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Original Article

A Study of the Inter-Industry Risk Spillover Effect in China's Stock Market

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Abstract:
We examine the inter-industry risk spillovers in China's stock market, exploring the impact of the recently implemented registration system reform. We find (1) the inter-industry spillovers intensify during financial crises; (2) the spillover effect is sector-specific, with the midstream and downstream sectors primarily exporting risks, whereas the upstream and supporting sectors mainly accepting risks; (3) the registration system reform has profound impact on the risk spillovers. Specifically, it reduces the risk spillovers among non-financial industries, but amplifies the finance sector's risk spillovers. Overall, we provide new insights into the risk transmission dynamic in China's stock market.
Keywords: China's stock market; industry risk spillover effects; ΔCoVaR; Quantile regression method; Registration system reform

1. Introduction

China has emerged as the second largest economy in the world. Its financial markets, as a consequence of the rapid development of the economy, have expanded significantly. Meanwhile, financial risks have accumulated alongside the evolvement of the financial markets. It has been documented in the literature that financial risks and risk contagion affect negatively the real economy (IMF, 2009; Adrian and Brunermeier, 2010). It is therefore increasingly important, for the benefit of society as a whole, to measure and manage financial risks and their spillovers across different industries.

The stock market is an important part of the financial market. At present, there are more than 5,000 listed companies in China's stock market, with a market capitalization of more than 12 trillion US dollars, which accounts for more than 65% of China's GDP. In recent years, China's stock market has accumulated risks and experienced abnormal volatility while undergoing rapid development. Under the influence of factors such as over-the-counter funding, the SSE Composite index dropped 3,000 points in about two months. Thousands of stocks' prices plunged by up to 10% every trading day for several consecutive days, and many highly leveraged investors' positions were forcibly liquidated. The excessive fluctuations of the stock market not only impact its healthy development but also have negative consequences for the real economy. Research on the spillover effect of the stock market is of great significance for managing stock market risks and the financial system. To understand the risk contagion characteristics of China's stock market thoroughly it is necessary to delve into the industry level and study the inter-industry spillover effect.

Price fluctuations and risk transmission in the stock market are directly influenced by cash flows, which are the result of investors' buying and selling decisions. Investors make buying and selling decisions based on information such as company fundamentals, economic policies and trading mechanisms, etc. The stock price fluctuations of one industry are transmitted to the other through two primary mechanisms. The first involves fundament information, inter-industry linkages arise through complex supply chain relationships, technological linkages, credit channels, and debt relationships. Such linkages play a key role in information transmission between different industries in the stock market (Cohen et al., 2008; Barrot et al., 2016; Yang Zihui et al., 2020). In practice, the synchronicity of the stock price fluctuations and the interconnectedness between industry entities complement each other: synchronicity enhances the correlation of fluctuations, while correlation strengthens the synchronicity of fluctuations. The second mechanism involves factors such as information transparency, stock liquidity, and investor sentiment etc., which directly influence investors' trading decisions.

In 2019, China launched the STAR market, kicking off the registration-based system reform. The reform introduced several milestone measures and innovations, including changes to listing conditions, trading rules, delisting rules, and refinancing. Additionally, it encouraged the participation of more institutional investors and long-term funds in the stock market. The registration system was extended to the ChiNext market in August 2020, and to the entire stock market in February 2023. These measures fundamentally altered the trading mechanisms of China's stock market, potentially leading to changes in the risk spillover relationships among different industries.

Table 1-1 the primary policies of the registration reform

Areas	**Policies**
Trading	Cancel the price limit for the first five trading days after the initial listing of a new stock. Thereafter, the daily price limit is increased from 10% to 20% on the STAR market and the Chi-Next market. New stocks are also allowed to be included in refinancing target on the first day of listing。 Introduce mechanisms such as temporary intraday trading suspension and effective price declaration range.
Listing	Allow loss-making companies , stocks with different rights, and VIE-structured enterprises to be listed. The number of listed companies grew rapidly, reaching 5107 by the end of 2023, an increase of 42% compared to 2018.
Delisting	Optimize delisting criteria, introducing composite financial indicators and trading indicators as delisting triggers. Simplify delisting procedures and improve efficiency.
Investor	The number and investment amount of institutional investors grew rapidly. By 2023, equity investment reached 9.4 trillion USD, a 30% increase compared to 2018.

We adopt the quantile regression method to calculate CoVaR and ΔCoVaR from the perspective of inter-industry spillovers to address the following questions: (1) Does the inter-industry risk spillover effect exist in China's stock market, and what are its characteristics? (2) What is the impact of the registration system reform on the inter-industry risk spillover effect in China's stock market?

Regarding the first question, the various industries of the national economy can be divided into upstream, midstream, downstream and supportive sectors. Midstream and downstream industries represent the demand side for upstream sectors and the supply side for end consumers, making them more likely to transmit risks to other sectors through the supply chain. Upstream industries primarily spread risks directly to downstream sectors, but their channels are more limited compared to midstream and downstream industries. Supporting sectors play a facilitating role and lack the ability to transmit significant risks to other sectors. Therefore, we hypothesize that midstream and downstream industries are more likely to export risks than the other two types of industries.

Regarding the second question, the core feature of the registration system its emphasis on information disclosure. Issuers are required to disclose information, especially innovative information, truthfully, accurately and completely, improving the quality of information disclosure. China's registration system reform mandates that companies strengthen the disclosure of innovative information, better revealing industry characteristics and providing investors with a stronger valuation basis for peer companies. This reform increases the information content of peer companies' stock prices. On the other hand, competitive pressure drives other companies within the same industry to provide more comprehensive information, thereby improving the market environment. Furthermore, the registration system reform focuses on the rule of law, the development of institutional investors, and value-based investing. These measures help suppress market panic and enable stock prices to reflect company value more accurately. Small and medium investors, armed with better-disclosed information, become more confident and exhibit reduced irrational trading behavior, resulting in lower stock price volatility. Consequently, we expect the registration system reform to improve the decision-making environment for investors, enhance information availability, and increase the proportion of institutional investors, thereby reducing risk spillovers in the stock market.

This paper may contribute to the existing literature in the following aspects: (1) It explores the risk transmission path and direction of inter-industry risk spillover effects in China's stock market, providing evidence to clarify the characteristics of inter-industry risk spillovers. (2) It examines the impact of the registration system reform on the inter-industry risk spillover effect in China's stock market, providing new insights into the factors influencing risk spillovers.

The subsequent structure of the article is arranged as follows. The second part is the literature review. The third part outlines the research methodology, sample, and data. The fourth part analyzes and measures the inter-industry risk spillover effect. The fifth part evaluates the impact of the registration reform. The sixth part presents the conclusions, implications, and further research plans.

2. Literature Review

2.1 Risk Spillover Effect between Different Markets and Industries

Over the years, many scholars at home and abroad have studied the risk spillover effect among financial markets in different countries, regions and types of financial markets. Qian et al. (2023) demonstrate that the stock market returns of the US, France and Japan Granger-cause China's stock returns. These results align with the correlated-fundamental theory (Bekaert G. 2014) the flight-to-liquidity or flight-to-safety theory (Cho J. 2016; Sarwar. 2017) and the wake-up call hypothesis (Longstaff F. 2010; Ahnert T.2022). Ahrend et al. (2022) find that financial markets in highly integrated countries are more susceptible to external influences. Zhao et al. (2022) find that Chinese banking has two-way risk contagion with banks in East Asia and Association of Southeast Asian Nations, South Asia, West Asia, and Central Asia. Xie et al. (2023) identify stock, fund, and futures markets as major risk transmitters, while bonds, gold, and shipping serve as safe havens. However, some studies argue against spillover effects. For instance, Li (2007) states that there is no evidence of financial contagion between the stock markets of China and the United States.

In terms of inter-industry risk spillovers, Chiu et al. (2015) use the conditional transcendental approach to measure the spillover effect of industry tail risks. Shahzad et al. (2017) find that risk interdependence is highest for the basic materials industry and lowest for the utilities industry, with spillovers peaking during the 2007–2008 financial crisis. Li et al. (2021) observe that the structure of inter-industry risk spillover networks changed significantly before and after the COVID-19 epidemic. Zhang et al. (2020) find that systemic risk and inter-industry risk spillover effects increase during market crash. Similarly, Lin et al. (2023) find that the COVID-19 epidemic caused cyclical risk feedback between industries, exacerbating economic downturns.

2.2 The Attributes of Risk Spillover Effect

Sholars find that risk spillovers are time-varying and asymmetric. Bhattacharya et al. (2020) identify that spillovers between different stock markets are more significant during financial crises. Li et al. (2021) find that the financial market risk spillover index is time-varying, volatile, uncertain, and significantly strengthened during key domestic and international policy announcements or risk events. Yang et al. (2024) find that COVID-19 had a substantial negative impact on various economic sectors in China. Seo-Yeon Lim et al. (2024) report that credit risk interconnectedness among Asian banks surged during the global financial crisis (GFC). European manufacturing sectors displayed high connectedness during both the GFC and the COVID-19 pandemic. In North American, bank risk surged notably following the collapse of Silicon Valley Banks (SVB) in March 2023. Additionally, the electricity and manufacturing sectors in Europe exhibited heightened CDS connectedness during the Russia-Ukraine war. Cui et al. (2024) analyze higher-order moment risk spillovers among oil, natural gas, gold, and the stock markets in Palestine and Israel, and find that the outbreak of the Israeli–Palestinian conflict has greatly intensified the total spillovers of volatility as well as higher-order moment risks. Dong et al. (2024) find that risk spillovers exhibit distinct time-varying characteristics, with extreme weather, climate policy uncertainty, and trade policy uncertainty exacerbating market risk spillovers. Su's (2017) study shows that that the spillover effect between stock markets is weaker from smaller to larger markets, suggesting a unidirectional contagion. Xu et al. (2018) find that risk contagion is U.S.-centric and asymmetrical, with Japan's stock market having a stronger left-tail spillover effect on China's market compared to the U.S. market. Cai et al. (2017) find that China is primarily a recipient of shocks from countries like the United States, Germany, and France. Luo et al. (2021) find that the risk export of the US financial market to other markets, except the UK under the original and medium-frequency component, is higher than that it receives. Yao et al. (2024) find that multiscale extreme risk spillovers significantly exist among four stock markets (shanghai, Shenzhen, Hongkong and London) with dynamic and asymmetric characteristics.

2.3 The Research Method of Spillover Effect

In terms of research methodology, most studies utilize time series analysis. The first is the volatility method, which traces back to Engle's ARCH model and its extensions, such as GARCH and DCC-GARCH models (Engle et al. 2002). The multivariate GARCH family model is widely applied to measure both return and volatility spillovers in financial markets, and to explore the mechanism of risk spillover effect. However, these models are not well-suited for multivariate systems due to the "curse of dimensionality". Engle et al. also propose the conditional autoregressive quantile (CAViaR) model to estimate time-varying VaR (Engle et al. 2004). Zhou et al. (2020) use industry return spillovers to measure industry risk in China's stock market and apply the GARCH-M model to analyze the relationships between macroeconomic variables and stock market industry risks. The second approach is the quantile regression method, which does not require specifying the data-generating process. However, the lack of distributional assumptions can lead to instability in statistical inferences at the data's sparse tails. Aadrian et al. (2010) pioneered the application of quantile regression to estimate the CoVaR model, laying the foundation for subsequent research on CoVaR. The third approach involves extreme value theory (EVT) risk measures. Common EVT methods include the peaks-over-threshold (POT) and the block maxima model (BMM), which focus on the tail distributions of the data series. However, studies extending EVT methods to dynamic analyses remain limited. In recent years, domestic literature has increasing drawn on Diebold and Yilmaz's approach, which employs generalized vector autoregressive (VAR) models to construct spillover indices through the variance decomposition of prediction errors. This method has been expanded by incorporating network topology to provide deeper insights into interconnected risk (Diebold,F. X. et al. 2012, 2014; Gong xiaoli et al. 2020; Huang et al. 2023; Sitara Karim et al. 2024).

2.4 The Research of Registration System Reform

Following the implementation of the registration system reform in China's stock market, scholars have studied its impacts. Most studies focus on the pricing efficiency under the registration reform. Liao (2023) finds that the premarket underpricing is lower under the registration system than under the approval system. Deng et al. (2024) find that the registration regime governing the STAR IPOs offers the most efficient pricing. Pan et al. (2023) find that the registration system reform improves the efficiency of Chinese IPO pricing. Wang et al. (2025) extend the research to the pricing efficiency in the secondary market and show that the reform also reduces stock mispricing in the secondary market. As for the reason, scholars argue that the registration system reform enhances information disclosure (Hu et al. 2023; Deng et al. 2024), mitigates agency problems and reduces investor sentiment (Wang et al. 2025), curbs speculation in the post-IPO period (Tang et al. 2024), and develops mutual funds (Sun et al. 2022). What's more, studies also show that the reform alleviates the government's preference for state-owned firms in IPO approval (Wu et al., 2024), reduces the cost of equity capital (Li et al. 2024), and has spillover effect towards non-registration listed firms, such as improving the information disclosure quality or increasing stock valuations of (Wang et al., 2023; Qin and Xiao, 2023). However, there are also studies show the opposite. Li et al. (2022) find that the reform may amplify the aggressive speculation on the newly listed stocks. Ye et al. (2024) find that the reform motivates firms to manipulate growth pre-IPO to meet new listing requirements.

To summarize, most studies conclude that, with the intensifying of global economic integration, risk spillover effect is prevalent not only between different financial markets within a country, but also in different countries or regions. The risk spillover effect is characterized by time-varying and asymmetric. However, there exist directions for further research:

First, the existing literatures on inter-industry risk spillovers mainly focus on the time-varying characteristic, few studies exploring the risk transmission path and direction of inter-industry risk spillover effect. An in-depth analysis of inter-industry risk spillovers of China's stock market can help identify the structural characteristics and propose more targeted risk management methods.

Second, the existing studies adopt event study method to explore influencing factors of the time-varying of spillover effect, they mainly focus on special periods such as the financial crisis, and sudden special events such as the COVID-19 epidemic. Some literatures explore the impact of policy mechanisms such as the Shanghai-Hongkong Stock Connect. The registration system reform has optimized the fundamental mechanisms of the China's capital market. Research about the impact of the registration system reform on the inter-industry risk spillover effect of China's stock market is still relatively scarce.

Third, most studies conclude that the registration system reform has improved information disclosure, pricing efficiency, and market stability. However, its impact on risk spillovers, especially at the inter-industry level, remains relatively underexplored. This study aims to address these gaps by investigating the effects of the reform on inter-industry risk spillovers in China's stock market.

3. Research Methodology, Sample and Data

3.1 Measurement of Spillover Effect

Adrian and Brunnermeier firstly proposed the CoVaR model, which measures the interplay of tail risk among interconnected financial institutions or assets, and in addition. Furthermore, they use ΔCoVaR to measure the extent of spillovers between two assets.

Given the return of a financial asset j, denoted as X_j, the CoVaR of the financial asset i at the quantile level q∈(0,1) and the moment t is denoted as $\mathrm{CoVaR}_{i|j,t,q} \mid \mathrm{VaR}_{j,t}$, which means under the condition that at-risk value of financial asset j is $\mathrm{VaR}_{j,t}$, The at-risk value of the financial asset i, i.e., its CoVaR can be defined as:

$$P\{X_{i,t} \leq \mathrm{CoVaR}_{i|j,t,q} \mid \mathrm{VaR}_{j,t}\} = q \qquad (1)$$

The risk spillover effect of asset j to asset i at moment t, i.e. $\Delta CoVaR_{q,t}^{i}$ is defined as:

$$\Delta CoVaR_{q,t}^{i} = CoVaR_{q,t}^{i|VaR_q^j} - CoVaR_{0.5,t}^{i|VaR_{0.5}^j} \qquad (2)$$

When q=0.5, it denotes the value at risk of financial asset j in an intermediate state.

The calculation methods of CoVaR mainly include three ways, the quantile regression method, the Copula function method and the DCC-GARCH model method. The Copula method is limited in depicting nonlinear time-varying risk relationships. The DCC-GARCH model is better suited for global risk but lacks detail on tail risk dynamics. As financial risks are often caused by tail events, this study employs the quantile regression method to calculate VaR and the ΔCoVaR (Gaglianone W P. et al. 2011; Rejeb A. B. et al. 2015). To address model instability and sparse tail data, robustness tests using different quantiles and alternative methods (e.g., DCC-GARCH) are conducted.

To study the risk spillover relationship between two financial assets, the first step is to establish the relationship between the returns (or losses) of the two financial assets, defining the two assets as i and j, in the case where the loss of asset j is X^j:

$$\hat{X}_q^{i|X^j} = \hat{\alpha}_q^j + \hat{\beta}_q^j X^j \quad (3)$$

Where $\hat{X}_q^{i|X^j}$ denotes q-quantile loss estimate of asset i under the condition that the q-quantile loss estimate for asset j at a certain confidence level is X^j.According to the definition of VaR, it can be derived:

$$CoVaR_q^{i|X^j} = \hat{X}_q^{i|X^j} \quad (4)$$

That is, the predicted value of asset i's loss under the condition of asset j's loss X^j, is the VaR of asset i's under the condition of X^j, i.e. the conditional value-at-risk CoVaR. The mathematical expression is:

$$CoVaR_q^{i|j} = VaR_q^{i|X^j = VaR_q^j} = \hat{\alpha}_q^j + \hat{\beta}_q^j VaR_q^j \quad (5)$$

According to equation (2), the risk premium of asset j over asset i can be derived as follows:

$$\Delta CoVaR_{q,t}^{i|j} = CoVaR_{q,t}^i - CoVaR_{0.5,t}^i$$
$$= \hat{\beta}_q^j \left(VaR_q^j - VaR_{0.5}^j\right) \quad (6)$$

3.2 Sample and Data

3.2.1 Sample and Data

This study uses the daily closing price of the CSI Broad Market industry Index from January 1, 2005 to August 31, 2023. Daily logarithmic returns are calculated as ($\ln(P_t / P_{t-1})$), resulting in 4,535 observations for each industry. The are computed the CoVaR and $\Delta CoVaR$ values are computed for all 11 first-level industry indices, which are published by China Securities Index Co. Ltd. These indices reflect the overall performance of companies in different industries in China's stock market. The index system began on December 31, 2004, with a base value of 1,000.

China's stock market registration system reform began in July 2019 with the launch of the STAR market. It was extended to the ChiNext market in August 2020 further expanded to the entire stock market in February 2023. To assess the reform's impact, we define the following periods: (1) Pre-registration reform period as August 2, 2016, to March 29, 2019. The last day is three months before the listing of the first STAR Market companies, allowing us to exclude the reform's influence entirely. (2) Post-registration reform period as January 1, 2021, to August 31, 2023, with a total of 647 return data. This period avoids the COVID-19 epidemic's immediate effects, which many scholars have shown to be relatively short-lived. For instance, Yang et al. (2024) find that the impact of the COVID-19 epidemic on China's financial market is relatively short. Shen et al. (2023) identify the impact period as January 20, 2020 to July 30, 2020. Tian et al. (2024) set the impact period from December 8, 2019 to November 30, 2020. As a robustness test, we further divide the post-registration reform period into a specific interval from January 1, 2023, to Sep 30, 2024, reflecting the loosening of China's COVID-19 lockdown policies.

3.2.2 Descriptive Statistics Results

Table 3-1 provides descriptive statistics for the daily returns of the 11 industry indices, with 4,535 observations each. The minimum and average values of the returns are relatively close to each other, the minimum values are all approximately -0.1, while average values range between 0.0001 and 0.001. The maximum values of all returns range from 0.084 to 0.096. Only finance sector has a negative median return. The 5% quartile of returns for four industries, i.e. finance, optional consumption, primary consumption, and public utility, are higher than -0.03. In terms of skewness and kurtosis, the skewness of all industry returns is less than 0 and the kurtosis is greater than 3, indicating that the distribution of all returns is characterized by sharp peaks and fat tails.

Table 3-1 Descriptive Statistics of Daily Returns of Different Industry Indices

	observations	**means**	**medians**	**S.D.**	**5%quantile**	**Min**	**max**	**Skewness**	**kurtosis**
Material	4535	0.0003	0.0015	0.0191	-0.0324	-0.0959	0.0861	-0.6641	5.9934
Real estate	4535	0.0003	0.0005	0.0206	-0.0332	-0.1005	0.0948	-0.4217	5.7410
Industry	4535	0.0003	0.0012	0.0181	-0.0303	-0.0962	0.0951	-0.7031	6.6903
Finance	4535	0.0004	-0.0001	0.0185	-0.0278	-0.1017	0.0954	-0.0568	6.7360
Optional Consumption	4535	0.0003	0.0012	0.0179	-0.0296	-0.0970	0.0933	-0.7186	6.5412
Energy	4535	0.0002	0.0005	0.0197	-0.0320	-0.0966	0.0924	-0.3057	5.8209
Communication	4535	0.0004	0.0014	0.0205	-0.0333	-0.1003	0.0947	-0.4823	5.6970
Primary Consumption	4535	0.0006	0.0009	0.0174	-0.0277	-0.0966	0.0897	-0.4714	6.0234
Information Technology	4535	0.0004	0.0015	0.0212	-0.0351	-0.0992	0.0951	-0.6065	5.2185
Medicine&Health	4535	0.0005	0.0011	0.0181	-0.0302	-0.0934	0.0908	-0.5364	5.8206
Public Utility	4535	0.0002	0.0007	0.0166	-0.0269	-0.0995	0.0839	-0.7100	7.5649

4. Measurement and Analysis of the Inter-Industry Risk Spillover Effect[1]

4.1 Results of Quantile Regression on a Rolling Basis

We adopt quantile regression with rolling windows to capture the time-varying characteristic of risk spillover effect. Scholars have used rolling window widths arbitrarily, or based on empirically choices or time cutoffs such as yearly, quarterly, monthly. However, there is no unified and clear guideline. Nyakabawo et al. (2015) argue that the selection should balance 'model estimation accuracy and representativeness over the subsample periods" but do not establish a statistical criterion for the optimal window width. Pesaran et al. (2005) demonstrate demonstrate that smaller subsample sizes reduce the risk of including multiple models but increase the standard error of parameter estimates. In this study, we use a window width of 200 and a step size of 30. Robustness tests are conducted by adjusting the width, step size, and quantile levels respectively.

4.1.1 Risk Spillover Mean Matrix and Net Risk Spillover Matrix

According to formula (6), the Δ CoVaR values are negative, and the larger the absolute value, the higher the degree of risk spillover from one industry to another. Calculating the average risk spillover values each industry accepts from and exports to the other 10 industries respectively, we get a matrix of average ΔCoVaR values, as shown in Table 4-3. In this matrix, each row is the mean values of risk spillover from the other 10 industries. The value in each cell indicates that the column name's corresponding industry's risk spillovers on the row name's corresponding industry, for example, the real estate sector's risk spillover mean value on the material sector is -0.0241. The last second column is the total risk spillovers from the other 10 industries of the row name's corresponding industry, for example, the material sector accepts the other 10 industries' risk spillovers with a total of -0.2692. The last row is the sum of spillovers to the other 10 industries of the column name's corresponding

[1] stata16.0 is used to calculate the spillover effect.

industry, for example, the sum of the risk spillovers of the material sector to the other 10 industries is -0.2827. The last column is the net spillovers of each industry to the other 10 industries, for example, the net risk premium of the material sector to the other 10 industries is -0.0135 (-0.2827 minus -0.2692). Negative value indicates a net risk exporter to the other 10 industries, and positive value indicates a net risk acceptor. Therefore, six industries (material, industry, primary consumption, optional consumption, medicine & health, public utility) net exports risk to other industries, and the remaining five industries net accept risk from the other industries.

Subtracting the risk spillover values of the two industries to each other in Table 4-1 yields the net risk spillover matrix, which is a 10×10 lower triangular matrix, as shown in Table 4-2. Each cell represents the net value of the risk spillovers of the column name's corresponding industry on the row name's corresponding industry. Negative values mean net risk exporter and positive values mean net receiver. The table reflects the interaction of risk spillovers between two different industries. In term of the material, it net exports to six industries: real estate, finance, energy, communications, information technology, and public utility, and net accepts risk from four industries: industry, optional consumption, primary consumption, and medicine & health.

Table 4-1 Risk Spillover Mean Matrix

Table 4-1 Risk Spillover Mean Matrix

Sectors/ΔCoVaR	Material	Real Estate	Industry	Finance	Optional Consumption	Energy	Communication	Primary Consumption	Information technology	Medicine & Health	Public Utility	Acceptance	Net export
Material		-0.0241	-0.0323	-0.0199	-0.0312	-0.0268	-0.0264	-0.0259	-0.0295	-0.0268	-0.0265	-0.2692	-0.0135
Real Estate	-0.0285		-0.0294	-0.0232	-0.0299	-0.0243	-0.0237	-0.0251	-0.0263	-0.0243	-0.0252	-0.2599	0.0358
Industry	-0.0302	-0.0234		-0.0195	-0.0308	-0.0238	-0.0264	-0.0259	-0.0300	-0.0275	-0.0259	-0.2632	-0.0189
Finance	-0.0241	-0.0219	-0.0246		-0.0241	-0.0212	-0.0196	-0.0202	-0.0215	-0.0189	-0.0213	-0.2174	0.0157
Optional Consumption	-0.0285	-0.0233	-0.0192	-0.0298		-0.0221	-0.0255	-0.0263	-0.0294	-0.0272	-0.0244	-0.2557	-0.0359
Energy	-0.0322	-0.0226	-0.0298	-0.0205	-0.0276		-0.0236	-0.0227	-0.0247	-0.0220	-0.0252	-0.2510	0.0255
Communication	-0.0305	-0.0240	-0.0321	-0.0194	-0.0322	-0.0237		-0.0261	-0.0350	-0.0284	-0.0260	-0.2772	0.0308
Primary Consumption	-0.02	-0.01	-0.02	-0.01	-0.02	-0.01	-0.02		-0.025	-0.02	-0.02	-0.22	-0.01

	50	96	61	64	69	92	22		6	58	16	86	91
Information Technology	-0.0317	-0.0244	-0.0336	-0.0196	-0.0346	-0.0240	-0.0332	-0.0285		-0.0313	-0.0268	-0.2877	0.0129
Medicine & Health	-0.0254	-0.0204	-0.0276	-0.0160	-0.0286	-0.0186	-0.0239	-0.0257	-0.0284		-0.0219	-0.2365	-0.0179
Public Utility	-0.0267	-0.0206	-0.0273	-0.0173	-0.0257	-0.0220	-0.0219	-0.0214	-0.0244	-0.0223		-0.2296	-0.0152
Export	-0.2827	-0.2242	-0.2821	-0.2017	-0.2916	-0.2255	-0.2464	-0.2477	-0.2747	-0.2545	-0.2448		

Table 4-2 Net Risk Spillover Matrix

Sectors	Material	Real Estate	Industry	Finance	Optional Consumption	Energy	Communication	Primary Consumption	Information technology	Medicine & Health
Real Estate	-0.0044									
Industry	0.0021	0.0060								
Finance	-0.0042	0.0013	-0.0051							
Optional Consumption	0.0027	0.0066	0.0116	-0.0057						
Energy	-0.0054	0.0017	-0.0060	0.0007	-0.0055					
Communication	-0.0041	-0.0003	-0.0057	0.0002	-0.0067	-0.0001				
Primary Consumption	0.0009	0.0055	-0.0002	0.0051	-0.0006	0.0035	0.0039			
Information Technology	-0.0022	0.0019	-0.0036	0.0019	-0.0052	0.0007	0.0018	-0.0029		
Medicine & Health	0.0014	0.0039	-0.0001	0.0029	-0.0014	0.0034	0.0045	0.0001	0.0029	
Public Utility	-0.0002	0.0046	-0.0014	0.0040	-0.0013	0.0032	0.0041	0.0002	0.0024	-0.0004

4.1.2 Net risk exports

Following the methodology described in Part 3, we get the ΔCoVaR values of each industry to the other 10 industries, with a total of 110(11×10) sets of ΔCoVaR values. Calculating the sum of the ΔCoVaR values of each industry to the other 10 industries and subtracting the sum of the ΔCoVaR values from the other 10 industries, we get the net ΔCoVaR values of each industry, and a line graph is plotted accordingly, which is shown in Figure 4-1.

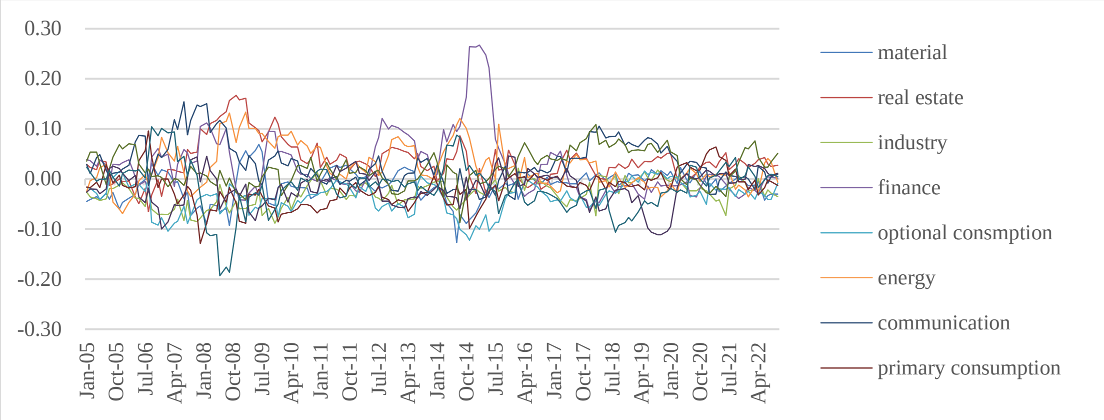

Figure 4-1 Net risk export by industry

By analyzing the line graphs of the net risk exports of the 11 industries and the risk spillover matrixes, we find that the inter-industry spillover effects of China's stock market show the following attributes:

（1） Time-variation

The net risk spillovers of 11 industries fluctuate within the test period. Overall, the fluctuation ranges are consistent with the results of the risk spillover matrix, material, industry, primary consumption, optional consumption, medicine & health, public utility sectors' net spillover values are mainly negative, indicating net export risks in a long period. Communication, finance, real estate, information technology, energy sectors' net spillover values are mainly positive, indicating net accept risks in a long period.

However, during 2007 to 2009, and 2014 to 2015, most industries' net spillovers amplify. Special financial events emerged in these two periods, the financial crisis triggered by the subprime mortgage crisis was spreading globally in 2007 to 2009, and China's stock market experienced significant abnormal fluctuations in 2014 to 2015, during which the SSE Composite index dropped approximately 40% in about two months. Under abnormal events such as financial crises, different industries face common impacts, and investors are generally pessimistic, investors make the same buying and selling decisions, leading to synchronous fluctuations in stock indices and risk spillovers between different industries.

Firstly, net risk exporting industries mainly experienced an increase in the degree of net risk spillover except medicine & health sector. The net ΔCoVaR value of material sector was lower than other intervals, with a minimum value close to -0.1 and the degree of risk spillover reaching its peak, after which the degree of net risk spillover began to ease at around June 2008. The net ΔCoVaR value of industry sector reached its lowest point of -0.08 in 2007, and the degree of risk spillover has since weakened, but the value was around -0.05 in most time intervals. The degree of net risk spillover of primary consumption reached its maximum in December 2007, with a net ΔCoVaR value of approximately -0.13. The degree of net risk spillover of optional consumption reached its maximum in June 2008, with a net ΔCoVaR value of about -0.07. However, in 2007, the risk spillover degree was even higher, with a minimum ΔCoVaR value of about -0.1. The degree of net risk spillover of public utility during this time interval is significantly higher than other times, which began to increase from December 2007 and reached its peak around September 2008, at approximately -0.19. Except for information technology, net risk-accepting sectors' degree of risk acceptance amplified. Communication had the highest net risk acceptance level around June 2008, at around 0.15, and since then declined slightly. The net risk acceptance of the finance sector remains relatively high, ranging from 0.04 to 0.07. Energy and real estate performed similarly, with a continuous increase in risk acceptance level. Energy reached its highest value of 0.1 around August 2008, while real estate reached its highest value of 0.16 around February 2009.

Secondly, during 2014 and 2015, the risk volatility of most industries was consistent with that of 2005 to 2006, finance sector's risk accepting level increased sharply and peaked during January 2015 to April 2015 with net

ΔCoVaR of about 0.27. However, some sectors showed differences. Medicine & health net accepted risk during 2005 to 2006, but net exported risk during 2014 to 2015, the degree of exporting was relatively low compared to other time periods. Public utility net accepted risk in some intervals of 2014 to 2015, while communication net exported risk. The reason may be that the cause of the financial crisis differs and led to different risk contagion status of different sectors. The subprime crisis was caused by the deterioration of overseas real economy and transmitted to China's real economy sector thereafter. Due to its relevance to the basic needs of residents, the fundamentals of medicine & health have been relatively less affected compared to other industries, resulting in net risk-accepting during 2005 to 2006. The abnormal fluctuations of China's stock market during 2014 to 2015 were mainly due to the deleveraging regulatory policies the authorities, which led to a rapid decrease in incremental funds in the stock market, resulting in a reversal of cashflow and sharp decline of the stock index. Therefore the reason was mainly the irrational trading of investors and there was no significant change in the fundamentals of the real economy. Public utility and communication sectors' risk contagion status may be caused by the irrational buying and selling of investors.

Thirdly, some industries may experience a reversal of risk spillover, with the most significant being information technology, which was in a state of net risk acceptance in most of the period but transitioned to a state of net risk export during 2005 to 2006 and 2014 to 2015. As a supporting industry, information technology is connected to all the other sectors, and its impact was transferred to other sectors during the outbreak and continuation of financial crises and other events. Finance was mainly in a state of net risk acceptance before June 2017 and has since transitioned to a net risk export state, but the degree of risk exporting is relatively weak. This indicates that after June 2017, the risk hedging role of the finance sector in China's stock market has weakened and should be given attention. Finance is intermediary between capital and real economy, when real economy lacks money, finance sector provides capital to support the operation of real economy and plays a counter-cycle role to alleviate the risks of real economy, therefore it net accepts risks from other sectors. However, due to the more and more complexity of the finance sector's product and the loose control of gears, finance sector may also amplify the risks when encountering crisis such as lack of liquidity, this may finally lead to the collapse of real economy by setting off a chain reaction.

In addition, we also analyze the impact of the COVID-19 epidemic on risk spillovers and the impact differentiates by industries. The net risk exporting degree of industry and optional consumption sectors rapidly expanded since the beginning of 2020, industry sector's risk exporting reached its maximum with a ΔCoVaR value of -0.07 in June 2021, and optional consumption peaked with a ΔCoVaR value of -0.05 in December 2020. The net risk exporting degree of medical & health gradually decreased from -0.1 in January 2020. The net risk acceptance of communication, information technology, and real estate also decreased, reaching its lowest point between April and June 2020. There showed no significant change in the risk spillover situation of other industries. From the above situation, the impact of the COVID-19 epidemic on inter-industry risk spillovers is relatively short, which is consistent with the analysis in section 3.3.1.

(2) Heterogeneity

Different industries' overall statuses of risk spillovers are heterogeneous. The industries with negative net risk spillover values are material, industry, primary consumption, optional consumption, medicine and health, and public utility, indicating that these six industries are net risk exporter. Optional consumption sector has the smallest net risk spillover value of -0.0359, meaning it has the highest ability to export risk. Following the primary consumption sector, with a net risk spillover value of -0.0191. The material sector has the lowest net risk spillover, with a net risk spillover of -0.0135. Industries with positive net risk spillover values are the real estate, finance, energy, communication, and information technology, which are in net risk-accepting position, absorbing the risk spillovers from other sectors. The real estate sector has the highest ability to absorb risks, with a net risk spillover value of 0.0358, followed by the communication sector, with a net risk spillover value of 0.0308. The finance sector has the lowest net risk spillover value of 0.0157. The findings are consistent with our hypothesis. The inter-industry risk spillover has a structural characteristic of "risk-exporting industry"-"risk accepting industry", the risk-exporting industries are mainly in the middle(material, industry) and downstream (primary consumption, optional consumption, medicine & health, public utility) of the industry chain, and the risk-accepting industries are mainly upstream(energy) and supporting sectors（finance, information technology, communication, real estate）.

(3) Asymmetry

Risk spillovers between different industries are asymmetric. Each two industry can be categorized into risk exporter and receiver, as shown in Table 4-2. Take the material and real estate sector as example, the real estate sector's risk spillover on the material sector is -0.0241, and the opposite is -0.0285, the material sector's risk spillover on the real estate sector is higher, thus the material sector is in net risk export position, and the net risk spillover value is -0.0044. The higher the overall net risk spillover value of an industry, the higher the risk spillovers of that industry to all other industries. For example, the optional consumption sector and industry sector both net risk export risk to other nine industries. This is consistent with the overall risk spillover situation mentioned earlier. The industries with higher net risk spillover value are mainly midstream and downstream of the industry chain, which spread risk upwards or downwards, while the industries with less net risk spillover are mainly supportive industries, which mainly play a supporting role in the production and operation process of other industries and accept risks.

4.2 Robustness Tests

We conducted the following robustness tests: (1) adjust the window width to 300 and 100 separately, with the step size remaining unchanged at 30;(2) adjust the step size to 20 with the window width remaining unchanged at 200. (3) adjust the quantile to 10% and 20% with the step size and the window width remaining unchanged. (4) calculate the spillover value using DCC-GARCH model. We display the results of window width of 300, step size of 30, window width of 300, step size of 30 at quantile 20%, and DCC-GARCH model, as shown in Figure 4-2 to 4-4. The results of the remaining robustness tests are in the appendix.

Overall, the results of the robustness test are consistent with those in part 4.1. The six net risk-exporting industries export risk over most period and the five net risk-accepting industries accept risk over most period. In terms of time-varying, the net risk spillovers of the 11 industries fluctuate over the observed time intervals and show relatively large fluctuations over the time intervals of financial crisis, and the directions are also consistent with the above results except information technology. However, the degree of spillover effect is slighter at quantile 20%, with ΔCoVaR values in the range of -0.1 to 0.1, indicating that the left tail risk is more contagious.

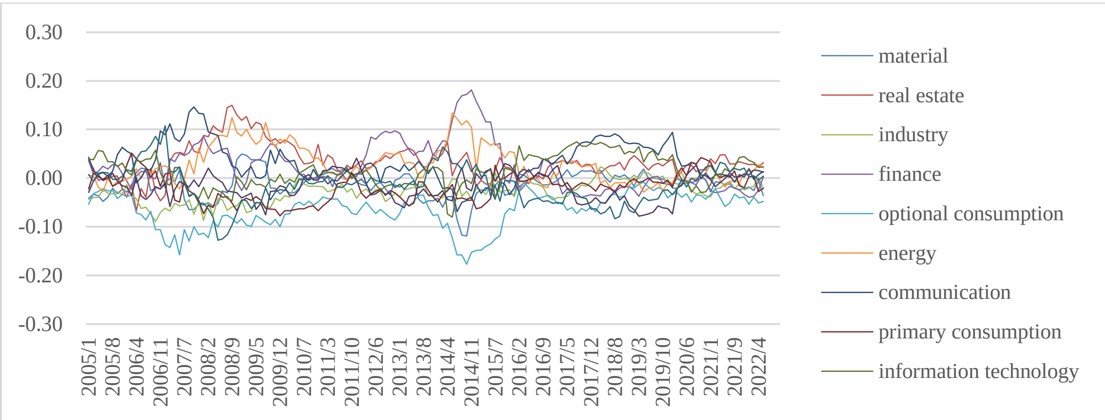

Figure 4-2 Net risk export by industry（window300, stepsize30）

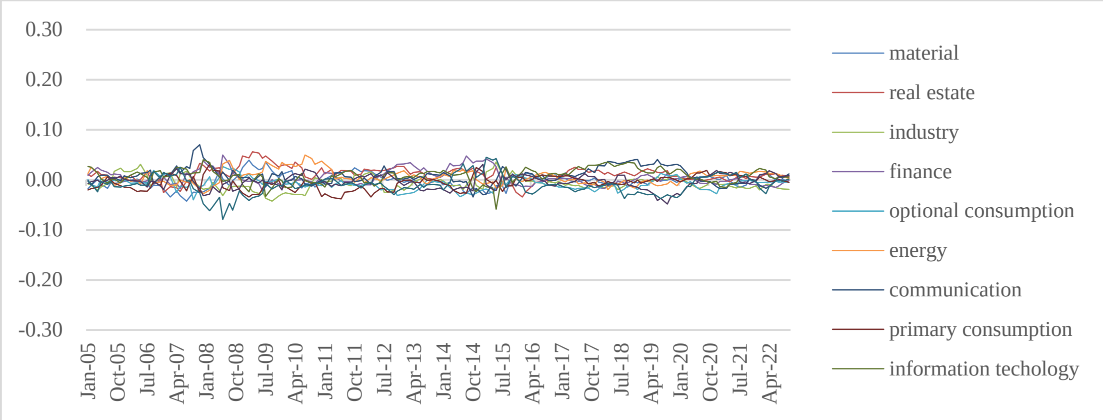

Figure 4-3 Net risk export by industry（window200, stepsize30, quantile 20%）

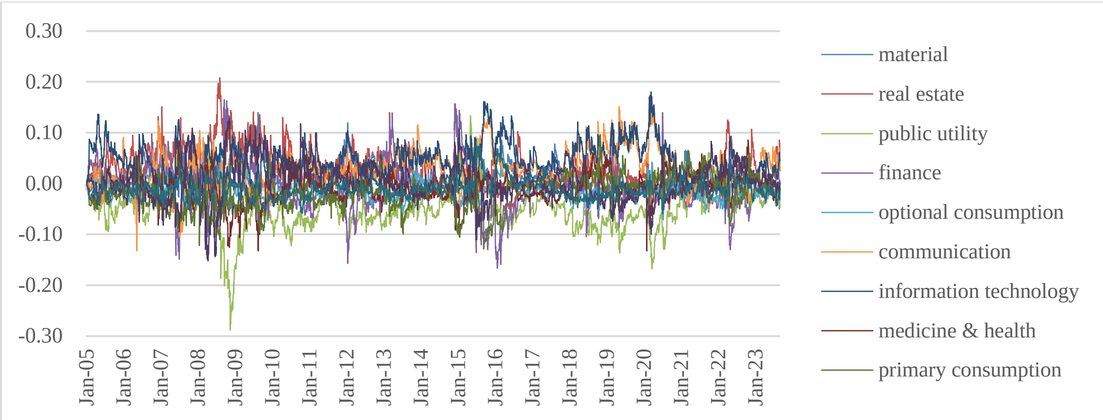

Figure 4-4 Net risk export by industry（DCC-GARCH model）

5. The Impact of the Registration Reform

Taking the number of samples into account, we adopt the quantile regression with a window width of 100 and a step size of 20 to calculate ΔCoVaRs of each industry before and after the registration system reform, respectively. We use t-test to analyze the difference of net risk spillovers of each industry, and risk spillovers of each two industries, as shown in Table 5-1 and Table 5-2. Analyzing Tables 5-1 and 5-2, we find that the overall risk spillovers decline after the registration reform.

Firstly, the degree of risk contagion decreases in most industries after the registration system reform, as evidenced by a decrease in risk export values or risk acceptance values. Three industries, which are primary consumption, medicine & health, and public utility, change from net risk exporter to net risk acceptance. Energy, information technology, and communication sectors' degree of risk acceptance decreases. The industry and optional consumption sector net export risk both before and after the registration reform, but the degree decreases. However, the finance sector and the material sector's risk spillovers increase after the registration system reform, and the finance industry is net risk-exporting in the test interval, which is consistent with the results that the finance sector changed from net risk-acceptance to net risk-exporting after 2018. In addition, there are significant differences in the values of net risk spillover before and after the registration system for six industries, including material, optional consumption, communication, information technology, medicine & health, and public utility, and the degree of risk contagion decreases for all five industries except material.

Secondly, the mean value of the differences of the spillover value of each two industry before and after the registration reform is -0.002, the median value is -0.002, and the total sum is -0.218, which indicates that, in general, the risk spillover values of each two industry decrease after the reform. In terms of changes between two specific industries, the differences are significant for about a half of industries, and the direction is also decreasing.

However, the risk spillovers between the finance sector and other sectors increase after the registration reform, which suggests finance sector's spillover strengthened since 2018 and further increased after the registration system reform. As an important sector which plays a role of countercyclical adjustment in macro economy, this change should draw the attention of the regulators. Measures should be taken to monitor and manage the risk of finance sector, in order to prevent the risk from spreading outward and strengthen the countercyclical adjustment role at the same time.

We also display the results of robustness test in table5-1 and table 5-2, the results are consistent. In terms of net risk spillover values, medicine & health and public utility sectors' spillover values turn to positive, information technology and communication sectors' degree of risk acceptance decreases, but not significantly. Industry and optional consumption sector's net export degree decreases. Finance, material sector's risk spillovers increase after the registration system reform. In terms of differences of the spillover value of each two industry before and after the registration reform, 76% of the differences are significant, and the direction is also decreasing.

Table 5-1 t test results for the differences of net spillover pre and post the reform

	Mean value pre-reform	**Mean value post-reform**	**differences（pre-post）**	**Mean Value Post-reform (Robustness)**	**differences（pre-post）(Robustness)**
Material	0.005	-0.013	0.018**	-0.011	0.016***
Real Estate	0.016	0.018	-0.002	0.039	-0.023
Industry	-0.026	-0.031	0.005	-0.015	-0.011
Finance	-0.007	-0.013	0.006	-0.040	0.033***
Energy	0.006	0.003	0.002	-0.034	0.040***
Optional Consumption	-0.034	-0.025	-0.009*	-0.018	-0.016***
Communication	0.050	0.008	0.042***	0.039	0.011
Primary Consumption	-0.004	0.002	-0.006	-0.003	-0.001
Information Technology	0.060	0.017	0.043***	0.047	0.013
Medicine & Health	-0.017	0.016	-0.033***	0.009	-0.026*
Public Utility	-0.049	0.012	-0.061***	0.002	-0.051***

Table 5-2 t test results for the differences of each two industries' spillover pre and post the reform

	differences（pre-post）	**differences（pre-post）(robustness)**		**differences（pre-post）**	**differences（pre-post）robustness**
real estate to material	-0.004*	-0.006***	**material to real estate**	-0.002	0.000
industry to material	0.003	-0.006***	**material to industry**	0.002*	-0.003*
finance to material	-0.001	-0.002	**material to finance**	0.003*	-0.003*
optional consumption to material	-0.001	-0.005***	**material to optional consumption**	0.000	-0.003**
energy to material	0.002	-0.007***	**material to energy**	0.005***	-0.010***
communication to material	0.000	-0.005***	**material to communication**	-0.004**	-0.003*
primary consumption to material	-0.007***	-0.005***	**material to primary consumption**	0.000	-0.002
information	0.003*	0.000	**material to information**	-0.002	-

technology to material			**technology**		0.004**
Medicine & Health to material	-0.006**	-0.006***	**material to Medicine & Health**	-0.001	-0.002
public utility to material	-0.004**	-0.009***	**material to public utility**	0.002	-0.005***
industry to real estate	-0.006***	-0.002	**real estate to industry**	-0.006***	-0.006***
finance to real estate	0.002	-0.002	**real estate to finance**	0.001	-0.004***
optional consumption to real estate	-0.004**	-0.003	**real estate to optional consumption**	-0.003	-0.005***
energy to real estate	-0.001	-0.009***	**real estate to energy**	0.000	-0.011***
communication to real estate	-0.004**	-0.004**	**real estate to communication**	-0.007***	-0.008***
primary consumption to real estate	-0.002	-0.002	**real estate to primary consumption**	-0.001	-0.003***
information technology to real estate	-0.004**	-0.002	**real estate to information technology**	-0.007***	-0.008***
Medicine & Health to real estate	-0.003	-0.003*	**real estate to Medicine & Health**	-0.003**	-0.005***
public utility to real estate	-0.004**	-0.014***	**real estate to public utility**	-0.002	-0.008***
finance to industry	0.000	0.001	**industry to finance**	-0.002	-0.006***
optional consumption to industry	0.001	-0.003	**industry to optional consumption**	0.001	-0.002
energy to industry	-0.002	-0.007***	**industry to energy**	-0.003	-0.014***
communication to industry	-0.003	-0.006***	**industry to communication**	-0.005**	-0.005***
primary consumption to industry	-0.004*	-0.004***	**industry to primary consumption**	-0.002	-0.005***
information technology to industry	0.002	0.000	**industry to information technology**	-0.004**	-0.003
Medicine & Health to industry	-0.006**	-0.005**	**industry to Medicine & Health**	-0.002	-0.003
public utility to	-0.006***	-0.010***	**industry to public utility**	0.005*	-

industry				*	0.006***
optional consumption to finance	0.001	-0.007***	**finance to optional consumption**	0.001	-0.001
energy to finance	0.002	-0.002	**finance to energy**	0.000	-0.007***
communication to finance	0.003**	-0.004***	**finance to communication**	0.000	-0.001
primary consumption to finance	0.003*	-0.003***	**finance to primary consumption**	0.005***	0.000
information technology to finance	0.004***	-0.003***	**finance to information technology**	0.002	0.003
Medicine & Health to finance	0.001	-0.005***	**finance to Medicine & Health**	0.003	0.002
public utility to finance	-0.003*	-0.007***	**finance to public utility**	0.000	-0.005***
energy to optional consumption	-0.004**	-0.006***	**optional consumption to energy**	-0.004**	-0.011***
communication to optional consumption	-0.001	-0.004***	**optional consumption to communication**	-0.006***	-0.006***
primary consumption to optional consumption	0.000	-0.005***	**optional consumption to primary consumption**	-0.004**	-0.009***
information technology to optional consumption	0.000	-0.001	**optional consumption to information technology**	-0.003	-0.003
Medicine & Health to optional consumption	-0.003*	-0.005***	**optional consumption to Medicine & Health**	-0.001	-0.004**
public utility to optional consumption	-0.007***	-0.010***	**optional consumption to public utility**	-0.003	-0.008***
communication to energy	-0.001	-0.006***	**energy to communication**	-0.007***	-0.009***
primary consumption to energy	-0.006**	-0.011***	**energy to primary consumption**	-0.007***	-0.006***
information technology to energy	-0.005***	-0.008***	**energy to information technology**	-0.008***	-0.006***
Medicine & Health to energy	-0.005**	-0.011***	**energy to Medicine & Health**	-0.003*	-0.003***
public utility to energy	-0.003*	-0.009***	**energy to public utility**	0.007***	-0.003***
primary consumption to communication	-0.003	-0.005***	**communication to primary consumption**	0.000	-0.005***

information technology to communication	-0.001	0.007***	**communication to information technology**	0.000	0.002
Medicine & Health to communication	-0.008***	-0.006**	**communication to Medicine & Health**	0.001	-0.003*
public utility to communication	-0.009***	-0.014***	**communication to public utility**	-0.001	-0.004***
information technology to primary consumption	-0.001	-0.004***	**primary consumption to information technology**	-0.002	-0.004**
Medicine & Health to primary consumption	-0.001	-0.007***	**primary consumption to Medicine & Health**	0.002	-0.005***
public utility to primary consumption	-0.008***	-0.010***	**primary consumption to public utility**	-0.004*	-0.008***
Medicine & Health to information technology	-0.010***	-0.007***	**information technology to Medicine & Health**	0.000	-0.001
public utility to information technology	-0.012***	-0.015***	**information technology to public utility**	-0.001	-0.003***
public utility to Medicine & Health	-0.007***	-0.009***	**Medicine & Health to public utility**	-0.005***	-0.007***

6. Conclusions and Recommendations

6.1 Conclusions

This study investigates the inter-industry risk spillover effect in China's stock market and evaluates the impact of the registration system reform. This study finds that the risk spillover effect is characterized by time-varying, asymmetric and heterogeneous.

(1) The inter-industry risk spillover effect exhibits a "risk-exporting industry" and "risk-accepting industry" structure. The six risk-exporting industries are predominantly midstream and downstream sectors, such as material, industry, primary consumption, and optional consumption. These sectors are demand-side entities for upstream industries and supply-side entities for end consumers, making them more likely to transmit risks. The five risk-accepting industries include upstream and supportive sectors, such as energy, finance, and communication. These sectors have limited channels for transmitting risks but readily absorb them from others.

(2) The risk spillover effect fluctuates over time, amplifying during financial crises and other special periods, and sectors' change in spillover differs due to the differences in the cause of the financial crisis. Some industries may experience a reversal of risk spillover, for instance, information technology sector was in a state of net risk acceptance in most of the period but transitioned to a state of net risk export during 2005 to 2006 and 2014 to 2015.

(3) The registration system reform reduces risk spillovers among non-financial sectors by improving information transparency and investor confidence. However, the finance sector's risk spillovers increased, transitioning from a net risk acceptor to a net risk exporter, underscoring its evolving role in the financial ecosystem.

6.2 Implications

Firstly, clarify the path of inter-industry risk spillovers in China's stock market, and establish fast feedback and processing mechanism to mitigate risk contagion paths. The interconnectedness of industries means that when one industry is negatively impacted, all other industries will be directly or indirectly affected. Thus, sourcing the risk and screening the path of contagion is an important way to control the spread of risk. In addition, develop a risk warning system using industry correlation indices to monitor systemically important industries and highly interconnected industries, and supervise "risk-exporting industries" and "risk-accepting industries" separately. What's more, pay attention to crisis period and adjust regulatory measures accordingly.

Secondly, control the leverage of the finance sector, strengthen its counter-cyclical adjustment capacity, in period of financial crisis. Improve the risk control capabilities of regulatory departments such as Finance and Securities, enhance the support for the real economy and stock market by banks insurance and funds, and introduce stabilization funds, prevent large fluctuations in the stock market triggered by factors such as the forced liquidation of positions. In addition, enhance the robustness and risk-resistant capacity of the real economy, decrease the negative effects brought about by various external shocks.

Thirdly, optimize and deepen the registration system reform. Establish a market ecology that fosters long-term investment, vigorously develop equity public funds, and significantly increase the proportion of equity funds. Improve the regulatory standards for abnormal trading and market manipulation and strengthen the regulation of high-frequency quantitative trading. Refining information disclosure mechanisms continually to ensure accuracy, transparency, and completeness, further reducing information asymmetry.

6.3 Limitations and further research plan

Firstly, this study uses the first level industry indices, which may over simplify the analysis. Future research could examine more segmented industry indices to provide deeper insights into risk spillovers.

Secondly, we study the impact of the registration system reform on the spillover effect. However, the post-registration period is relatively short and the data selected is limited. As the registration system reform matures, future research should contain more data to evaluate its sustained impact.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Competing interests

The authors declare that they have no conflicts of interest.

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Appendix

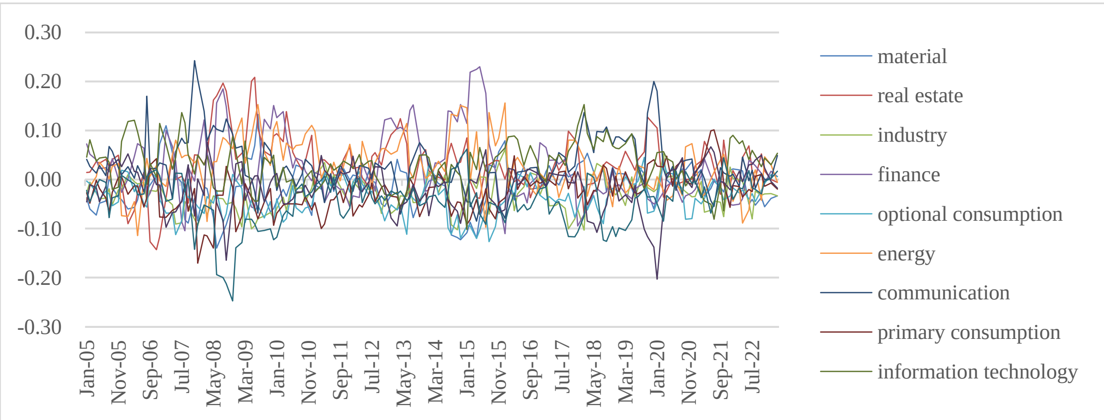

Figure 1 Net risk export by industry（window100, stepsize30）

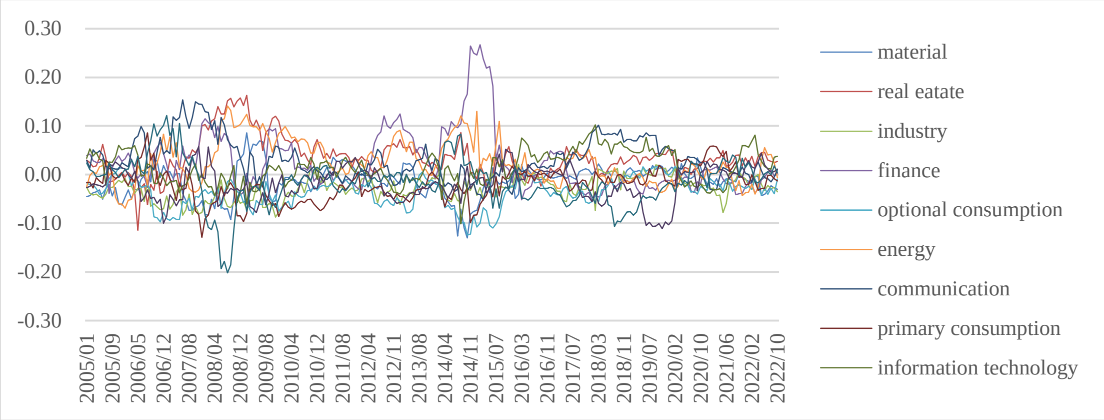

Figure 2 Net risk export by industry（window200, stepsize20）

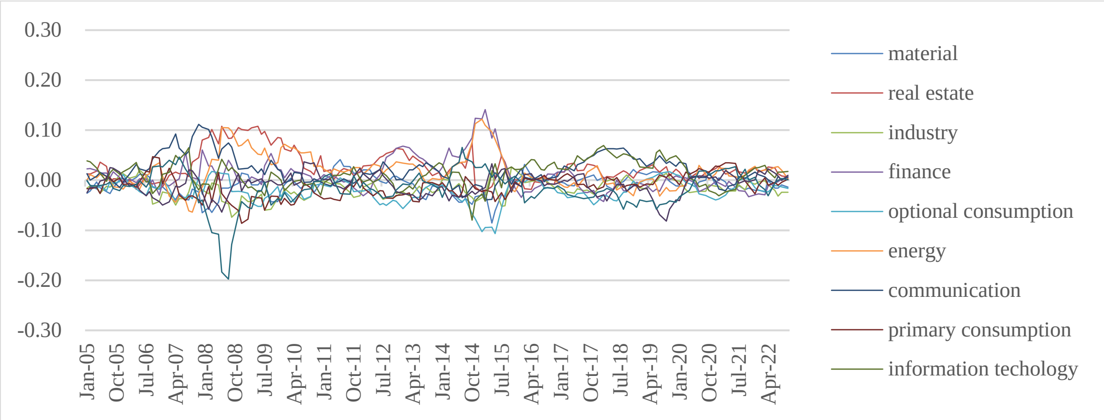

Figure 3 Net risk export by industry（window200, stepsize30, quantile 10%）