A Bayesian analysis based on multivariate stochastic volatility model: evidence from green stocks

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Abstract

Green stocks are companies environmental protective and friendly. We test Green stock index in Shanghai Stock Exchange and China Securities Index as safe-havens for global investors. Suitable multivariate-SV model and Bayesian method are used to estimate the spillover effect between different assets among local and global markets. We choose multivariate volatility model because it can efficiently simulate the spillover effect by using machine learning MCMC method. The results show that the Environmental Protection Index (EPI) of Shanghai Stock Exchange (SSE) and China Securities Index (CSI) have no significant volatility spillover from Shanghai stock index, S&P index, gold price, oil future prices of USA and China. During COVID-19 pandemic, we find Green stock index is a suitable safe-haven with low volatility spillover. Green stock indexes has a strongly one-way spillover to the crude oil future price. Environmentally friendly investor can use diversity green assets to provide a low risk investment portfolio in EPI stock market. The DCGCt-MSV model using machine learning of MCMC method is accurate and outperform others in Bayes parameter estimation.

Keywords Green stock · Spillover Effect · Machine learning · Markov chain Monte Carlo · Bayesian analysis

1 Introduction

Green stocks are companies environmental protective and friendly. Environmentally friendly company can lower the carbon emission and enhance their competitiveness (Green et al. 2012). Solar, wind and other alternative energy has included in Green stocks. With green stocks, investors not only have the opportunity to obtain sustained
returns from their investments, but also help reduce pollution and the overall pollution of the planet. Finding a listed green company is not a difficult task. In fact, most brokerages can use a variety of different resources, including stock market ratings, to easily identify Green stocks. As in most investment situations, investors want to diversify their investment portfolios with green stocks. The protective green stocks exhibited unforgettable toughness during crisis in 2008 and 2020 (Chakrabarti and Sen 2021).

The SSE Environmental Protection Index is based on the United Nations Integrated Environmental and Economic Accounting System (2020) for the definition of environmental protection stocks. The stocks of clean technology and products are included in the theme of environmental protection stocks. It adopts an equal weighting method to reflect the environmental protection stocks in the Shanghai market. The CSI Environmental Protection Index is like the SSE Environmental Protection Index. The CSI Environmental Protection Index industry is distributed in lithium batteries, photovoltaics, wind power, hydropower, etc. Lithium battery and photovoltaic industry chain account for about 70% in Green stocks. China, Europe and the United States have proposed carbon neutral action targets (2021). The growth of the new energy vehicle market is relatively certain, and the future growth of the lithium battery industry chain is expected to be prosperous. According to GlobalData’s research report, the installed capacity of solar power plants in 2020 is 117GW. By 2025, the global installed capacity of solar power plants is predicted to be 368GW, with a 5-year growth rate of 25%.

Gold has been considered as a safe haven for risk diversity in history, but it is changed in nowadays. Choudhry et al. (2015), Boubaker and Raza (2017), Wen and Cheng (2018) and Iqbal (2017) have proved robust empirical evidence for gold can be seen as safe-haven of stock market and bonds market in some crisis period. For example, the price of gold will rise a lot during financial crisis with intense volatility (Hood and Malik 2013). Compared with Dollar or even Cryptocurrency, gold has lost its elderly power as a safe-haven (Choudhry et al. 2015). It is difficult to diversity the volatility assets between gold and stock market. Crude Oil prices controlled by the OPEC and USA in both demands and supplies (Behar and Ritz 2017). With the growing demands market, China build its own Crude Oil trading market in Shanghai as INE. Crude oil price volatility has affected by the stock market with no doubt and highly comovement to the economy (Ran and Voon 2012; Nazlioglu et al. 2013). Stock markets of All BRICS country have spillover from crude oil prices (Boubaker and Raza 2017). Spillover effect has been widely learned with the proceeding of Globalization (He et al. 2022). Maghyereh et al. (2017) has found low spillover from stock to gold but with high spillover from oil to the stock. Cryptocurrency (Wang et al. 2019) and crude oil volatility index (Chen et al. 2018) have found spillover effect in newly research. Zhang et al. (2022) have tested the absorptive capacity among stock price indices during the Crisis of COVID19, and the result indicate stock prices varied by industry and country at different rates. Green stock index give us a new choice to enhance the stock portfolio with defense risk strategy.
Bayesian Analysis (Carlin and Louis 1997) using Markov chain Monte Carlo method has been widely used to solve complex problems in financial engineering and machine learning (Andrieu et al. 2003; He et al. 2021). Gibbs sampling has been widely used in Bayesian analysis. The Gibbs method is to sample each variable in the multivariate distribution in sequence under the condition that other variables are observed and sampled. MEKK-GARCH (Bollerslev 1986) and MSV (Liesenfeld and Richard 2003) are two main simulation models to solve plural time series. We choose multivariate volatility model because it can efficiently simulate the spillover effect by using machine learning which is more accurate than GARCH model (Chun et al. 2019). Following Asai et al. (2006) and Omori et al. (2007), we have used the MSV model to solve NP-problem by WinBUGS software to sampling and updating (Spiegelhalter et al. 2003). This paper uses the Bayesian analysis by machine learning to solve the dynamic correlation and volatility spillover with MCMC estimation.

2 Multivariate stochastic volatility model

2.1 Stochastic volatility model

2.1.1 Basic MSV model

\[
y_t = \text{diag}(\exp(q_t/2))\varepsilon_t, \varepsilon_t \sim N(0, I)
\]

\[
q_{t+1} = \mu + \text{diag}(\phi_{11}, \phi_{22})(q_t - \mu) + \xi_t, \xi_t \sim N(0, \text{diag}(\sigma_{\xi_1}^2, \sigma_{\xi_2}^2)) \quad (1)
\]

In Eq. (1), \(y_t\) is the yield sequence. \(\phi_{11}, \phi_{22}, \varepsilon_t\) are unknown variables. \(\xi_t\) is the independent disturbance of yield sequence volatility. \(\sigma\) is the standard error. \(\phi_{11}\) and \(\phi_{22}\) are the variables of continuous.

2.1.2 GC-MSV model

\[
y_t = \text{diag}(\exp(q_t/2))\varepsilon_t, \varepsilon_t \sim N(0, I)
\]

\[
q_{t+1} = \mu + \begin{pmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{pmatrix} (q_t - \mu) + \xi_t, \xi_t \sim N(0, \text{diag}(\sigma_{\xi_1}^2, \sigma_{\xi_2}^2)) \quad (2)
\]

In Eq. (2), Yu and Meyer (2006) increase one-way spillover test in the basic model. If \(\phi_{12}\) and \(\phi_{21}\) simulation results are not equal to zero, a spillover test in volatility is obvious. \(\phi_{12}\) represents the spillover from \(\phi_2\) to \(\phi_1\) which means the volatility in \(\phi_2\) is the Granger cause of \(\phi_1\)’s volatility. \(\phi_{21}\) is the opposite. \(\phi_{11}\) and \(\phi_{22}\) show the volatility cause from its own volatility of \(\phi_1\) and \(\phi_2\).
2.1.3 DC-MSV model

\[ y_t = \text{diag}(\exp(q_t/2))\varepsilon_t, \varepsilon_t \sim T(0, \Sigma_{\varepsilon,t}, o), \]
\[ \sum_{\varepsilon,t} = \left( \begin{array}{c} 1 \\ \rho_t \\ 1 \end{array} \right) \]
\[ q_{t+1} = \mu + \text{diag}(\phi_{11}, \phi_{22})(p_t - \mu) + \xi_t, \xi_t \sim i.i.d. N(0, \text{diag}(\sigma_{\xi,1}^2, \sigma_{\xi,2}^2)), \]
\[ r_{t+1} = v_0 + v_{ac} (r_t - v_0) + \sigma_o o_t, o_t \sim i.i.d. N(0, 1), \rho_t = \frac{\exp(r_t) - 1}{\exp(r_t) + 1} \]  \quad (3)

In Eq. (3), \( \rho_t \) is the dynamic correlation between \( y_1 \) and \( y_2 \) changing with time. Yu and Meyer (2006) has used the Fisher method to improve the Basic MSV model like the Tsay (2005) do in the MARCH model.

2.1.4 DCGCt-MSV model

\[ y_t = \exp(q_t/2)\varepsilon_t, \varepsilon_t \sim T(0, \Sigma_{\varepsilon,t}, o), \sum_{\varepsilon,t} = \left( \begin{array}{c} 1 \\ \rho_t \\ 1 \end{array} \right), \]
\[ q_{t+1} = \mu + \psi(p_t - \mu) + \xi_t, \xi_t \sim i.i.d. N(0, \text{diag}(\sigma_{\xi,1}^2, \sigma_{\xi,2}^2)), \]
\[ r_{t+1} = v_0 + v_{ac} (r_t - v_0) + \sigma_o o_t, o_t \sim i.i.d. N(0, 1), \rho_t = \frac{\exp(r_t) - 1}{\exp(r_t) + 1}. \]  \quad (4)

In Eq. (4), DCGCt-MSV model has improved with Dynamic correlation and Spillover effect variables. If \( \phi_{12} \) and \( \phi_{21} \) simulation results are not equal to zero, a spillover test in volatility is obvious (Yu and Meyer 2006). \( \phi_{12} \) represents the spillover from \( \phi_2 \) to the \( \phi_1 \) which means the volatility in \( \phi_2 \) is the Granger causes of \( \phi_1 \)'s volatility. \( \phi_{21} \) is the opposite. \( \phi_{11} \) and \( \phi_{22} \) show the volatility cause from its own volatility of \( \phi_1 \) and \( \phi_2 \). \( \rho_t \) is the dynamic correlation between \( y_1 \) and \( y_2 \) changing with time. \( y_t \) obeys \( T \) distribution.

2.2 Markov Monte Carlo method and Gibbs sampling

We have using the Markov Monte Carlo method to estimate the paraments of MSV model as follows:

\[ P\{X_0 = x_0, X_1 = x_1, \ldots, X_t = x_t\} = P(X_0 = x_0) \prod_{t-1}^t P(X_i = x_i | X_{i-1} = x_{i-1}). \]
Therefore,

\[ p(x_{t-1}, x_t) = P(X_t = x_t | X_{t-1} = x_{t-1}). \]

\[ p(x, x') = \pi(x_1 | x_2, \ldots, x_n) \pi(x_2 | x_1', \ldots, x_n') \cdots \pi(x_n | x_n'). \]

Gibbs sampling simulates joint distribution through conditional distribution sampling, and then deduces the conditional distribution directly through the simulated joint distribution, so as to cycle. It has been used to calculate the MCMC problems as follows:

1. Sampling \( x_1^{(t)} \) from \( \pi(x_1 | x_2^{(t-1)}, \ldots, x_n^{(t-1)}) \);
2. Sampling \( x_2^{(t)} \) from \( \pi(x_2 | x_1^{(t)}, x_3^{(t-1)}, \ldots, x_n^{(t-1)}) \);

......
(i) Sampling \( x_i^{(t)} \) from \( \pi(x_i | x_1^{(t)}, x_{i-1}^{(t)}, x_{i-1}^{(t-1)}, \ldots, x_n^{(t-1)}) \);

......
(n) Sampling \( x_n^{(t)} \) from \( \pi(x_n | x_1^{(t)}, x_2^{(t)}, \ldots, x_{n-1}^{(t)}) \);

\[ X = (X_1, X_2) \] is a multivariate normal distribution:

\[
\begin{pmatrix}
    x_1^{(t)} \\
    x_2^{(t)}
\end{pmatrix}
\sim
\mathcal{N}
\left( \begin{pmatrix}
    \rho^{2t-1} x_2^{(0)} \\
    \rho^{2t} x_2^{(0)}
\end{pmatrix},
\begin{pmatrix}
    1 - \rho^{4t-2} & 1 - \rho^{4t-1} \\
    1 - \rho^{4t-1} & 1 - \rho^{4t}
\end{pmatrix} \right).
\]

If \( t \to \infty \), the distribution of \( (X_1^{(t)}, X_2^{(t)}) \) will be converged.

### 3 Empirical analysis

#### 3.1 Data and preprocessing

In this section, we choose nine sets of data including the Shanghai Environmental Protection Index(SE), the Shanghai Composite Index(SH), CSI Environmental Protection Index(CE), CSI 300 Index(HS), China Gold Price(CG), American Crude Oil Futures Price(AO), China Crude Oil Futures Price(CO), US S&P Index and British FTSE Index(FS). We choose the closing price of common trading day from March 27, 2018 to December 3, 2021. We have got 849 valid data from public database of stock market. Green stock as we defined as Shanghai Environmental Protection Index(SE) and CSI Environmental Protection Index(CE). The crude oil future price(AO,CO) represent the traditional carbon emission industry and the gold price(CG) represent the elderly safe-haven of stock market. The Shanghai Composite Index(SH) and CSI 300 Index(HS) represent the fresh investor of emerging market which is try to achieve the carbon neutrality. US S&P Index and British FTSE Index(FS) represent the mature investor of developed market. Table 1 is the descriptive statistics of nine assets. Obviously, Crude oil price is different from the normal distribution. Only in May 20, 2020, the closing price of American Crude Oil Futures is almost zero which is unseen in history. Jarque-Bera value show that the distribution is not a N-distribution in recent year.
Table 1 Descriptive statistics

|       | SE    | SH    | CE    | HS    | CG    | AO    | CO    | SP    | FS    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Mean  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Median| 0.047 | 0.012 | 0.019 | 0.008 | -0.004 | 0.194 | 0.064 | 0.067 | 0.063 |
| Maximum| 5.302 | 7.533 | 6.279 | 7.399 | 5.366 | 680.9 | 12.809 | 8.904 | 8.665 |
| Minimum| -9.187| -8.054 | -9.443 | -8.235 | -4.842 | -750.2 | -11.209 | -12.831 | -11.515 |
| SD    | 1.627 | 1.202 | 1.779 | 1.356 | 0.903 | 35.0 | 2.388 | 1.388 | 1.222 |
| Skewness| -0.493 | -0.311 | -0.323 | -0.231 | -0.226 | -2.929 | -0.055 | -1.041 | -1.194 |
| Kurtosis| 5.377 | 8.603 | 5.224 | 6.509 | 7.530 | 417.9 | 5.649 | 21.596 | 18.683 |
| Jarque–Bera| 234.3 | 112.1 | 189.8 | 443.0 | 733.3 | 609.0 | 248.7 | 1238.9 | 890.2 |
3.2 Parameter estimation

We first estimate the MSV model of Shanghai Composite Index (SH) and Shanghai Environmental Protection Index (SE). Using the updating tool of WinBUGS, we abandon the first 10,000 update simulations and sample the last 80,000 result as Table 2. Time series iteration and dynamic trace of $\mu_{sh}$ and $\mu_{se}$ are shown as Fig. 1. In Table 2, $\psi_{shse}$ is the simulation result of the volatility spillover from Shanghai Environmental Protection Index (SE) to Shanghai Composite Index (SH). As Yu proposed (2006), the spillover effect is significant if $\psi_{shse}$ is more than zero. The 2.5 and 5% quantile of $\psi_{shse}$ is less than 0. The spillover from Shanghai Environmental Protection Index (SE) to Shanghai Composite Index (SH) is not exist in 95% confidence interval. $\psi_{sesh}$ is less than 0 too. The two-way spillover is not exist. Green stock volatility is not affected by the main market. The volatility simulation result of $\mu_{sh}$ is $-0.04726$, which is lower than $\mu_{se}$. The volatility of Shanghai Composite Index (SH) is lower than Shanghai Environmental Protection Index (SE). The volatility persistence parameter $\psi_{sh}$ of Shanghai Composite Index (SH) is 0.9714 and the $\psi_{se}$ of Shanghai Environmental Protection Index (SE) is 0.962. The Shanghai Environmental Protection Index (SE) volatility persistence is lower than Shanghai Composite Index (SH).

Figure 1 show the time series and dynamic trace iteration result of 50,000 iterations with 2 Markov chains. In Fig. 2, using the Gelman test, we can see the result of lines are convergent. Figure 3 show the dynamic correlation result between Shanghai Environmental Protection Index (SE) to Shanghai Composite Index (SH). Table 3 show the DIC test results of DC-MSV, GC-MSV, GCt-MSV, DCGC-MSV, RSDGC-MSV and DCGCt-MSV. We use 6 different model to simulate the same data of SH and SE. pD values reflects the RSDGC-MSV model is the most complexity model, but DIC values show the fittest model is the DCGCt-MSV model. The DCGCt-MSV model using machine learning of MCMC method is accurate and outperform others in Bayes parameter estimation.

In Table 4, we estimate the spillover effect of Shanghai Environmental Protection Index (SE) and 8 asset prices with 8 simulations. All simulation results are converged and tested like SH and SE. $\psi_{shhs}$, $\psi_{zhsh}$, $\psi_{shzh}$, $\psi_{cosh}$ and $\psi_{spsh}$ in 95% confidence is more than zero which means spillover effect exist. First, Shanghai Environmental Protection Index (SE) and CSI Environmental Protection Index (CE) has a spillover effect between each other. It is no doubt green stocks are highly synchronized. Second, American Crude Oil Futures Price (AO) and China Crude Oil Futures Price (CO) have one-way volatility spillover from Shanghai Environmental Protection Index (SE). The green stock price has a reverse effect to crude oil price. Third, the US S&P Index (SP) has a spillover effect from SE but British FTSE Index (FS) have no exist spillover effect. The gold price has no spillover effect too. In Table 5, we estimate the spillover effect of CSI Environmental Protection Index (CE) with 7 simulations in the same way. The result is like SE, the green stock has proved are highly related.
Table 2 The simulation results of SH and SE

| Node   | Mean  | sd    | MC error | 2.50% | 5.00% | 10.00% | Median | 97.50% | Start | Sample |
|--------|-------|-------|----------|-------|-------|--------|--------|--------|-------|--------|
| \(\mu_{sh}\) | \(-0.04726\) | 0.1766 | 0.00589 | \(-0.3586\) | \(-0.3052\) | \(-0.2468\) | \(-0.06232\) | 0.3616 | 10000 | 80002 |
| \(\mu_{se}\) | 0.5193 | 0.1684 | 0.00544 | 0.1528 | 0.2385 | 0.3186 | 0.5266 | 0.8326 | 10000 | 80002 |
| \(o\) | 9.663 | 2.125 | 0.07637 | 6.438 | 6.786 | 7.248 | 9.358 | 14.65 | 10000 | 80002 |
| \(\psi_{sh}\) | 0.9714 | 0.01569 | 0.00061 | 0.9343 | 0.9423 | 0.9503 | 0.974 | 0.9944 | 10000 | 80002 |
| \(\psi_{sise}\) | \(-0.001325\) | 0.01377 | 0.00050 | \(-0.02813\) | \(-0.02317\) | \(-0.01801\) | \(-0.001529\) | 0.02731 | 10000 | 80002 |
| \(\psi_{se}\) | 0.962 | 0.01804 | 0.00070 | 0.9188 | 0.9288 | 0.9383 | 0.9648 | 0.9893 | 10000 | 80002 |
| \(\psi_{sesh}\) | 0.01157 | 0.01648 | 0.00060 | \(-0.01861\) | \(-0.01308\) | \(-0.007303\) | 0.01057 | 0.04842 | 10000 | 80002 |
| \(\sigma_{\psi_{sh}}\) | 0.1092 | 0.02123 | 0.00098 | 0.07247 | 0.07741 | 0.0832 | 0.1076 | 0.155 | 10000 | 80002 |
| \(\sigma_{\psi_{se}}\) | 0.1239 | 0.02687 | 0.001254 | 0.08293 | 0.08723 | 0.09284 | 0.1199 | 0.1855 | 10000 | 80002 |
4 Conclusion

The green stock spillover effect simulation result can give some recommendations for properly EPI invest diversification, which need more research. Environmentally friendly investor can use diversity green assets to provide a low risk investment portfolio in EPI stock market. The empirical results for investors in green stocks conclusion as follows: (1) Shanghai Environmental Protection Index(SE) and CSI Environmental
Protection Index (CE) has a two-way spillover effect. Each of them have no spillover from other non-green markets. It has proved as a trait of the safe haven of stock market. (2) Crude oil price has a one-way spillover from green stock market. It has reflect the green energy market is overwhelming the traditional industrial market day by day. (3) The US S&P Index has more attention to the green stock market, while British FTSE Index have no exist spillover effect from green stock. Green stocks will be a safe-haven under the crisis of pandemic. We tested DC-MSV, GC-MSV, GCt-MSV, DCGC-MSV, RSDGC-MSV and DCGCt-MSV model. The DIC result show the DCGCt-MSV model using machine learning of MCMC method is accurate and outperform other models in bayes parameter estimation. Our future studies base on the result of green stock will focus on the competition between gold price and green stock, which is the best safe-haven for stock market.

### Table 3 DIC test result of DC-MSV, GC-MSV, GCt-MSV, DCGC-MSV, RSDGC-MSV and DCGCt-MSV

| Model       | Dbar   | Dhat   | pD     | DIC    |
|-------------|--------|--------|--------|--------|
| DC-MSV      | 4839.49| 4700.92| 138.572| 4978.06|
| GC-MSV      | 4847.97| 4714.92| 133.046| 4981.02|
| GCt-MSV     | 3986.91| 3936.3 | 50.61  | 4037.52|
| DCGC-MSV    | 4827.07| 4680.75| 146.322| 4973.4 |
| RSDGC-MSV   | 4651.5 | 4401.54| 249.953| 4901.45|
| DCGCt-MSV   | 3611.83| 3540.3 | 71.536 | 3683.37|
| Node    | Mean   | SD    | MC error | 2.50%  | 5.00%  | 10.00% | Median   | 97.50%   | Start | Sample | Spillover effect |
|---------|--------|-------|----------|--------|--------|--------|----------|----------|-------|--------|------------------|
| $\psi_{szsh}$ | $-0.001325$ | 0.01377 | 4.97E-04 | $-0.02183$ | $-0.02317$ | $-0.01801$ | $-0.001529$ | 0.02731 | 10000 | 80002 | no exist          |
| $\psi_{shsz}$ | 0.01157  | 0.01648 | 6.04E-04 | $-0.01861$ | $-0.01308$ | $-0.007303$ | 0.01057  | 0.04842 | 10000 | 80002 | no exist          |
| $\psi_{shsh}$ | 0.07299  | 0.04667 | 0.002039 | 0.006764 | 0.0143  | 0.0234  | 0.06519  | 0.1887  | 10000 | 80002 | exist            |
| $\psi_{hssh}$ | 0.01366  | 0.02659 | 0.001127 | $-0.02458$ | $-0.01927$ | $-0.01334$ | 0.00867  | 0.08582 | 10000 | 80002 | no exist          |
| $\psi_{zshh}$ | 0.1806   | 0.1139  | 0.005585 | 0.03379  | 0.04196 | 0.05388 | 0.1575   | 0.4502  | 10000 | 80002 | exist            |
| $\psi_{shzh}$ | 0.1247   | 0.1078  | 0.005204 | 0.01029  | 0.019   | 0.03041 | 0.09525  | 0.4569  | 10000 | 80002 | exist            |
| $\psi_{shco}$ | $-0.01382$ | 0.01185 | 3.84E-04 | $-0.03772$ | $-0.03335$ | $-0.02852$ | $-0.01364$ | 0.009742 | 10000 | 80002 | no exist          |
| $\psi_{cosh}$ | 0.03546  | 0.01667 | 5.83E-04 | 0.004232 | 0.009694 | 0.01534 | 0.03476  | 0.07104 | 10000 | 80002 | exist            |
| $\psi_{shao}$ | $-0.01782$ | 0.006545 | 2.18E-04 | $-0.03199$ | $-0.02932$ | $-0.0264$  | $-0.01737$ | $-0.006087$ | 10000 | 80002 | no exist          |
| $\psi_{aosh}$ | 0.06021  | 0.02117 | 7.11E-04 | 0.01813  | 0.02564 | 0.03355 | 0.06039  | 0.1023  | 10000 | 80002 | exist            |
| $\psi_{shcg}$ | $-0.008735$ | 0.01053 | 2.76E-04 | $-0.03013$ | $-0.02624$ | $-0.02187$ | $-0.008592$ | 0.01187 | 10000 | 80002 | no exist          |
| $\psi_{cgsh}$ | 0.01583  | 0.01617 | 4.85E-04 | $-0.01441$ | $-0.009233$ | $-0.00356$ | 0.0151   | 0.04982 | 10000 | 80002 | no exist          |
| $\psi_{shsp}$ | $-0.01208$ | 0.006763 | 1.92E-04 | $-0.02558$ | $-0.02312$ | $-0.02054$ | $-0.01203$ | 0.001391 | 10000 | 80002 | no exist          |
| $\psi_{spsh}$ | 0.05451  | 0.02842 | 9.90E-04 | 0.002147 | 0.01066 | 0.01981 | 0.053    | 0.1146  | 10000 | 80002 | exist            |
| $\psi_{shfs}$ | $-0.01325$ | 0.009654 | 2.79E-04 | $-0.03396$ | $-0.02999$ | $-0.02562$ | $-0.01267$ | 0.004505 | 10000 | 80002 | no exist          |
| $\psi_{fssh}$ | 0.01333  | 0.01726 | 5.26E-04 | $-0.02206$ | $-0.0151$  | $-0.007895$ | 0.01338  | 0.04734 | 10000 | 80002 | no exist          |
| Node   | Mean   | SD     | MC error | 2.50%  | 5.00%  | 10.00% | Median | 97.50% | Start | Sample | Spillover effect |
|--------|--------|--------|----------|--------|--------|--------|--------|--------|-------|--------|------------------|
| \(\psi_{zzh}\)          | -3.62E-04 | 0.0101 | 3.07E-04 | -0.01944 | -0.01589 | -0.01227 | -7.30E-04 | 0.02131 | 10000 | 80002 | no exist          |
| \(\psi_{zs}\)         | 0.005622  | 0.01351 | 4.56E-04 | -0.02004 | -0.01579 | -0.01108 | 0.005372 | 0.03309 | 10000 | 80002 | no exist          |
| \(\psi_{zhhs}\)       | 0.04409   | 0.03281 | 0.001406 | -0.003406 | 0.002666 | 0.009672 | 0.03798 | 0.1212  | 10000 | 80002 | exist            |
| \(\psi_{zhsh}\)       | 0.01654   | 0.01837 | 6.97E-04 | -0.01321 | -0.009006| -0.004113 | 0.01446 | 0.05869 | 10000 | 80002 | no exist          |
| \(\psi_{zhco}\)       | -0.006201 | 0.01497 | 5.09E-04 | -0.03259 | -0.02828 | -0.02352 | -0.007316 | 0.0273  | 10000 | 80002 | no exist          |
| \(\psi_{cozh}\)       | 0.03528   | 0.01755 | 6.60E-04 | 0.005646 | 0.009854 | 0.01471  | 0.03343 | 0.07488 | 10000 | 80002 | exist            |
| \(\psi_{zhao}\)       | -0.01359  | 0.006645| 2.35E-04 | -0.02765 | -0.02486 | -0.02201 | -0.01328 | -0.00133 | 10000 | 80002 | no exist          |
| \(\psi_{aozh}\)       | 0.05528   | 0.02601 | 9.42E-04 | 0.007133 | 0.01533  | 0.02405  | 0.05391 | 0.1114  | 10000 | 80002 | exist            |
| \(\psi_{zhcg}\)       | -7.29E-05 | 0.01107 | 3.22E-04 | -0.02048 | -0.01709 | -0.01336 | -5.86E-04 | 0.02348 | 10000 | 80002 | no exist          |
| \(\psi_{czg}\)        | 0.02164   | 0.01421 | 4.62E-04 | -0.002938| 9.91E-04 | 0.005174 | 0.02035 | 0.05424 | 10000 | 80002 | no exist          |
| \(\psi_{zhsp}\)       | -0.009621 | 0.007974| 2.38E-04 | -0.02516 | -0.0223  | -0.01929 | -0.009758| 0.006896 | 10000 | 80002 | no exist          |
| \(\psi_{psz}\)        | 0.0538    | 0.028   | 9.18E-04 | 0.002451 | 0.01041 | 0.01949  | 0.0524  | 0.1133  | 10000 | 80002 | exist            |
| \(\psi_{zhfs}\)       | -0.00847  | 0.009753| 2.89E-04 | -0.02874 | -0.02512 | -0.02099 | -0.008082| 0.009604 | 10000 | 80002 | no exist          |
| \(\psi_{fszh}\)       | 0.01263   | 0.01569 | 4.83E-04 | -0.01757 | -0.01256 | -0.006792| 0.0123  | 0.04457 | 10000 | 80002 | no exist          |
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Declarations

Conflict of interest  The authors declare that they have no conflict of interest.

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