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Evolution of the Spillover Effect of Pilot Carbon Markets in China

Xiangxiang Lv, Ying Zhang, Xuxia Li, Qi Zhang, Xinghua Fan*
Faculty of Science
Jiangsu University, Jiangsu 212013
Zhenjiang, China
*Corresponding author: fan131@ujs.edu.cn

***Abstract*—China officially launched the nation-wide carbon emission trading scheme at the end of 2017 on the experiences of its regional carbon trading pilot. The national scheme will still be on the initiation stage in the near future. Researches on the spillover effect across the pilot carbon markets help find the leading market in price discovery and provide references for the design of market mechanisms and related policy formulation in the national carbon market. The time-varying parameter state space model was used to analyze the trend of mean spillover effects across the seven pilot carbon markets in China. Results show that there is network of mean spillover across China's seven pilot carbon markets, among which the Shenzhen, Guangdong, and the Shanghai pilot have spillover effects to and from other pilots, which the Beijing, Hubei, and Tianjin pilot are all receiver of spillover effects. But the Chongqing pilot is isolated from the network. The spillover effects all are one-way. Their values are significant at the early time period of the markets and tend to zero in the late period. Results reflect a certain correlation between China's pilot carbon market, a sound basis of market integration and a gradual improvement of market mechanism in those pilots. Investors are suggested to consider the spillover effects between markets, and managers to strengthen the carbon market mechanism.**

Keywords—carbon market; mean spillover effects; state space model; time-varying parameter (key words)

I. INTRODUCTION

The carbon emission trading market is a primary innovative practice of using markets mechanisms to control and reduce greenhouse gas emissions and promote green and low-carbon development. China took the initiative to assume the responsibility of great power. Starting in June 2013, China has established carbon trading pilot markets in five cities (Shenzhen, Beijing, Shanghai, Tianjin and Chongqing), and three provinces (Guangdong, Hubei and Fujian). At the end of 2017, the Nation Development and Reform Commission (NDRC) released its Guidelines of National Carbon Emissions Trading Market Construction Plan (Power Generation Industry), which indicate that the official start of China's establishment of a national carbon trading market. It is currently only included in the power industry, but it has surpassed the European Union Emission Trading Scheme (EU ETS) and become the world's largest carbon trading system[1]. During the new period of China's carbon markets exploration, the discrepancy in system design and the independent operation of each carbon market have made the pilot carbon markets significantly different after more than four years of pilot work. However, there are many realistic factors in one market make fluctuations tend to be transmitted to other markets through market participants [2]. Is there a spillover effect between China's pilot markets? How does this spillover effect change? How integrated is China's carbon market? Can it be the basis for a unified national carbon market? These issues are urgent concerns for the establishment of a national carbon market. Under this background, we can grasp the influencing factors and mechanisms between carbon pilots by studying the spillover effects of fluctuations in pilot markets and provide empirical support for the construction of national carbon market. There are two types of spillover effects in the financial market: mean spillover effects and volatility spillover effects. The mean spillover effect refers to the impact of changes in one market price or return on other carbon markets, and this impact has a positive or negative effect. The volatility spillover effect refers to the impact of changes in a carbon market on other carbon markets with no plus or minus, but only size. Vector autoregressive model (VAR) [3] and vector error correction model (VEC) [4] are commonly used methods to study the mean spillover effect. Most of the volatility spillover effects are based on one or more GRACH models.

Carbon market presents environmental, market and financial, and policy-based attributes [5]. Empirical studies on spillover effects of the carbon market are mostly focused on volatility spillover effects between the EU carbon market and other markets. Reboredo [6] used a multivariate conditional autoregressive model with a binary logarithmic normal distribution to study the volatility spillover effect between the EU carbon market and the oil market and found that there is a spillover effect between the two markets. Liu and Xie [7] studied the mean spillover effect between the EUA and CER markets applied the VAR model. The results show that a unidirectional mean spillover effect from the EUA market to the CER market, and the spillover effect is negative. Wang and Guo [8] constructed a spillover index through the variance decomposition of prediction errors and studied the dynamic spillover effects between the EU carbon market and energy markets (West Texas Intermediate crude oil, Brent crude oil, and natural gas markets). Natural gas market has significant volatility spillover effects to the carbon market. Zhang and Sun [9] used the DCC-GRACH-BEEK model to explore the dynamic fluctuation spillover effect between the EU carbon market and the fossil energy market (coal, natural gas, Brent crude oil market). There are also significant spillover effects from the carbon market to the natural gas market.

The Chinese carbon trading market is confronted with challenges such as inefficiency of carbon price, trading volume, market liquidity, and information transparency due to the short establishment time of China's carbon market [10–12], but the carbon trading market in China from the state of inefficiency to weak form efficiency gradually [13]. The comprehensive evaluation of the pilot markets shows that the three markets in Hubei, Beijing, and Shenzhen have matured well [14–16]. Studies on the spillover effects of the Chinese carbon market are rather sparse. Sun [17] uses the DCC-MGARCH (1, 1) model to analyze the price volatility spillover effect between the EU emissions carbon market and China's carbon trading market. The results show that there are a long-term equilibrium and mutual leading relationship between the two markets. The spillover effect from the EU market to the China's carbon market is being more obvious. Wang and Gao [2] calculated the spillover effects among the China's carbon trading markets by sextuple VAR-GARCH-BEKK model with asymmetric t distribution and analyzed the structure characteristics and spatial correlation of the carbon markets by social network analysis. Wang et al. [18] employs the multivariate GARCH(1,1)- BEKK model to analyze the volatility spillovers among the Guangdong pilot market, Shenzhen pilot market and Hubei pilot market. The empirical results show that there are significant spillover effects from Guangdong to Hubei, Hubei to Shenzhen and Shenzhen to Guangdong during Phase I. The spillover effect is only significant from Shenzhen to Guangdong during Phase II as well as the whole sampling.

Existing research has laid the foundation for this paper to explore the relationship between the prices of pilot carbon markets. For the research on the effects of volatility spillovers between China's carbon pilots, Wang [2] et al. and Wang et al.[18] both adopted the GARCH-BEKK model. The GARCH model allows time-series not to obey normal distribution and eliminates heteroscedasticity. However, there is a theoretical flaw in univariate GARCH model [19]. The GARCH model could describe the static volatility spillover effects among markets, but it is difficult to measure the evolutionary trajectory of volatility spillovers among markets. In this paper, a time-varying parameter state space model is used to characterize the dynamic mean spillover effects among the pilot carbon markets in China, focusing on the time-varying relationship between the markets and analyzing the magnitude of the corresponding spillover effectiveness.

II. Method and Data

A. *The time-varying parameter space state model*

The state space model establishes the dynamic relationship between observable variables and system internal variables, which is generally used for multivariate time series. Let y_t be a $k \times 1$-dimensional observable vector containing k economic variables, and unobservable variables of m economic systems, such as rational expectations, measurement errors, and long-term income, reflect the true state of the system and are called state vector α_t. We defined

$$\begin{cases} Signal\ Equation: y_t = Z_t\alpha_t + d_t + \varepsilon_t, t = 1, \dots, T, \\ State\ Equation:\ \alpha_t = \Gamma_t\alpha_t + c_t + R_t\eta_t, t = 1, \dots, T, \end{cases} \quad (1)$$

Where T is the sample length, ε and η are normal distribution that are independent of each other, and obey the mean value and constant variance. They represent the disturbance terms of the measurement equation and the state equation. The covariance matrix is:

$$\Omega_t = var\begin{pmatrix}\varepsilon_t \\ \eta_t\end{pmatrix} = \begin{pmatrix}H_t & G_t \\ G_t & Q_t\end{pmatrix}, \quad (2)$$

where Z_t, Γ_t, R_t, H_t, Q_t, G_t, d_t, c_t are called system matrices or vectors. One task of the state space model is to estimate these parameters. It is generally assumed that the state vector αt is subject to the AR(1) model[20].

There are two advantages to using state space model [21]. First, the state space model incorporates unpredictable variables into the observable model and obtains the estimation results together with it; The second is that the state space model uses Kalman filtering, a powerful iterative algorithm, to filter out the effects of unpredictable factors.

B. *Data and summary statistics*

The purpose of this paper is to study the mean spillover effect among China's pilot carbon markets. Due to the short establishment time of the Fujian carbon trading market and relatively few trading data, it is not included in this study. As there are multiple types of transactions in the Shenzhen market, this article selects SZA-2013 as the Shenzhen carbon market data. This study spans the period from January 5, 2015, to June 29, 2018. The data for the price series are sourced from the China Carbon Emissions Trading Network (http://www.tanpaifang.com/). Excluding non-trading day data, a total of 848 observations were obtained.

Fig.1 shows the price series for seven carbon markets. Market prices fluctuated in different ranges, and Beijing and Shenzhen prices were relatively high. There are horizontal line segments of different lengths in Chongqing and Tianjin markets, indicating that the market activity is relatively low. There is no significant consistency in the trends of the price curves, indicating that the degree of price correlation in each market is low.

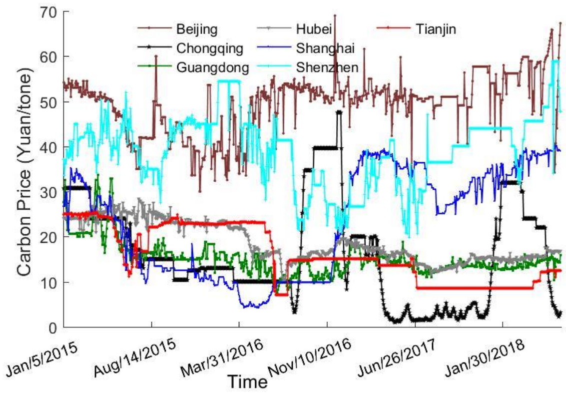

Fig. 1. *Carbon price in Chinese carbon pilots.*

This paper used carbon price return to study the spillover effects between the seven carbon pilots because of the instability of the price series. Let ReBJ, (ReCQ, ReGD, ReHB, ReSH, ReSZ, ReTJ) represent the return of Beijing (Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, Tianjin) pilot. The unit root test results show that the return of each market has rejected the unit hypothesis at a significant level of 1%. Therefore, state space model analysis can be performed.

III. EMPIRICAL RESULTS

A. Spillover relationship

A seven-variable vector autoregressive (VAR) model was constructed to represent the correlation between carbon markets. Based on the five information criteria (LR, FPE, AIC, SC, HQ) in Table 1, the optimal lag order of the VAR model is 2. Then Granger causality test was performed on seven variables to determine the causal relationship between the variables. The results are shown in Table 2.

Table 1. Lag and information criteria of VAR model.

Lag	Log L	LR	FPE	AIC	SC	HQ
0	7724.499	NA	2.64e-17	18.310	-18.270	-18.294
1	7909052	365.602	1.91e-17	-18.631	-18.317*	-18.510
2	8007.734	193.854	1.70e-17*	-18.749*	-18.159	-18.523*
3	8041.823	66.398*	1.76e-17	-18.71	-17.848	-18.382

Note: * denotes that the following variables are Granger causes of row at 10% confidence level.

Table 2. The results of Granger causality test.

Chi-sq	ReBJ	ReCQ	ReGD	ReHB	ReSH	ReSZ	ReTJ
ReBJ		0.0290	3.4150	0.4454	0.7837	0.1447	1.7771
ReCQ	1.0979		0.4347	0.9009	0.9082	2.5072	0.7600
ReGD	1.8000	0.2784		0.0634	3.4606	7.8813**	0.8269
ReHB	0.2424	0.4038	0.7586		4.6938*	0.0053	0.3492
ReSH	0.9317	0.2993	4.6911*	1.0128		1.9927	1.1542
ReSZ	9.6737***	0.0542	2.2525	2.3851	0.0916		0.0893
ReTJ	0.0425	0.0787	3.6413	3.1690	1.4029	7.1464**	

Note: ***, **,* denotes that the following variables are Granger causes of row variables at 1%, 5%, 10% confidence level, respectively.

Fig.2 shows the Granger spillover relationship diagram, where circles represent the carbon market, and directional arrows indicate the direction of the overflow. It can be found that Beijing pilot return is the Granger reason for Shenzhen carbon market, Shenzhen carbon market is the Granger reason for Guangdong and Tianjin, Guangdong pilot is the Granger reason for Shanghai pilot, and the Shanghai is the Granger reason for Hubei. These six markets form a network of spillover relationships, and the Chongqing market is independent of the network. In the network of this study, the Shenzhen market has a two-out, one-in spillover relationship, which plays an important role. This is related to the earliest establishment of the market and broader industry coverage, which has strong market effectiveness. The conclusion is the same as that of Wang et al. [18]. However, the results of the Granger causality in this paper are quite different Wang et al. [2], which may be caused by different sample intervals.

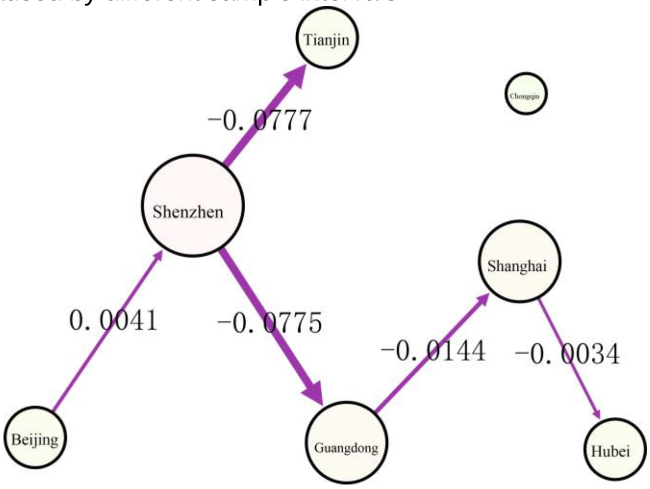

Fig. 2. *Granger spillover relationships network between carbon pilots.*

B. Spillover analysis

The OLS method was used to establish fixed parameter models for the Shenzhen and Guangdong carbon markets, Shanghai and Hubei carbon markets, Guangdong and Shanghai carbon markets, Beijing and Shenzhen carbon markets, and Shenzhen and Tianjin carbon markets. According to the results of model test (table 3), the OLS model for the Shenzhen and Guangdong pilots is significant at a significance level of 1%. Five pairs of Granger causality time-varying state space models can be obtained by taking $k = 1$ in (1),

$$\begin{cases} Signal\ Equation: Y_t = c_1 + sv_t X_t + \epsilon_t \\ State\ Equation: sv_t = c_2 + c_3 sv_{t-1} + \eta_t \end{cases} \quad (3)$$

Where X_t in turn denotes the return of Shenzhen (Shanghai, Guangdong, Beijing and Shenzhen) pilot, Y_t in turn denotes the return of Guangdong (Hubei, Shanghai, Shenzhen and Tianjin) pilot, and sv_t is the corresponding time-varying impact coefficient.

Table 3. Significance test results of fixed parameter model.

	F-statistic	p value
ReSZ − ReGD	9.4690	0.0022
ReSH − ReHB	0.0222	0.8817
ReGD − ReSH	0.9789	0.3227
ReBJ − ReSZ	0.9709	0.3247
ReSZ − ReTJ	4.1819	0.0412

Combining the data of each variable, we get the signal equation of between pilots by using Kalman filter algorithm:

$$\mathrm{ReGD} = -0.000630 + sv_1 ReSZ + [var = \exp(-5.370911)] \quad (4)$$

$$\mathrm{ReHB} = -0.000422 + sv_2 ReSH + [var = \exp(-6.482628)] \quad (5)$$

$$\mathrm{ReSH} = 0.000509 + sv_3 ReGD + [var = \exp(-5.549545)] \quad (6)$$

$$\mathrm{ReSZ} = 0.000292 + sv_4 ReBJ + [var = \exp(-5.28449)] \quad (7)$$

$$\mathrm{ReTJ} = 0.000769 + sv_5 ReSZ + [var = \exp(-5.25189)] \quad (8)$$

The corresponding time-varying parameters $sv_1 - sv_5$ are given in fig.3.

In order to examine the reliability of the estimation results, it is necessary to check whether the residuals of the measurement equations are stable. If the residual sequence is stationary, it is a credible estimate. If the residual series is not stationary, it may be 'pseudo-regression' [22]. The ADF test is performed on the residuals of the signal equation of the state space model. The test results show that all the residual sequences are stable at the significance level of 1%, and the time-varying state space model can be used for research.

As can be seen in fig.3, there exist significant time-varying characteristics between carbon pilots. On the whole, there are obvious fluctuations in the state series, indicating that the pilot market spillover effect is not constant. Secondly, the fluctuation of time-varying parameters has obvious phase characteristics. Before July 10, 2015, the time-varying parameters fluctuated greatly, and then significantly decreased. Before July 10, 2015, the time-varying parameters fluctuated greatly, and then significantly decreased. The reason is that in the initial stage of market operation, each market is still in the exploration stage, and market information has a greater impact on prices. In the later stages, each market initially formed its own characteristics of the mechanism, which was not easily affected by other markets, and the spillover effects between markets tended to stabilize. In the first stage, the impact of the Beijing market on the Shenzhen market was the largest and was positive. Since then, the magnitude of the relationship has staggered, but the difference is not as obvious as before.

Fig. 3. *Evolution of spillover parameter among carbon markets.*

Individually, each evolutionary trajectory has its own characteristics. The spillover effect of the Shenzhen pilot to the Guangdong pilot fluctuated between −0.3081 and 0.8168, with an average effectiveness of −0.0775. Specifically, during the quarter from January 5, 2015, to April 13, 2015, the volatility spillover effect of Shenzhen carbon market to Guangdong carbon market has weakened sharply, from a maximum of 0.816 to -0.3081. This shows that the Guangdong carbon market was relatively fragile at the beginning, and the spillover effect of the Shenzhen carbon market to the Guangdong carbon market changed from promoting to inhibiting. The subsequent small increase gradually tended to a stable process, indicating that with the continuous improvement of the market mechanism, the suppression effect of the Shenzhen carbon market on the Guangdong carbon market gradually decreased, and the Guangdong market became more mature.

The spillover effect of Shanghai pilot to the Hubei pilot fluctuated between -0.0446 and 0.1452, with an average of -0033. On the whole, the spillover effect of Shanghai carbon market to Hubei carbon market is not very obvious, which is related to the high maturity of the Hubei carbon market. Existing research shows that the Hubei carbon market is the best in terms of market maturity, operation performance and comprehensive evaluation [14]. However, the Hubei carbon market has not spillover effect to other markets. And the possible reason lies in market efficiency [18].

The spillover effects of Guangdong pilot to Shanghai pilot and Beijing pilot to Shenzhen pilot changed in opposite directions. The former showed an upward trend throughout the sample period, while the latter showed a decrease in volatility. One year before the sample period, the former is an inhibitory effect, and the late period action direction is exactly the opposite of the prophase.

The spillover effect of the Shenzhen pilot to Tianjin pilot fluctuated from -0.1783 to 0.039, with an average of -0.0777. From the specific trend of the graph, the elastic time-varying coefficient of Shenzhen carbon market to Tianjin carbon market is constantly changing. Except for the overflow effect of 0.0393 on June 27, 2016, the rest of the time is negative. This phenomenon indicates that the Shenzhen carbon market has a reverse suppression effect to Tianjin carbon market.

Fig.2 also shows the size of the inter-market spillover effect. The numbers next to the directed arrows indicate the average spillover effect during the sample period. A positive sign denotes a positive promotion relationship, and a negative sign denotes a negative inhibitory effect. In terms of average effectiveness, only the Beijing carbon market has a positive effect on the Shenzhen carbon market. The Shenzhen carbon market has the largest spillover effect on the Tianjin carbon market and the Shenzhen carbon market on the Guangdong carbon market, while the Shanghai carbon market has the smallest impact on the Hubei carbon market.

IV. CONCLUSION

In this paper, we analyze the mean spillover effects across China's pilot carbon markets by applying a time-varying parameter state space model. Results show that there is network of mean spillover across China's seven pilot carbon markets. More precisely, the Shenzhen pilot carbon market is net receiver of Beijing carbon market, and at the same time, it is net transmitters of shocks to Guangdong and Tianjin markets. The Shanghai pilot has spillover effects to and from other markets. It is affected by the net spillover effect from Guangdong pilot, while there is a net spillover effect to Hubei pilot. Secondly, the time-varying parameter state space models of the Shenzhen and Guangdong carbon markets, Shanghai and Hubei carbon markets, Guangdong and Shanghai carbon markets, Beijing and Shenzhen carbon markets, and Shenzhen and Tianjin carbon markets were constructed based on the Granger causality test conclusions to study the dynamic evolution of spillover effectiveness across China's pilot carbon markets. We find that the Shenzhen carbon market has the largest spillover effect on Guangdong and Tianjin carbon markets, but the impact is a restraining effect. Rising carbon prices in the Shenzhen carbon market will cause carbon prices in the Guangdong and Tianjin carbon markets to decrease. On the whole, the market's spillover effectiveness changed drastically in the initial period of the sample, and the spillover effect in the later period was not obvious.

The spillover network of pilot carbon markets show evidence of a significant correlation among the considered markets, which meets the carbon market integration requirements and price regulation goals. This is the basis for a unified national carbon market. In the early stage of the full launch of the national unified carbon trading market, some suggestions should be considered when investors invest and government formulates legal policies. First, investors should not only pay attention to the price changes of the invested markets, but also comprehensively consider the price behavior of the markets that have spillover effects to this market, especially the Shenzhen market, in order to obtain the best return when participating in the carbon market trading. Second, relevant departments need to take measures to promote linkages between carbon markets. There are currently only five pairs of spillover relationships among the seven pilot markets, and the pilot markets have a low density of spillover effects. Local and central governments should improve the price management system of the carbon market, optimize the market operation mechanism, further promote the correlation between carbon markets, and increase the activity of the unified carbon market across the country. Third, coordination between central and local governments should be strengthened. The central government department needs to make reasonable use of the average spillover effect existing in the local pilot markets, improve trading regulations and policies and system design and implement corresponding policies during the operation of the national unified carbon market.

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