectively in green technology patent Numbers, unit gross industrial waste gas emissions, the unit GDP energy consumption as an index, based on the time series data of 1987-2017 multivariate VAR model, and through the granger causality test and generalized impulse response analysis and variance analysis method, to explore the green innovation and environment pollution and energy consumption in our country. The results show that green innovation can indeed improve environmental pollution and energy consumption to some extent, but due to the immature development of green innovation in China, its effect on improving environmental pollution and energy consumption is limited.

Keywords. Environmental pollution; Energy consumption; VAR model; Impulse response.

1. The introduction
In recent years, the international community has become increasingly aware of the importance of green innovation due to the increasing shortage of resources, environmental degradation and other global problems caused by rapid economic growth. Innovation is the source power of economic development, and green contains the requirements of environmental protection and resource conservation in today's society. Green innovation has become the inevitable choice for countries around the world to seek long-term development and win competitive advantages. Since the reform and opening up, with the rapid growth of China's economy, resource consumption and environmental pollution problems are increasingly serious, "the 13th five-year plan" clearly pointed out that the solution to the development problems... The concept of innovative, coordinated, green, open and Shared development must be firmly established, stressing the importance of innovation-driven and green development in China's economic and social development. Green innovation, as a combination of innovation-driven and green development, will play a more important role than ever before in the new normal, when China's economy is slowing down and resources and environment are severely constrained.

Scholars generally recognized from the perspective of environmental benefits and economic benefits coordination degree to define of green innovation, research on the economic benefits of the green innovation has not a few, but now how about green innovation environmental benefits, and the environment between the relationship of the concrete is how, to such problems as environmental pollution, energy consumption and improve the effect of related research is less. Based on time series data from 1987 to 2017, this paper established a vector autoregression model (VAR), and conducted an
empirical study on whether green innovation could improve environmental pollution and energy consumption in China through granger causality test, generalized impulse response analysis and predictive variance analysis.

2. Theoretical basis and research methods

2.1. Indicator selection and data sources

In order to ensure the accuracy and rationality of the search results, the preliminary experiment was carried out first. According to the ESTConcordance and IPCGreenInventory on the official website of China's intellectual property office, the annual number of green technology patent applications (pat) in China from 1991 to 2015 was searched through the search method for analysis and comparison. The search results are shown in table 1.

| Year | Green technology patent applications |
|------|--------------------------------------|
| 1987 | 2585                                 |
| 1988 | 2171                                 |
| 1989 | 146                                  |
| 1990 | 2784                                 |
| 1991 | 2466                                 |
| 1992 | 1637                                 |
| 1993 | 3980                                 |
| 1994 | 4500                                 |
| 1995 | 3298                                 |
| 1996 | 1796                                 |
| 1997 | 3528                                 |
| 1998 | 5785                                 |
| 1999 | 2923                                 |
| 2000 | 4520                                 |
| 2001 | 7203                                 |
| 2002 | 3426                                 |
| 2003 | 13702                                |
| 2004 | 24429                                |
| 2005 | 36588                                |
| 2006 | 55081                                |
| 2007 | 28549                                |
| 2008 | 67218                                |
| 2009 | 86163                                |
| 2010 | 80068                                |
| 2011 | 80682                                |
| 2012 | 154953                               |
| 2013 | 114858                               |
| 2014 | 218650                               |
| 2015 | 191686                               |
| 2016 | 154244                               |
| 2017 | 334116                               |

Vector autoregressive model is referred to as the VAR model, is more common and more classic econometrics field measurement model, which was first put forward in the 1980 s by Sims, initially used to measure the risk of stock trading, but with the constant promotion of the model, found that it can be applied in many fields, and got the measure of recognition. VAR model is often used to predict interconnected time series system and analyze the dynamic impact of random disturbance on variable system, so as to reveal the impact of various economic shocks on the formation of economic variables.

2.2. The expression of the VAR model:

\[ y_t = \theta_1 y_{t-1} + \ldots + \theta_p y_{t-p} + H x_t + \varepsilon_t \quad (t=1,2,\ldots,T) \]  

Where, \( y_t \) is the column vector of endogenous variables of \( k \) degree, \( x_t \) represents the column vector of exogenous variables of \( d \) dimension, \( \theta \) represents the order of hysteresis, and \( t \) represents the number of samples. \( \theta_1 \ldots \theta_p \) and \( H \) are the coefficient matrices to be estimated. Epsilon constant \( \varepsilon_t \) is a \( k \times 1 \) dimension matrix, which can be correlated with each other synchronously, but not with its own lag value, and not with the variable on the right side of the equation. The transformation of equation (4) into a matrix is as follows:
A simple transformation of equation (5) can also be expressed as follows:

\[ y_t = \theta_1 y_{t-1} + L + \theta_p y_{t-p} + \varepsilon_t \]  

(2)

Where, is the residual of yt regarding the regression of exogenous variable xt. Equation (2) can be written as follows:

\[ \theta(L)y_t = \varepsilon_t \]  

(3)

In: \( \theta(L) = I_k - \theta_1 L - \theta_2 L^2 - \ldots \) Is the parameter matrix of the lag operator L, k by k. In general, equation (7) is a non-restrictive vector autoregression model. The impact vector is a white noise vector and is called the reduced form of the impact vector because it has no institutional meaning.

In order to facilitate the description, the VAR models considered below are all unrestricted vector autoregressive models without exogenous variables, and theta is used to represent the coefficient matrix, as follows:

\[ y_t = \theta_1 y_{t-1} + \ldots + \theta_{p} y_{t-p} + \varepsilon_t \]  

(4)

This paper set up by the green technology patents aene logpat, unit GDP energy consumption and industrial emissions of the total cost of the unit production of afq multivariate VAR model, and through the granger causality test, impulse response analysis and variance decomposition analysis of green innovation and dynamic relationship between energy consumption and industrial emissions for empirical research.

2.3. Model of VAR

The reliability of VAR model estimation depends on the stationarity of variables. If the variable is a stationary time series, the unconstrained VAR model can be directly constructed. If the variables are unstable, it is necessary to check whether there is a co-integration relationship between the variables involved in the model. If the cointegration relation exists, the vector error correction model must be used. If it is neither stationary nor cointegration, it is necessary to make a difference to the variable to make it stationary.

Since logpat, aene and afq are all stable, this paper directly established the VAR model through Eviews8.0. Firstly, the optimal lag time is determined. As can be seen from table 5, when akichi information criterion (AIC) and Schwartz (SC) criterion are inconsistent, the lag order satisfying more criteria is adopted, so the optimal lag order of this mode

| hysteresis | logL     | LR         | FPE    | AIC       | SC       | HQ       |
|------------|----------|------------|--------|-----------|----------|----------|
| 0          | -116.2849| NA         | 1.006837| 8.520353  | 8.663090 | 8.563989 |
| 1          | -22.23544| 161.2277   | 0.002329| 2.445389  | 3.016334 | 2.619932 |
| 2          | -11.25683| 16.46792   | 0.002076| 2.304059  | 3.303213 | 2.609511 |
| 3          | -3.551676| 9.906630   | 0.002434| 2.396548  | 3.823910 | 2.832907 |
After the maximum lag time is determined to be 2, in order to test whether the estimated VAR model is reliable, so as to carry out subsequent impulse response function and variance decomposition analysis, the stability test of the VAR model must be carried out. It can be seen that all the values of roots in the model are less than 1, and all the points after taking the reciprocal are located in the unit circle, indicating that the established model is stable.

3. Granger causality Test

Table 4 shows the granger causality test results of logpat, aene and afq with a lag time of 2. It can be seen that at the significant level of 5%, energy consumption is the granger cause of industrial exhaust emissions, and industrial exhaust emissions are the granger cause of green technology patents. At a significant level of 10%, energy consumption is the granger cause of green technology patents, and neither industrial exhaust emissions nor green technology patents are the granger cause of energy consumption, nor are green technology patents the granger cause of industrial exhaust emissions.

| Table 3. lag structure test of VAR model |
|-----------------------------------------|
| Root | Modulus |
| 0.934929 | 0.934929 |
| 0.852818 | 0.852818 |
| -0.299423–0.334200i | 0.448713 |
| -0.299423+0.334200i | 0.448713 |

| Table 4. Granger causality test |
|--------------------------------|
| null hypothesis | sample size | F statistic | probability value |
| Afq is not aene's granger cause | 29 | 0.00586 | 0.9942 |
| Aene is not afq's granger cause | 6.29677 | 0.0063 |
| Logpat is not aene's granger cause | 0.71079 | 0.5013 |
| Aene is not logpat's granger cause | 3.08924 | 0.0640 |
| Logpat is not afq's granger cause | 0.16110 | 0.8521 |
| Afq is not logpat's granger cause | 4.74609 | 0.0183 |

Can be seen from table 5, the energy consumption of green technology patent impact response of an unit, the current 0.021784, with a positive response from 2-0.009004, has continued to decline, until the lowest level in 6-0.169559, and then start rising steadily, but is still negative in 10 period, during the analysis period, aene response to the accumulation of logpat value is 1.14564. In other words, as the number of green technology patents logpat increases, the energy consumption of aene will decrease. In terms of the response of green technology patents to the impact of energy consumption on a unit, the response was 0 in the current period, -0.03317 in the second period, but positive 0.074111 in the third period, and then negative. In other words, as energy consumption increases, the number of green technology patents increases in the short term and decreases in the long term.
4. Dynamic relationship between green technology patents and energy consumption

Table 5. Results of generalized impulse response analysis

| period | Logpat to aene the pulse response | Logpat to afq the pulse response | Aene to logpat The pulse response | Afq to logpat the pulse response |
|--------|----------------------------------|---------------------------------|----------------------------------|---------------------------------|
| 1      | 0.000000(0.00000)                | 0.000000(0.00000)               | 0.021784(0.03230)                | -0.036366 (0.07598)            |
| 2      | -0.03317 (0.13799)               | 0.417530(0.14531)               | -0.009004 (0.06006)              | -0.054854 (0.11379)            |
| 3      | 0.074111(0.11202)                | 0.121864(0.11949)               | -0.094194 (0.08543)              | -0.117622 (0.14361)            |
| 4      | -0.014334 (0.08512)             | 0.154386(0.07841)               | -0.143163 (0.10532)              | -0.216194 (0.15708)            |
| 5      | -0.058052 (0.07202)             | 0.134389(0.05509)               | -0.164709 (0.11762)              | -0.228951 (0.16455)            |
| 6      | -0.090213 (0.06857)             | 0.087534(0.05750)               | -0.169559 (0.12308)              | -0.215263 (0.16100)            |
| 7      | -0.121628 (0.06190)             | 0.076993(0.04762)               | -0.162374 (0.12269)              | -0.186382 (0.14810)            |
| 8      | -0.136349 (0.05874)             | 0.058885(0.04813)               | -0.151831 (0.11919)              | -0.150419 (0.13231)            |
| 9      | -0.145321 (0.05942)             | 0.044992(0.04870)               | -0.141144 (0.11438)              | -0.119099 (0.11635)            |
| 10     | -0.150072 (0.06137)             | 0.035386(0.04969)               | -0.131446 (0.10965)              | -0.093239 (0.10219)            |
| add up | -0.67503                        | 1.131959                       | -1.14564                      | -1.41839                      |

Can be seen from table 5, industrial emissions of green technology patent response curve and the energy consumption of green technology patent response curve shape similar, but the current response of industrial emissions of 0.036366, has declined since then, until the fall to lowest 5-0.228951, then slowly rise, during the analysis period, aene response to the accumulation of logpat value is 1.41839. This suggests that industrial emissions will fall as the number of green technology patents rises. According to the response of green technology patent to the impact of one unit of industrial exhaust emission, it is 0 in the current period and reaches the maximum value of 0.417530 in the second period, then fluctuates and decreases until it approaches 0. In other words, as industrial emissions continue to rise, so do green technology patents.

4.1. Variance decomposition of green technology patents with energy consumption and environmental pollution

As can be seen from table 6, the average contribution of green technology patents to variance decomposition of energy consumption and industrial exhaust emissions was about 13% in the 10 period. According to the previous impulse response analysis, the impact of green technology patents on both was negative. This shows that the reasons affecting energy consumption and environmental pollution are various, and green innovation is an important factor, and green innovation can indeed improve environmental pollution and energy consumption to a certain extent. The average contribution of energy consumption to variance decomposition of green technology patents is relatively low, about 3%, while the average contribution of industrial exhaust emissions to variance decomposition of green technology patents is relatively high, about 28%. This also is easy to understand, energy consumption is the inevitable trend of economic development, relative industrial emissions have less effect on the ecological, industrial emissions of more and less directly affects the air environment is good or bad, as
the deepening of environmental pollution, human beings will inevitably increase the demand for green, green technology increased the number of patents is inevitable, it accords with the practice development.

Table 6. Mean value of variance decomposition of green innovation, energy consumption and environmental pollution

| variable | Green technology patents on aene, afq | Patents of aene and afq on green technology |
|----------|--------------------------------------|--------------------------------------------|
|          | Variance decomposition average contribution /% | Variance decomposition average contribution /% |
| aene     | 13.7100609                             | 3.8763663                                 |
| afq      | 12.6224902                             | 28.557051                                 |

5. Conclusion and prospect

Based on the 1987-2017 green innovation and energy consumption, environmental pollution related time series data, from the Angle of view of the green innovation environmental benefits, respectively in green technology patent applications, the unit GDP energy consumption, unit gross industrial emissions as an index, between VAR model is established, and through the granger causality test, generalized impulse response analysis and variance analysis to explore the green innovation and dynamic relationship between energy consumption and environmental pollution, get the following conclusion.

(1) Green technology patent applications, the unit GDP energy consumption and GDP of industrial waste gas emissions granger causality between three variables: the energy consumption is the granger reason of industrial emissions, industrial emissions is a granger cause of green technology patents, energy consumption is a granger cause of green technology patents. This shows that, when environmental pollution and energy consumption become increasingly serious, green innovation will be stimulated to a certain extent, that is, social demand for green innovation will be stimulated.

(2) According to the generalized impulse response analysis, green innovation has a positive response to the impact of energy consumption or environmental pollution. The difference is that the positive response caused by energy consumption impact is short-term, while the positive response caused by environmental pollution is long-term. However, both energy consumption and environmental pollution have negative responses to the impact of green innovation, and both of them are long-term. In other words, green innovation can improve energy consumption and environmental pollution to some extent.

(3) Through variance decomposition, it is found that green innovation contributes about 13% to energy consumption and environmental pollution, while energy consumption contributes far less to green innovation than environmental pollution.

In general, China's green innovation has played a certain role in improving energy consumption and environmental pollution, but the impact of green innovation is still small, and did not reach the expected effect. In order to further alleviate the problems of resource shortage and environmental pollution and expand the environmental benefits of green innovation, it is necessary to deepen the understanding of green innovation, attach importance to the role and influence of green innovation, and protect the development and application of green technology. For example, we will vigorously crack down on industries and enterprises that consume a lot of energy and pollute a lot, and promote their transformation and upgrading through compulsory means. For the implementation and application of green innovation companies and enterprises to take economic support, give a certain amount of subsidies or reduce the relevant tax, in order to make up for the economic costs caused by the environmental benefits; We will deepen the "green channel" for green technology patent applications, simplify application procedures and reduce patent fees. Actively propagandize green thought, promote our country economy health, sustainable development.
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