Time-series prediction algorithm based on VAR model to analyze the impact of trade openness on carbon emissions

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Abstract. Based on time-series statistical data from 1990 to 2020, this study empirically studied the impact of trade openness on carbon emissions changes through two representative explanatory variables, namely foreign trade dependence and foreign investment dependence, using Eviews software through cointegration tests, impulse response functions, and variance decomposition methods based on VAR model from time-series prediction algorithm. The impulse response function and variance decomposition methods were used to analyze the dynamic shock effects and the degree of influence of foreign trade dependence and foreign investment dependence on carbon emissions respectively. Based on the VAR model results, foreign trade dependence and foreign investment dependence can affect the carbon emissions.

Keywords: Time-series prediction algorithm, VAR model, Eviews analysis

1 Introduction

Time-series prediction algorithm based on VAR models are used to analyze and predict the important links before representative explanatory variables. This statistical method is used to make sense of the data and the relationships in it, and based on the results of the statistics it makes sense to get reasonable inferences. Exploring the role of trade on carbon emissions is a new way of considering the influencing factors of carbon emissions，the intention of this paper is to analyze the dynamic link between trade openness and carbon emissions through building the VAR model.

China's reform and opening-up policy from 1983， the remarkable scale of foreign trade from 1990 onwards. As an important province in the rise of central China, Hubei's level of economic development is in the middle and upper reaches of the country, and although the proportion of trade is not high, the year-on-year growth has remained at a stable range level. Therefore, this paper adopts the more recent data related to foreign trade in Hubei Province from 1990 to 2020, and uses VAR model to specifically decompose and analyze the influence of the degree of openness of foreign trade on carbon emissions through empirical analysis.

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2 Review of the literature

The environmental Kuznets curve has been empirically studied by a number of researchers. At the very least, it shows the relationship between environmental quality and income levels. The study of the specific link between trade and CO_2 from the perspective of the environmental Kuznetso curve has a large literature base of scholarly research. Li Xiuxiang et al. (2004) , Liu Q et al (2008), He J.（2010） and Li Kai et al. (2011)all analyzed the growth of export trade reduced carbon emissions to a certain extent on China's environmental quality from the perspectives of Kuznetso curve [1-4]; Li and Lu (2010) found that international trade can reduce total carbon emissions and carbon emissions per unit of output in industrial sectors, and China has not become a "polluter's paradise" for developed countries because of foreign trade[5]. And there are various econometric models and research methods for the study of this relationship, Pang Jun and Zhang Junzhe (2014) using LMDI factor decomposition method to study the implied carbon in Sino-European international trade[6];Pang, Jun et al. (2015) studied the carbon emissions implied by trade between China, the United States, Europe and Japan based on the MARIO model[7];Jan Hua (2017) constructed a panel data threshold regression model based on Chinese provincial panel data to empirically analyze the threshold effect of trade openness affecting per capita carbon emissions in China[8];Based on panel data of 30 inter-provincial regions in China, Xu Boyu and Liu Xiahui (2022) investigated the degree of influence of China's import and export trade on carbon emissions in the primary industry and the role of R&D investment in it[9]， and Zeng Haiying and Yue Huan (2015) on the other hand, utilized panel data of 41 prefecture-level cities in the Yangtze River Delta region[10]. Most of the literature focuses on the import and export trade of the whole country, but few focus on the impact of provincial trade on carbon emissions. In fact, trade policy preferences have an impact on the economic development of provinces and cities as well as the implementation of energy conservation and emission reduction. We take Hubei province as an example and study the impact of trade openness on carbon emissions through VAR model.

3 Data and VAR model

3.1 Variable selection

This paper is based on the more recent statistics from 1990-2020 in the China Statistical Yearbook and Hubei Statistical Yearbook as the data source. Most of the previous domestic and foreign literatures studying the relationship between trade openness and carbon emission have adopted the index of trade dependence to reflect the degree of trade openness, while ignoring the examination of other trade openness indicators. Therefore, this paper expresses the degree of trade openness as two parts: foreign trade dependence and foreign investment dependence. Foreign trade dependency is the ratio of total import and export trade to Hubei's regional GDP, recorded as TR. foreign investment dependency is expressed as the ratio of foreign direct investment to Hubei's regional GDP in the current year, recorded as FD.

Based on the measurement method provided by IPCC, energy consumption is converted into standard coal in a uniform unit of heat and multiplied by a uniform carbon emission factor to obtain carbon emissions. Carbon emissions are denoted as CC.

In order to avoid violations of classical assumptions in the study, the above variables were logarithmically treated with lnCC, lnTR and lnFD as the study variables. The model experiments in this paper were all conducted based on Eviews software.

3.2 Descriptive statistics

Table 1 reports the results of descriptive statistics for the main variables. where the mean values of lnFD and lnTR are -3.5946 and -2.5122, respectively, and the medians are -3.4679 and -2.4449, respectively, with little difference in the statistical properties of the variables themselves after logarithmic treatment; The standard deviations of the two variables are 1.1564 and 0.2226, which are relatively different from the means, indicating that the foreign trade dependence varies more than the foreign investment dependence at different points in the sample period. The descriptive statistical analysis results in a relatively balanced data structure, allowing for the next step of VAR model analysis.

Table 1. Descriptive statistics

variable	obs	Mean	Median	Maximum	Minimum	Std. Dev.
lnCC	31	8.8070	8.6351	9.8958	7.7115	0.7215
lnFD	31	-3.5946	-3.4679	-2.7414	-7.9525	1.1564
lnTR	31	-2.5122	-2.4449	-2.2170	-2.9994	0.2226

3.3 VAR model building

3.3.1. VAR model.

VAR model is based on big data analysis technology, using computer software Eviews derived from an important model in the time-series prediction algorithm, used to analyze and predict the dynamic link between random variables, and its model expression is as follows:

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \cdots + \phi_p y_{t-p} + Hx_t + \varepsilon_t \quad (1)$$

3.3.2. Time-series stability test.

The ADF unit root test is used to test the stability of the series, and its test form is set as neither intercept term nor time trend, and the test results are shown in Table 2: the ADF statistics of variables lnCC and lnTR are greater than their critical values and are unstable; lnFD is stable at the 5% and 10% significance levels. When the 1st difference is made, lnTR and lnFD pass the stability test at all significance levels. When the 2nd difference is made, lnCC passes the smoothness test at all significance levels. There-

fore, lnCC, lnTR and lnFD all pass the ADF test and are stable. The series of three variables: carbon emissions, foreign trade dependence and foreign investment dependence, are stable series.

Table 2. ADF Statistics

item	variable	ADF statistics	1%	5%	10%	result
level	lnCC	5.58	-2.65	-1.95	-1.61	unstable
	lnTR	-0.28	-3.64	-2.95	-2.61	unstable
	lnFD	-2.29	-2.65	-1.95	-1.61	stable
1st difference	lnCC	-0.96	-2.66	-1.95	-1.61	unstable
	lnFD	-3.99	-2.65	-1.95	-1.61	stable
	lnTR	-5.91	-2.65	-1.95	-1.61	stable
2nd differernce	lnCC	-5.75	-2.66	-1.95	-1.6	stable

3.3.3. Optimal lags.

When building a VAR model, choosing the optimal lags ensure that the model can accurately capture the dynamic response of the economic system, thus improving the model's predictive effectiveness. If the lag period is too short, the long-term trend and cyclical fluctuations of the economic system may not be captured; if the lag period is too long, it may lead to model overfitting. To determine the lag order in the VAR model with comprehensive consideration, here the optimal lag order p of the VAR model will be examined using the criteria of LR, FPE, AIC, SC and HQ. Table 3 show the results that except LR, SC, the more criteria include FPE, AIC and HQ consider the lag period to be 5 and therefore, the lag order is 5.

Table 3. Optimal Lags

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-2.1634	NA	0.000299	0.397184	0.542349	0.438987
1	84.9321	147.3925	7.40E-07	-5.610167	-5.029507*	-5.442958
2	94.4135	13.85737	7.37E-07	-5.647195	-4.63104	-5.354579
3	109.5544	18.63489*	5.00E-07	-6.119568	-4.667918	-5.701545
4	118.0687	8.514372	6.16E-07	-6.082211	-4.195067	-5.538782
5	139.561	16.5325	3.24e-07*	-7.043154*	-4.720514	-6.374318*

3.3.4. Cointegration test.

Johansen cointegration tests were performed on lnCC, lnTR and lnFD assuming no constant and time trend terms in the model. The test results are shown in Table 4: the trace statistic and λ-max statistic reject the original hypotheses of R=0, R≤1, and R≤2 at

5% significance level, indicating that there is a cointegration relationship among lnCC, lnTR and lnFD, i.e., there is a long-term equilibrium relationship between carbon emissions and foreign trade dependence and foreign investment dependence in Hubei Province.

Table 4. Test Results

Hypothesized	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.681132	5.89E+01	29.79707	0
At most 1 *	0.623299	3.03E+01	15.49471	0.0002
At most 2 *	0.210822	5.92E+00	3.841466	0.015

3.3.5. Granger test of causality.

The cointegration test above confirms the existence of a long-run cointegration relationship among these three variables, but the causality in the specific direction is still uncertain. The Granger causality test is used to analyze the causal relationships among them, and the test results show that: foreign trade dependence in Hubei Province is the Granger cause of the increase in carbon emissions. In the same way, foreign investment dependence is the Granger cause of the change in carbon emissions in Hubei Province.

3.3.6. Model stability test.

In this paper, the characteristic root test of the established VAR(5) model is performed, the Fig.1 show that the inverse of all root modes lie within the unit circle, indicating that the estimated VAR model is stable. The model stability ensures the realization of the next impulse response function and variance decomposition analysis.

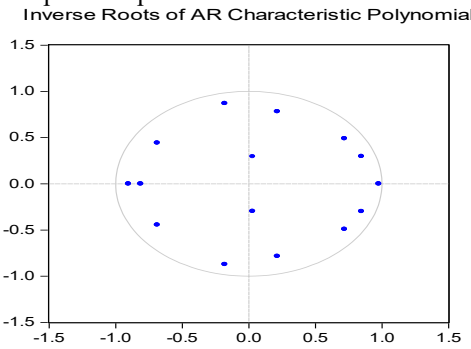

Fig. 1. Model stability test

3.3.7. Impulse response function.

The VAR model construct in this paper performs impulse response function analysis so as to explore the path changes of the dynamic relationship among lnCC, lnTR and lnFD, setting the lag order to 30 periods, and the impulse response results are shown in Fig.2 : there is a similarity in the trend of the impact of foreign trade dependence and

foreign investment dependence on carbon emissions, both of which have a large impact effect in the early stage, and the impact strength slows down slightly and approaches a stable level in the later stage. The impact of foreign trade dependence on carbon emissions is a long-term positive effect, reaching the maximum shock level of 0.025851 in the lag 3 period, and the impact of foreign trade dependence on carbon emissions is a lasting effect as the lag period advances, that is, the level of foreign trade in Hubei Province will have a continuous positive impact on the change of carbon emissions. The impact of foreign investment dependence on carbon emissions is a long-term negative effect, except for the small positive fluctuations in periods 4-6 and 14-18, and its negative effect continues to advance. Its maximum negative effect level of -0.011734 in period 7 indicates that the level of foreign investment in Hubei Province will have a continuous negative effect on the change of carbon emissions, but its negative effect on carbon emissions is small in terms of the lagged 30 period results. So what we get from this simulation experiment is that foreign trade dependence has a larger positive impact on carbon emissions, while foreign investment dependence has a smaller negative impact on carbon emissions.

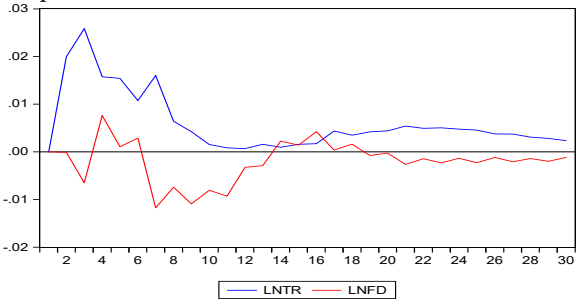

Fig. 2. Impulse response function result

3.3.8. Variance decomposition analysis.

This paper uses variance decomposition based on VAR model to analyze the contribution of shocks to carbon emissions by lnCC, lnTR and lnFD, and the results of variance decomposition are shown in Table 5: the contribution of foreign trade dependence to the change in carbon emissions is greater than that of foreign investment dependence. The contribution of foreign trade dependence to carbon emissions gradually decreases from the maximum contribution of 17.60238% in the 3rd period, indicating that foreign trade dependence not only has an immediate effect on carbon emissions but also has a strong impact in the long term, but this effect gradually decreases until 6.4173% in the 30th period. The contribution of foreign capital dependence to carbon emissions reaches a maximum value of 2.4733% in the 11th period of the lag, and then decreases slightly and gradually until 1.8753%, indicating that the contribution of foreign capital dependence to carbon emissions has a short-term time lag and a significant long-term effect. In contrast, the average contribution of foreign investment dependence is only 1.77%, while the average contribution of foreign trade dependence reaches 8.26%. This result is consistent with the conclusion obtained from the impulse response function analysis above, i.e., the effect of foreign direct invest-

ment on carbon emissions is smaller than that of import and export trade. The variance decomposition analysis of the contribution of foreign trade dependence and foreign investment dependence to carbon emissions allows the government to better target its emission reduction policies in response to trade openness.

Table 5. Varinace decomposition of lncc

Period	lnFD	lnTR	Period	lnFD	lnTR	Period	lnFD	lnTR
1	0	0	11	2.473258	8.577561	21	2.089281	6.974303
2	0.00019	8.285023	12	2.400291	8.174198	22	2.054322	6.914653
3	0.692274	17.60238	13	2.350051	7.900766	23	2.026509	6.845062
4	1.165927	15.30678	14	2.317212	7.727918	24	1.998471	6.802904
5	0.781791	11.97024	15	2.241107	7.458844	25	1.977263	6.74083
6	0.738068	11.22315	16	2.252517	7.288311	26	1.945991	6.66329
7	1.511574	11.76043	17	2.218309	7.244719	27	1.928139	6.60113
8	1.625165	10.55929	18	2.188454	7.160324	28	1.909105	6.544649
9	2.034843	9.575082	19	2.13889	7.05281	29	1.894002	6.478204
10	2.247915	9.179468	20	2.103542	7.001111	30	1.875302	6.417354

4 Conclusions

The above empirical analysis leads to the following conclusions:

1.The series of three variables, carbon emissions, foreign trade dependence and foreign investment dependence, are stable series. Johansen cointegration test found that there is a cointegration relationship between carbon emissions and foreign trade dependence and foreign capital dependence. The Granger causality test results show that foreign trade dependence and foreign investment dependence are significant influences on carbon emissions.

2. The simulation results of impulse response function analysis based on VAR model show that the cumulative value of foreign trade dependence impulse response is positive, while foreign investment dependence is negative, both of them have certain lag effect. The impulse response curve of foreign trade dependence is located above the horizontal line, and the expansion of foreign trade will lead to the increase of carbon emission in Hubei Province in the long run. The impulse response curve of foreign investment dependence roughly show a continuous negative downward trajectory, and the foreign investment dependence has a negative impact on carbon emissions in the long run. From the peaks of carbon emissions caused by the impulse of foreign trade dependence and foreign investment dependence in the whole response period (0.025851 and -0.011734, respectively), the impulse of foreign trade dependence on carbon emissions is stronger than that of foreign investment dependence. This result show that the increase of carbon emission due to the expansion of import and export scale ,which reflects that the role of various trade policies formulated by Hubei pro-

vincial government to optimize the import and export structure is still limited or its effect is not yet visible.

3. The simulation results of the variance decomposition analysis based on the VAR model show that the average contribution of foreign trade dependence and foreign investment dependence to the carbon emission variance decomposition is 8.26% and 1.17% respectively in the whole prediction period, and they both show a decreasing trend, which in turn indicates that the current trade industrial policy in Hubei Province is transforming to low carbon.

However, the assumptions of the experiment are relatively simple, and the actual analysis of the situation will be more complex and needs to be further analyzed in the context of the current situation. In view of the above analysis results, it can be seen that the two measures of foreign trade dependence and foreign investment dependence, which measure the degree of regional trade openness, have a long-term sustainable effect on Hubei's carbon emissions. Given that the long-term effects of foreign trade dependence and foreign investment dependence on carbon emissions are in opposite directions, blindly expanding trade scale may increase the generation of carbon emissions.

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References

1. Li Xiuxiang, Zhang Ting.（2004）An empirical analysis of the impact of export growth on China's environment, taking C02 emissions as an example. Journal of international trade, (7):9-12.https://kns.cnki.net/kcms/detail/detail.aspx?FileName=GJMW200407002&DbName=CJFQ2004.
2. Liu Q, Zhuang X, Jiang KJ, Han W.（2008）Analysis of energy-carrying capacity and carbon emissions in China export trade. China Industrial Economics, (8):46-55. DOI:10.19581/j.cnki.ciejournal.2008.08.005.
3. He J.（2010）Environmental impacts of international trade: Industrial emissions of sulfur dioxide (S02) in Chinese provinces. China Economics (Quarterly), (1):415- 443. DOI:10.13821/j.cnki.ceq.2010.02.001.
4. Li Kai,（2011）Qi Shaozhou. Trade openness, economic growth and carbon dioxide emissions in China. Economic Research Journal, (11): 60-69. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=JJYJ201111007&DbName=CJFQ2011.
5. Li S., Lu X. Xiang.（2010）International trade, polluting industry transfer and industrial C02 emissions in China. Economic Research Journal, (1):16-23. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=JJYJ201001003&DbName=CJFQ2010.

6. Pang Jun, Zhang Junzhe.（2014）Implied carbon emissions of China-Europe trade and its influencing factors-analysis based on MRIO model and LMDI method. International Economic and Trade Research, 30(11):51-65. DOI: 10.13687/j.cnki.gjjmts.2014.11.005.
7. Pang Jun, Shi Yuanchang, Xie Xi et al.（2015）A comparative analysis of the implied carbon characteristics of trade between China, the United States, Europe and Japan based on MRIO model. Climate Change Research, 11(03): 212-219. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=QHBH201503009&DbName=CJFQ2015.
8. Jim H.（2017）Analysis of the threshold effect of trade opening on the impact of carbon emissions in China. World Economic Study, 276(02):38-49+135-136. DOI:10.13516/j.cnki.wes.2017.02.005.
9. Xu Boyu, Liu Xiahui.（2022）A study on the carbon emission effect of import and export trade on primary industry-a threshold test based on provincial R&D input data in China. On Economic Problems, 510(02):27-33. DOI:10.16011/j.cnki.jjwt.2022.02.004.
10. Zeng Haiying, Yue Huan.（2022）Industrial structure, foreign trade and carbon emissions--an empirical analysis based on 41 prefecture-level cities in the Yangtze River Delta region. Journal of Industrial Technological Economics, 41(01):71-77. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=GHZJ202201007&DbName=CJFQ2022.