Research on Cross-market Transmission of Systemic Financial Risk Based on Financial Stress Index

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Abstract— *With the ever-increasing financial innovation, the interconnection between financial markets has become increasingly close, and systemic financial risks have become more complex and easier to spread among financial markets. This paper first selects 25 representative indicators to construct the financial stress index of the stock, bond, foreign exchange, real estate, and banking markets. Using the DAG model, empirically studies the pressure transmission direction of each sub-market, and then constructs a vector with time-varying parameters. Autoregressive model to study the time-varying effects of financial pressure transmission in various sub-markets. The research found that the real estate market is the main risk receiving market, and the stock market and the banking system are the main risk transmission markets; financial marketization policies intensify the transmission of financial pressure in the short term, and the long-term pressure transmission effect will also weaken; the short-term effect of pressure transmission involving the foreign exchange market More obviously, the long-term effects of pressure transmission involving the banking system will be more obvious.*

Keywords— *Financial stress index; directed acyclic graph; TVP-SVAR model; risk contagion.*

I. INTRODUCTION

General Secretary Xi Jinping pointed out that the prevention and resolution of financial risks, especially to prevent the occurrence of systemic financial risks, is the fundamental task of financial work, but also the eternal theme of financial work. Although China's prevention and control of major risks has achieved phased results, but the prevention and resolution of systemic financial risks is still one of the major issues that must be long in the process of high-quality development of our economy. In the current complex financial and economic environment, the financial network formed by the interconnectedness of financial institutions can lead to the rapid spread of changes or shocks faced by a single market to the vast majority of associated markets in the financial system. The risk spillover from a single market in distress will be spread among the system through the interconnected network, leading to further spillover effects of systemic risk from financial institutions, which in turn will strengthen the systemic risk of individual financial markets.

The risk spillover from a single market in distress will spread through the inter-system network and lead to the further spread of systemic risk spillover from financial institutions, which in turn strengthens the hazard and penetration of systemic risk in individual financial markets and eventually leads to the outbreak of systemic crisis. In addition, due to the increased correlation between financial institutions and financial sectors, negative shocks are more easily transmitted and spread, which not only amplifies the possibility of risk contagion, but also enhances the degree of damage and impact of risk shocks. Therefore, it is important to accurately grasp the correlation between markets and study the path mechanism of risk contagion between China's markets and its dynamic changes to maintain China's financial security and stability.

In summary, most of the existing risk contagion spillover studies in the literature focus on different industries, regions and sectors, while there are fewer studies on risk spillover across markets. This paper intends to investigate the direction of financial stress transmission in different submarkets, sort out the direction of financial stress transmission in different markets, and analyze the effect of stress transmission between different markets and the effect of stress transmission in each submarket at a specific point in time. Based on the research on financial risk measurement and financial risk contagion spillover, this paper uses principal component analysis to measure the stress index of different markets of financial risk; adopts the DAG model considering contagion factors, constructs the directed acyclic diagrams of different markets, and sorts out the risk transmission paths of different markets; uses the time-varying parameter vector autoregression method to analyze the mechanism of financial stress transmission across markets based on the directed acyclic diagrams, and analyzes the dynamic change characteristics contained in them. The conclusions of this study will help China's financial system to deal with systemic risks effectively and promote financial market reform smoothly.

II. STUDY DESIGN

A. Variable description

Systemic financial risk is formed by the accumulation of risk contagion from multiple financial subsystems, and it can reflect the fact that it originates from multiple financial markets and financial institutions. The financial stress index can better reflect the level of risk stress in the market due to uncertainty and changes in expected losses. In this paper, based on the indicator selection methods of Tao Ling and Zhu Ying (2016), Ding Lan et al. (2019), Li Shaofang and Liu Xiaoxing (2020), and Ding Hui et al. (2020), we select representative indicators of different submarkets such as stocks, bonds, foreign exchange, real estate, and banks, and construct a monthly stress index from 2010 to 2021 using principal component analysis to examine the financial risk in different markets. Based on the availability of data, the following five market indicators are selected. The data time period is from April 2010 to March 2021. Table 1 gives the selection of each market stress indicator variable, calculation method, significance of the indicator, data

sources and attributes.

TABLE 1. Market Pressure Base Indicator Pool

	Indicator Name	Calculation method	Indicator Meaning	Data source	Properties
Stock Market	SSE Volatility for the past 12 months		Stock Market Volatility Indicators	Wind	+
	CSI 500 Volatility	garch（1，1）	Stock Market Volatility Indicators	Wind	+
	CSI 300 Volatility	garch（1，1）	Stock Market Volatility Indicator	Guotaian	+
	Domestic Listed Companies:Total Market Capitalization:YoY		Reflects the prosperity of the stock market		+
	Stock turnover: month-on-month value: year-on-year		Reflecting the prosperity of the stock market		+
Bond Market	SSE Corporate Bond Volatility		Bond Market Volatility Indicator	Wind	+
	SSE Treasuries Near Dec Volatility		Bond Market Volatility Indicator	Wind	+
	SSE Corporate Bond Volatility Near Dec		Bond Market Volatility Indicator	Wind	+
	Term spreads	Treasury Yield to Maturity:5 years - Treasury Yield to Maturity:1 year	Reflects spread between long-term and short-term funding	Wind	+
	China Bond Composite Index		Reflects consolidated bond returns	Wind	+
Foreign Exchange Market	Change in Foreign Exchange Reserves	Foreign exchange (central bank foreign exchange holdings)/m2	The higher the foreign exchange reserves, the stronger the resilience to risk	Wind	_
	Renminbi Real Effective Exchange Rate Index		Change in the foreign value of the RMB	Wind	_
	China-US Spread	3-month libor-single-month interbank offered rate Garch(1,1) take monthly average	RMB exchange rate pressure		+
	RMB/USD Exchange Rate Volatility		Future asset value and other investor uncertainty	Guotaian	+
	Exports month-on-month		Foreign trade activity	Wind	_
	Imports month-on-month		Foreign trade activity	Wind	_
Real Estate Market	National Housing Boom Index		Reflecting changes in the boom of the real estate industry	Wind	_
	Source of funds for real estate development: Self-financing: Cumulative year-on-year		Real estate market prosperity	Wind	_
	Investment in real estate development: Cumulative year-on-year		Investment activity in the real estate market	Wind	_
	Sales area of commercial properties: Cumulative year-on-year		Prosperity of real estate market	Wind	_
Banking Market	Interbank interest rate spread	SHIBOR 1Y—SHIBOR 1W	The spread of long- and short-term funds split, the more severe the crisis, the larger the spread	Wind	+
	Non-Performing Loan Ratio		The higher the NPL ratio, the higher the risk	Wind	+
	Loan-to-Deposit Ratio		Reflects the ability to resist risk	Wind	+
	M2 year-on-year growth rate/year-on-year growth rate		Reflects the efficiency of economic operation	Wind	+
	Ted Spread	LIBOR 3M	Reflects the degree of protection of banks against external risk shocks		+

B. Stability tests for different market stress indices

The ADF test, PP test, and DF-GLS test were used to test the unit root of the data. The test results in Table 2 show that the bond market has a unit root under the DF-GLS test, the banking system has a unit root under all three test results, and the rest of the data are a smooth time series with a significance level of 1%. The results of the first-order difference value test indicate that each variable behaves as a smooth series without unit roots at the 1% significance level. Therefore, there is no pseudo-regression in the subsequent TVP-SVAR analysis.

TABLE 2. Unit root test results

	ADF	PP	DF-GLS	results
Stock Market	-3.129***	-2.782***	-3.020***	Stable
First order differential	-9.191***	-9.498***	-8.662***	Stable
Bond Market	-3.329***	-3.310***	-0.268	Non-Stable
First order differential分	-11.525***	-11.901***	-9.132***	stable
Foreign Exchange Market	-10.271***	-10.359***	-10.065***	stable
First order differential	-9.980***	-102.326***	-9.495***	stable
Real Estate Market	-4.984***	-8.982***	-3.796***	stable
First order differential	-10.317***	-41.858***	-12.442***	stable
Banking System	-1.943**	-1.615*	-1.385	Non-Stable
First order differential	-14.048***	-18.706***	-11.988***	Steady

Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels, respectively.

III. EMPIRICAL ANALYSIS

A. Results of causality tests and parameter estimation

According to the correlation (AIC, SC) criterion, this paper chooses to establish a VAR model with a lag of 1. According to the established VAR model, the correlation matrix of perturbations among variables is obtained by fitting the model as follows:

$$\begin{bmatrix} 1.0000 & 0.2378 & 0.0784 & 0.1616 & -0.0237 \\ 0.2378 & 1.0000 & -0.0607 & -0.1385 & 0.0603 \\ 0.0784 & -0.0607 & 1.0000 & -0.0147 & -0.0388 \\ 0.1616 & -0.1385 & -0.0147 & 1.0000 & -0.0721 \\ -0.0237 & 0.0603 & -0.0388 & -0.0721 & 1.0000 \end{bmatrix}$$

Based on the above correlation coefficient matrix, the matrix was substituted into TETRAD software and the PC algorithm was used to analyze the unconditional correlation coefficients and partial correlation coefficients among the variables, and then the contemporaneous causality between the variables was obtained. Since the data used in this paper span 132 months and the sample observations are less than 200, which is a small sample estimation, a significance level of 20% is chosen with reference to the studies of Chuang Deng and Man Xu (2019) and Taifeng Xie and Wentao Li (2021) to avoid the problem that DAG analysis may underestimate the contemporaneous causality among variables; The results show that the real estate market dominates in the cross-market stress transmission, and there are causal relationships from the banking system to the real estate market, the foreign exchange market to the real estate market, and the stock market to real estate; in addition, the stock market is also influenced by the banking system and the foreign exchange market; the banking system is affected by the bond market.

The model parameters were estimated based on MCMC method with 10,000 sampling times. As shown in Figure 1 Table 3 the CD statistics are all greater than 0.01 and the sampling results tend to converge. The invalid factors of all parameters are lower than 100, indicating that the number of valid results of model sampling meets the demand. Therefore, the sampling results of this paper are valid.
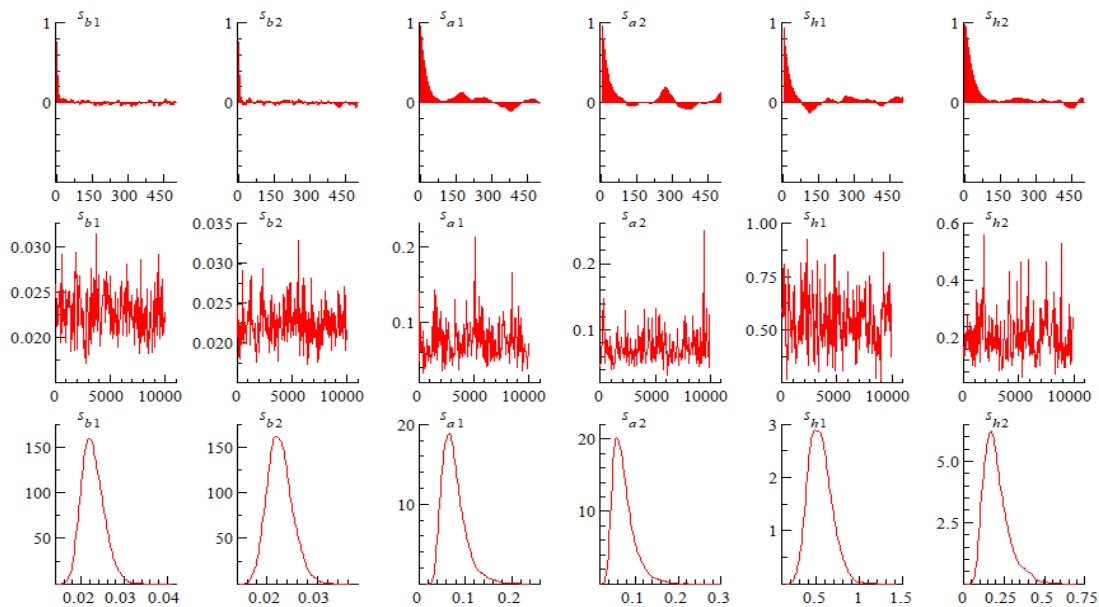

Figure 1. TVP-SVAR Model Sampling Results

TABLE 3. Parameter estimation results

Parameters	Average value	Standard deviation	95%Confidence interval	CDStatistical quantities	Invalidation factor
Sb1	0.0227	0.0026	[0.0185,0.0284]	0.694	11.14
Sb2	0.0226	0.0025	[0.0182,0.0278]	0.095	9.60
Sa1	0.0756	0.0253	[0.0412,0.1401]	0.170	55.98
Sa2	0.0742	0.0259	[0.0420,0.1410]	0.920	50.89
Sh1	0.5430	0.1351	[0.3183,0.8360]	0.280	36.70
Sh2	0.2034	0.0786	[0.0972,0.4042]	0.028	62.93

Figure 2 presents the time-varying characteristics of stochastic volatility for each market variable. Figure 3 shows that the stochastic volatility of the stock market reached a peak in mid-2015 and then rapidly converged, indicating that the Chinese stock market has been operating basically smoothly over the long term. However, it is worth mentioning that a stock market crash eventually occurred from June 15 to July 9, 2015 due to a chain reaction formed by the cleanup of over-the-

counter placements, over-the-counter financing and deleveraging of graded funds. Bond market volatility took a large dip between 2012 and 2013 and has since gradually recovered, with an overall downward trend. Stochastic volatility in the foreign exchange market gradually increased from 2014 and was affected by the trade war between the U.S. and China, which resulted in greater volatility in the foreign exchange market after 2018. Stochastic volatility of the real estate market peaked in 2015 and rapidly trended downward, reaching its lowest point in 2020 and fluctuating at zero value overall. The stochastic volatility of the banking system peaked in 2012 and eventually converged to zero value, remaining

basically stable except for a small shock after the outbreak of the new crown pneumonia outbreak.

A. Equally spaced impulse response analysis

The TVP-SVAR model constructed with time-varying parameters allows for heterogeneity analysis with different lead times and different time points. Given the time-lagged nature of pressure transmission between markets, constraints of one, two, and three advance periods are chosen for analyzing the short-, medium-, and long-term shock effects of pressure transmission in different markets.
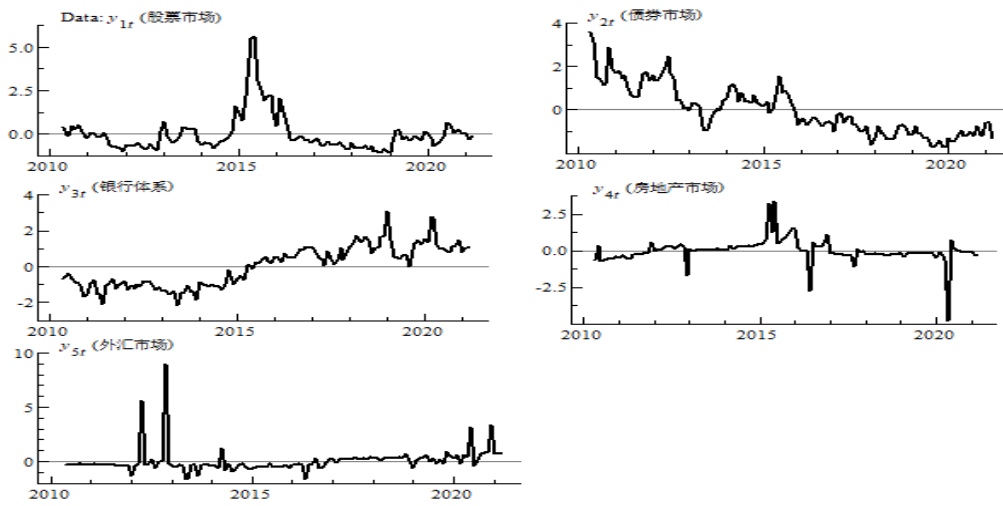

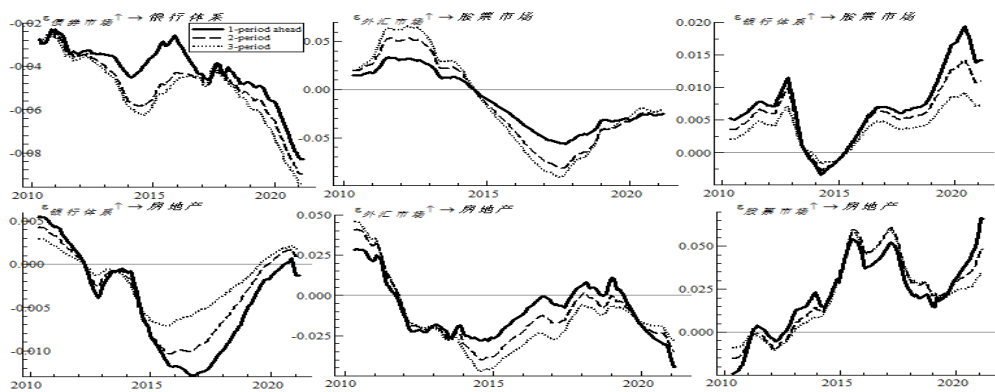Figure 2. Time-varying characteristics of stochastic volatility of each variable

Figure 3. Equal interval impulse response graph

1. Impulse response of stock market pressure to foreign exchange market pressure

Figure 4 (row 1, column 2) shows the results of the stock market response to foreign exchange market pressure. The time-varying characteristics of the early 3 periods are relatively significant in terms of intensity, indicating that the effect of foreign exchange market on stock market pressure is more pronounced in the long run. The impulse response of the stock market to the foreign exchange market pressure shock shows a positive impulse response until mid-2014 and peaks in 2012, and after 2015 it shows a negative impulse response and peaks in 2017. The reason for the volatility, from the internal factors,

is the asymmetric two-way volatility spillover effect between the stock market and the foreign exchange market (Xiong, Zhengde, 2013).In 2012 and 2015, China reformed and adjusted the exchange rate, which improved the elasticity of the exchange rate and the tendency of the RMB to depreciate, which in turn caused an increase in short-term capital inflows, leading to the movement of stock prices. After the global financial crisis, stock prices were positively and increasingly influenced by short-term capital flows, and short-term capital inflows contributed to the increase in stock prices. The reform of the exchange rate market not only reduced the level of pressure on the RMB exchange rate and increased the

22

sensitivity of capital flows to the exchange rate, but also changed the situation of China's imports and exports, which in turn affected listed companies with high dependence on imports and exports, and the pressure was further transmitted to the stock market. In addition, the direct cause of the 2015 stock market crash was deleveraging, behind which there was also the influence of the exchange rate depreciation factor, which made non-leveraged funds flow out of the stock market rapidly. From the external factors, the trade friction between China and the United States gradually intensified and eventually escalated into a trade war. Trade war caused a sharp decline in global stock markets, the reason is that with the start of the trade war companies and investors will avoid the risks of the stock market, so the short-term stock market will be affected more drastically. But stock market volatility is mainly affected by psychological and other factors, and exchange rate market volatility is mainly affected by factors such as the dollar and external uncertainty cycle behavior. From a fundamental point of view, the risks are generally controllable and the capital market has sufficient conditions for healthy development. After that, China also launched a series of policies to stabilize the development of the foreign exchange market, and the response of the stock market pressure after 2017 also gradually reduced.

2. impulse response of real estate market pressure to foreign exchange market pressure

Figure 4 (row 2, column 2) shows the results of the response of the real estate market to foreign exchange market pressure. The impulse response of the real estate market to foreign exchange market shocks is positive at the beginning, turns negative around 2012, starts to decrease and gradually approaches zero after 2015, and starts to gradually increase again after 2019. The foreign exchange rate and the real estate market are closely linked, as a fall in the exchange rate will benefit exports, and the demand for labor and capital as well as land will increase, as the land factor has supply rigidity and thus causes price increases, which in turn affects housing prices; a rise in the exchange rate, with the stability of international commodities and a relatively lower domestic price level, will further boost housing demand as consumers feel an increase in subjective wealth. 2010 exchange rate reform After that, the pressure of RMB appreciation was released and a large amount of capital flowed into the country, which prompted the development of the domestic real estate market; however, influenced by the financial crisis and the loose monetary policy of the United States, RMB appreciation slowed down domestic capital also gradually flowed out, and the impact of the foreign exchange market on real estate also gradually weakened, tending to zero value and gradually turning into a negative impact around 2012; in 2015 "The volatility of China's foreign exchange market increased around the time of the epidemic in early 2020 (Fang Yi, 2021), and exchange rate fluctuations had a significant impact on real estate market prices. .

3. Impulse response of banking system stress to bond market stress

From Figure 4 (row 1, column 1), it can be seen that the impact effect of bond market stress on banking system stress is negative, with a significant time-varying feature in the early 3 periods, and an overall increasing trend except for a shock in

2016. The link between the banking system and the bond market is that Chinese bonds (mainly treasury bonds) are mainly held by commercial banks, and the central bank changes the money market benchmark interest rate through monetary policy which in turn affects treasury bond rates as well as other bond rates; banks will use the interbank market to make credit assets into bonds and derivatives financial products, and also package high-risk products such as options futures into ordinary fixed-income products. The impact of the development of bank credit business on the development of the bond market is shown as the crowding out effect (Ye, Fang, 2020), so the bond market pressure on the banking system pressure gradually increases; the reason for the shock in 2016 is that the formation mechanism of the market-based benchmark interest rate system in 2015 has not been perfected, and it is difficult for the information display function of different bond markets to play; the exchange rate changes also inhibit the local currency bond market as a whole and the government local currency The development of the bond market.

4. Impulse response of stock market stress to banking system stress

Figure 4 (row 1, column 3) shows that the overall response of stock market pressure to banking system pressure is positive, which briefly turns negative in 2014, with a significant effect of one period ahead, and the overall response shows an "M" trajectory of rising, then falling, then rising again. Since 2012, the benchmark interest rate of the People's Bank of China (PBOC) has shown a general downward trend. The reason why the response is "first down and then up" is mainly due to the continuous improvement of China's regulatory requirements for the financial market. A large number of risks, commercial banks also suffered a big impact, Internet finance and commercial banks systemic risk is positively correlated. The reasons for this are mainly due to two aspects firstly Internet finance increases bank insolvency risk by directly pushing up bank funding costs and reducing bank profitability and indirectly pushing up bank loan interest rates and increasing credit risk in two ways (Dai, 2014). Secondly Internet finance promotes free competition in the financial market and the marginal profit obtained by banks is reduced increasing the risk.

5. Impulse response of real estate market stress to stock market stress

Figure 4 (row 2, column 3) shows the results of the response of the real estate market to stock market pressure. The real estate market shocks to stock market pressure are initially negative, then turn positive and gradually increase, and then "fall and then rise" in 2015 after a shocking trend. With the expansion of the real estate market and the deepening of the financial market reform in China, the real estate market is more and more closely linked to the stock market. The stock market affects the real estate market mainly due to its wealth effect and substitution effect. The wealth effect of stock market refers to the change of holders' wealth due to the rise and fall of stock prices, which in turn affects consumption and short-term marginal propensity to consume to influence economic development. Also the stock market and the real estate market have the same macroeconomic environment, so the economic cycle has a transmission effect on both markets and the

23

movements in both markets will be the same. The substitution effect refers to the negative relationship between the movements of the two markets due to the profit-seeking nature of capital during the stock market downturn, when market capital seeks high returns while real estate as the main way to preserve and increase value will attract a large amount of capital, leading to a rise in the real estate market and a fall in the stock market. therefore, the substitution effect will cause the movements of the two markets to show a negative relationship. the volatile shock of the stock market during the 2015 stock market crash also spread to the real estate market, after which the government adopted a number of policy regulation tools to attract more capital, which had an increasingly significant regulatory effect on the stock market. Later, with the outbreak of the new crown pneumonia epidemic, the stock market and housing market also suffered a major impact.

6. Impulse response of real estate market stress to banking system stress

Figure 4 (row 2, column 1) shows the results of the response of the real estate market to banking system stress. The response of real estate to banking system shocks is initially positive and then turns negative, decreases and gradually tends to zero in 2016, and the time-varying feature of 1 period ahead is relatively significant. There is interconnectedness between real estate and banking credit risk, concentrated among some companies; the contagiousness of credit risk from banking to real estate is stronger than that from real estate to banking (Liu, Xiangyu, 2018). Banks are the main source of real estate financing. Since the financial crisis, the loose monetary policy of enhancing the liquidity of the banking system has also exacerbated the formation and bursting of the real estate bubble. Also the excessive growth of credit is one of the important reasons for shortening the real estate cycle and accelerating the formation and bursting of the real estate bubble (The 1985-1994 global real estate cycle:Its causes and consequences).The size of shadow banks increased in 2015-2016 compared with the previous year by 88.92%, shadow banks, being less affected by macroeconomic regulation, can readily provide funds to the real estate sector even during tight monetary policies, directly promoting investment in the real estate industry. While traditional commercial banks favor lending to large enterprises or state-owned enterprises, shadow banks favor lending to some high-risk medium and small real estate development enterprises, and can provide funds to the real estate industry at any time even during tight monetary policies because of the low impact of macroeconomic regulation, which directly promotes investment in the real estate industry, thus leading to increased macro-financial risks and inducing financial crises. In addition local government debt also affects the real estate market risk through the land finance transmission path of land mortgage, local governments provide guarantees to obtain loans from commercial banks to increase fiscal capacity (Ma, Shucai, 2020). And the negative response from 2016 began to decrease mainly because real estate loans may have an inverse impact on commercial bank risk, that is, the higher the number of real estate loans, the lower the risk faced by commercial banks (Ma, Li, 2021). Also the state's regulatory policy of counter-real estate cycle camera decision has reduced the correlation between real estate's and banks.

IV. CONCLUSIONS AND POLICY RECOMMENDATIONS

The development of digital finance has increased the business linkages of different markets such as stocks, bonds, foreign exchange, real estate, and banks, which has increased the correlation and complexity of risks among these markets and accelerated the speed of risk transmission. The risk correlation network of the financial system also gradually takes on high-dimensional and time-varying characteristics, making it easier for financial risks to be transmitted and spread within the financial system. Based on this background, this paper sorts out the cross-market transmission of financial stress in different markets at the theoretical level, and analyzes the effects of important points in time on stress transmission in different markets. At the empirical level, we use 25 indicators from different markets to synthesize the financial stress indices of different markets in China, adopt the DAG model with contagion factors, construct the directed acyclic graphs of different markets, and construct the time-varying parametric vector autoregressive model (TVP-SVAR) with stochastic fluctuation terms on this basis to analyze the dynamic changes embedded in it and explore the stress transmission effects among different markets, and draw the following conclusions the following conclusions.

(1) The contemporaneous causal relationships among various submarkets are clear and explicit, and there are transmission paths of financial stress transmission from bond market to banking system to real estate market, from banking system to stock market, from foreign exchange market to real estate market, and from foreign exchange market to stock market to real estate market.

(2) The real estate market and stock market are increasingly hit by other market pressures after the epidemic.

(3) The short-term effect of pressure transmission from foreign exchange market to stock market to real estate market is more obvious, and the long-term effect of pressure transmission from bond market to banking system, and from banking system to real estate market and stock market is more obvious.

(4) Under the dynamic shock of different advance periods, the pressure of foreign exchange market to stock and real estate market pressure gradually weakened from positive effect after a brief rebound but overall negative effect. The positive impact of banking system pressure on stock market pressure shows an "M" shaped trajectory, which briefly decreases to a negative impact; the positive impact of banking system pressure on real estate market pressure gradually decreases to a negative impact and then rises again and tends to zero. The negative impact of bond market pressure on banking system pressure has been increasing. The influence of stock market pressure on real estate market pressure is negative at first and then turns positive with an overall "N" shape trajectory.

(5) Based on the utility of shocks at different points in time, the impact of financial stress transmission is more significant during the implementation of major policies, mainly due to the imperfection of the regulatory system and the need for the market to adapt to the period, and as the policy advances, the impact of stress between markets also gradually weakened.

Based on the above research findings, this paper argues that under the current complex internal and external environment and economic and financial conditions, the following countermeasures should be taken to effectively prevent systemic financial risks and their cross-market contagion.

(1) The real estate and stock markets are more vulnerable to other market stress shocks in the post-epidemic era, and should focus on the real estate and stock markets and other market stress transmission and risk spillovers. We should adhere to the principle of housing without speculation, and continue to precisely regulate the real estate market according to local conditions and city-specific policies. When regulating the market, it is necessary to clarify the driving factors that lead to changes in inter-market relations, make full use of the impact of these factors on inter-market relations, effectively formulate and apply market regulation policies, reasonably respond to external shocks, and maintain the healthy and stable development of both markets.

(2) The marketization of exchange rate, interest rate and securities market will increase the pressure transmission between markets in the short term and weaken the transmission effect in the long term. The breadth and depth of financial markets should be enhanced in the continuous financial reform and innovation, prompting commercial banks to continuously innovate richer financial services, improve the allocation capacity of commercial banks' asset and liability structures, and provide a solid micro foundation for the interest rate marketization reform. Supervision of its own foreign exchange market and short-term liquid capital should be strengthened. Regulators should strengthen the awareness of exchange rate risk management and establish an exchange rate risk management system, while they should pay attention to the risk of monetary policy operations, the risk of excessive exchange rate fluctuations and the risk of capital flows to prevent abnormal fluctuations of RMB exchange rate due to the above risks. Establish a sound risk prevention and control mechanism among markets and gradually realize financial openness.

(3) Increase the monitoring of money market as well as liquidity risks. The central bank routinely adopts full-scale or targeted downgrade operations, which will release a large amount of liquidity, and needs to pay more attention to money market and liquidity risks, and do timely monitoring to avoid risks from being transmitted to other markets through money market, so as to effectively prevent systemic financial risks.

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