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Volatility spillovers in the US-China financial markets: Evidence from BEKK-GARCH model

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ABSTRACT

This study investigates the spillover effects of volatility between the financial markets of the US and China using the BEKK-GARCH model on daily data from 4 January 2016 to 31 December 2021. The results, validated by the Wald test, reveal significant findings: First, the internationalization of the RMB has enhanced China's influence on the USD, resulting in volatility spillovers between the US dollar index and China's foreign exchange market. Second, while volatility spillovers exist between Chinese and US stock markets, the ARCH effect has weakened following the trade war. Finally, there are spillover effects between the Chinese and US bond markets, though these are less pronounced compared to the foreign exchange markets. These findings highlight the evolving nature of volatility spillovers between the US and Chinese financial markets, especially in the context of a trade war. The practical implications suggest that investors and policymakers should closely monitor these spillover effects to manage risks better and make informed decisions in an increasingly interconnected global market.

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Contribution/ Originality: This study uniquely investigates post-trade war volatility spillovers between US and Chinese markets using the BEKK-GARCH model. To the authors' knowledge, it is the first to analyze spillover effects across forex, stock, and bond markets during this period, with results validated by the Wald test.

1. INTRODUCTION

Since China acceded to the WTO in 2001 (Yang, 2001) with the accelerating pace of economic globalization and the gradual increase in economic exchanges between countries around the world, governments and regulatory authorities have taken measures to accelerate the development of finance, for example, by relaxing existing laws and regulations that restrict the financial system and providing a more liberal market environment. As a result, the financial sector has been able to open up to the outside world at an ever-increasing pace, and international financial competition has intensified. However, this increased liberalization and international integration has also led to more significant financial risks, such as the amplification of volatility and risk contagion between countries' financial markets (Wang, 2003).

More international capital is flowing into and out of the countries' financial markets, making them more connected. These inflow and outflow have made financial markets more dependent on each other, resulting in stronger price synergies and cross-border spillover effects. One country's financial markets are influenced not only by their historical fluctuations but also by fluctuations in other countries' markets, a phenomenon that geopolitical events have notably intensified. These fluctuations have led to the concentration of systemic risks across financial markets, creating new challenges for regulators.

On March 23, 2018, US President Donald Trump signed a trade memorandum at the White House, announcing tariffs on up to $60 billion of Chinese imports and restrictions on Chinese investments in US mergers and acquisitions. This event marked the beginning of what became widely known as the trade war (Lu, 2018).

Numerous academics have looked into how the market responds to trade disputes. During the US-China trade war, Huynh and Burggraf (2020) looked at the co-movement of the global stock market and discovered that formerly symmetric movements turned negative with hefty tails. They contend that trade disputes endanger the stability of international markets. According to De Nicola, Kessler, and Nguyen (2020) growing trade tensions caused China's main stock markets to drop by 50–60% in the first part of 2018. Similarly, Gjerstad, Meyn, Molnár, and Næss (2021) note that news has a significant impact on financial markets, and even small tweets from President Trump can cause significant fluctuations in the stock market.

Because of the significance of the foreign currency, stock, and bond markets in the financial markets, it is imperative to evaluate the volatility spillovers. Comprehending the financial risk transfer mechanism and devising solutions for mitigation are critical concerns for China in light of the escalating trade tensions. Therefore, for effective risk prevention, it is imperative to analyze volatility spillovers in major financial markets.

In the wake of increased trade tensions, managing financial risk requires an understanding of the volatility spillovers between the US and Chinese financial markets both before and after a trade war. This study identifies important regions of financial risk contagion and examines how the trade war changed the dynamic linkages across these markets using the BEKK-GARCH model (Engle & Kroner, 1995).

2. LITERATURE REVIEW

2.1. Trade Friction between China and the US

The financial crisis of 2008 caused serious economic problems for numerous nations (Acharya & Schnabl, 2010). The European Union, the United States, and several other economies responded to these difficulties by enacting domestic trade protectionist policies that helped to lessen the crisis' consequences. Global trade frictions and conflicts have intensified due to this shift toward protectionism (Hsieh, 2009). As important trading partners with significant economic power, the US and China have both become entangled in the rise of protectionism, with China emerging as one of the main recipients of US protective measures.

There are many facets and a complex trade relationship between the US and China. Both the bilateral economic relationship and the global trade climate have been significantly impacted by trade tensions and protectionist actions between the two nations (Tam, 2020). These events demonstrate how crucial diplomacy, negotiation, and international collaboration are to resolving trade-related issues and advancing a more steady and predictable pattern of international trade. The following are the primary reasons why trade tensions exist between the US and China:

2.1.1. The Substantial Trade Surplus Between China and the US

One noteworthy aspect of bilateral commercial ties is the significant trade surplus that exists between the United States and China. Not only has this trade deficit lasted for a long period, but it has also gotten worse with time. The trade imbalance has expanded, and the trade gap has become more noticeable as commerce between the two nations has increased. There is limited information on how China's internal policies have contributed to the country's ongoing trade deficit, despite the fact that China maintains a sizable and continuous trade surplus with the US (Kim, 2014). The dynamics of commerce between the two nations have long included this imbalance. Reducing this trade deficit, with China as the primary target, has been a top policy objective of the Trump administration.

China is especially susceptible to trade disputes started by the Trump administration since it contributes significantly to the US trade imbalance. China has, therefore, had to act proactively to handle and manage these trade issues (Sharma, Leung, Kingshott, Davcik, & Cardinali, 2020). Effective trade policies, discussions, and tactics are critical to fostering a more balanced relationship between the United States and China, as seen by the ongoing trade surplus between the two nations.

2.1.2. Macroeconomic Imbalances within China and the US

China and the United States have distinct economic systems and different growth paths. Domestic consumption largely drives US economic growth, prompting the government to implement strategies that often lead to overconsumption. With high consumption levels and inadequate domestic savings, the US frequently runs a trade deficit, relying on imports to mitigate this imbalance (Kojima, 2000; Morrison, 2013).

In 2017, the private sector savings rate in the US reached another historic low at 3 percentage points. Paradoxically, this period coincided with a surplus in domestic consumption, resulting in a significant deficit in the private sector balance. A similar situation existed in the public sector. The prolonged imbalance between investment and consumption has contributed to a substantial trade deficit in the US (Holinski, Kool, & Muysken, 2012). However, the literature primarily focuses on the symptoms of the trade deficit and does not fully explore the underlying structural causes, such as fiscal policy mismanagement and long-term reliance on debt-driven consumption. This research gap leaves room for further exploration of the role of policy decisions in deepening these macroeconomic imbalances.

In response to this issue, the US implemented a series of measures to mitigate the deficit. However, these actions also exacerbated the fiscal situation, making it evident that the emergence of the US trade deficit is an inevitable consequence of the imbalance between domestic investment and savings. In contrast to the US, Chinese consumers tend to exhibit more conservative spending habits. Additionally, China has long pursued policies that prioritize suppressing consumption while promoting increased investment, which has restrained domestic consumption to some extent (Gilboy, 2004). Consequently, China faces a situation of underconsumption and excessive savings. Furthermore, China's economic development heavily relies on investment and external demand, driving an increase in Chinese product exports and limited demand for imported products. These policies, in turn, exacerbate the issue of trade surplus (Cai, Wang, & Zhang, 2010).

2.1.3. The US Direct Investment in China and the Imposition of Export Controls

As the US service industry continues to flourish domestically, its manufacturing sector has gradually begun to decline, prompting many US companies to shift their production overseas in order to increase their profits. China's labor force has always had a very obvious advantage, so China has always been the main transfer of these companies. In the bilateral trade between China and the US, many of the exports to the US are realized in Chinese multinational corporations.

Moreover, due to the export controls imposed by the US, there is a clear trade imbalance. As China and the US are at different stages of development, there is a gap between the two countries' current economic development, which makes the trade products of the two countries complementary. In addition to the differences in the domestic situation, the two countries have differences in resources. China, being one of the most populous countries, boasts an abundant labor force, in contrast to the US, a developed country with a highly developed and mature technological dimension. However, they acknowledge the role of US export controls in creating this imbalance. They often overlook the broader geopolitical motivations behind these controls, such as concerns over intellectual property theft and national security. These factors have had a significant influence on the imposition of these restrictions.

According to the principle of comparative advantage, China exports labor-intensive products to the US, while the US exports technology-intensive products (Mayer, Butkevicius, Kadri, & Pizarro, 2003). Only by complementing each other's strengths can the economies of the two countries develop smoothly. On the contrary, due to the imbalance in demand for products between the US and China and the restrictions on the export of US high-tech products, the trade gap between the two countries has grown bigger over time.

2.2. The Impact of the US-China Trade War on Trade

The 2018 US-China trade war marked a significant shift in US trade policy, signaling a break from its usual support for global market integration. By late 2019, the US had levied tariffs on roughly $350 billion worth of Chinese imports, while China responded with tariffs on $100 billion of US exports. These measures significantly affected both economies, with US consumers facing higher prices and both nations experiencing declines in real incomes, although the overall impact has been relatively small (Fajgelbaum & Khandelwal, 2022; Handley & Limão, 2017). However, while these studies provide valuable insights into the immediate economic consequences of tariffs, they tend to underestimate the long-term structural impacts on GSCs (Global Supply Chains), which can be far-reaching beyond the initial welfare loss.

Numerous research works have examined the economic consequences of these tariffs, continuously highlighting the substantial expenses incurred by both importers and domestic consumers. For instance, Amiti, Redding, and Weinstein (2019) and Amiti, Redding, and Weinstein (2020) demonstrate that although the US government received an extra $14 billion in tariff revenues, the duties were nearly totally passed through to domestic pricing, resulting in cumulative welfare losses. These findings primarily focus on the short-term results and financial metrics, such as welfare losses and tariff revenues; however, they do not sufficiently examine the long-term effects of these tariffs on trade relations, technical innovation, and industrial strategy between the two countries. These results corroborate those of Fajgelbaum, Goldberg, Kennedy, and Khandelwal (2020) who demonstrate that trade wars cause wealth transfers from foreign purchasers to US producers and the government, as well as higher import prices. Even so, the total decline in real income in the United States is still negligible. Even though the overall loss of US real revenue is relatively minor, these estimates typically overlook indirect consequences, such as forcing businesses to recognize their supply networks, which can have long-term effects on both economies. Furthermore, other nations—often referred to as "bystanders"—have benefited from the disruption of trade flows between the United States and China by developing new export prospects (Bown & Zhang, 2019; Chor & Manova, 2012; Fajgelbaum, Goldberg, Kennedy, Khandelwal, & Taglioni, 2021).

China's economy is expanding quickly, and it continues to have a significant trade surplus with the US. The introduction of tariffs is the first step toward a rise in bilateral hostilities that will have a major impact on the stability and integration of the world economy. Although Steinbock (2018) contends that these growing tensions are becoming more multilateralized and represent a significant risk to the stability of the world economy, the study falls short in its analysis of how RTAs (Regional Trade Agreements) and other international institutions can mediate or lessen them.

According to Kapustina, Lipková, Silin, and Drevalev (2020) and Zheng, Zhou, Li, Padula, and Martin (2023) the United States has four primary objectives. These are to reduce trade imbalances and promote employment, restrict China's access to US technology, restrain China's military buildup, and reduce the federal budget deficit of the United States. They contend that, in the end, a trade war would lower productivity and economic efficiency in both nations. Goulard (2020) agrees, stating that given the power and size of both countries' economies, a trade war might make the slowdown in world production and international commerce worse. However, the literature does not explore how trade war impacts interact with other global economic patterns, resulting in more intricate long-term effects.

Scholarly investigation has also focused on the wider influence of international trade. According to Tu, Du, Lu, and Lou (2020) analysis of the effects of the US-China trade dispute on international trade, bilateral trade has significantly decreased, with imports going to nations like Mexico, Japan, and Germany. They did point out, though, that a total switch to other suppliers would mean higher prices and utility losses.

2.3. US-China Trade War and Financial Risk

President Donald Trump signed a memorandum on March 23, 2018 that forbade Chinese corporations from conducting mergers and acquisitions within the US and imposed substantial tariffs on imports from China worth up to US$60 billion. The US-China trade war officially began at this point (Fajgelbaum & Khandelwal, 2022).

The imposition of tariffs has escalated costs and reduced orders for import and export enterprises, leading some companies to face production cuts, shutdowns, and the need for adjustment and restructuring (Chen & Pantelous, 2022). These studies focus on the short-term impact of corporate restructuring on corporate profitability and market fundamentals but do not fully explore the indirect impact of corporate restructuring on long-term financial stability.

Psychological factors, such as external uncertainty and exchange rate fluctuations, influence stock market volatility in addition to economic factors, potentially exacerbating market instability. Therefore, the potential downside risk of US-China trade frictions in Chinese stocks has become a key area of concern. While the current literature acknowledges these psychological factors, it lacks research on how geopolitical tensions can exacerbate market reactions by affecting investor sentiment beyond their direct economic impacts. This gap suggests the need for more nuanced research that considers both economic and psychological dimensions when assessing market risks.

The impact of trade frictions on financial markets has attracted widespread attention from the academic community. Previous studies have shown that markets tend to fluctuate symmetrically before a trade war breaks out, but during the conflict, there will be significant negative downward volatility and heavy tails, which pose systemic risks to global markets and may trigger simultaneous declines in multiple markets (Huynh & Burggraf, 2020; Shi, 2022). However, while these studies provide useful insights into market behavior during periods of high volatility, they often overlook how policy responses or international cooperation efforts can mitigate these risks. Future studies could examine how international financial institutions' interventions, or coordinated fiscal or monetary policies between China and the US, can stabilize financial markets in the face of systemic concerns brought on by trade. Furthermore, studies have demonstrated a strong correlation between stock prices and shipping freight rates, with the American stock market being more responsive to shifts in the shipping freight market than the Chinese stock market. The possibility of a trade war spreading to other markets rises when commerce between the United States and China declines (Gong, Li, Chen, & Shi, 2020; He, Lucey, & Wang, 2021).

Academics have extensively researched the systemic hazards resulting from US-China trade disputes. For instance, Sheng, Uddin, Sen, and Hao (2024) used the generalized spillover index approach within a Markov switching vector autoregression (MS-VAR) framework to evaluate the asymmetry of regime-related volatility spillovers in the stock markets of Shanghai, Hong Kong, and the United States. Their results indicate a strong negative asymmetric effect that varies with market institutions and increases during times of high market volatility. Similarly, Wijaya, Zunairoh, Eriandani, and Narsa (2022) investigate how trade policy uncertainty during the US-China trade war leads to broader economic policy uncertainty and how systemic risk emerges in ASEAN markets. The possible influence of non-financial shocks, including changes in geopolitics or technology that may also cause market volatility, is not taken into account by their model. Future models that include these characteristics may give a more comprehensive view of systemic risk.

2.4. Theoretical Basis of Volatility Spillover Effects

2.4.1. Theory of Interest Rate Parity

Interest rate parity (IRP) allows investors to profit from interest rate differentials by borrowing money for a certain amount of time from a country with a lower interest rate and investing it in a country with a higher interest rate. This arbitrage causes exchange rates to fluctuate until the possibilities disappear (Chinn & Meredith, 2004; Engel, 2016; Obstfeld & Rogoff, 1996; Taylor, 1987). The future exchange rate's premium or discount should equal the difference in interest rates between the two nations when equilibrium is reached; if not, risk-free arbitrage will bring the two nations' interest rates back into balance.

In arbitrage, investors transfer their funds from the nation with the lower interest rate to the one with the higher interest rate. This activity impacts the exchange rates of both countries, leading to an appreciation of the currency in the nation with the higher interest rate. This arbitrage pushes down the country's interest rate until the rates in both countries equalize (Edison & Pauls, 1993). At this equilibrium point, both the exchange rate and the interest rate stabilize. Consequently, changes in one country's interest rate or exchange rate trigger adjustments in other countries' interest rates and exchange rates, demonstrating the interconnectedness of global financial markets (Froot & Thaler, 1990; Rogoff, 1996).

2.4.2. Theory of International Capital Flows

Often referred to as the MacDougall model or the theory of perfect competition, the general model of international capital flows in a classical economic theory explains the motivations behind international capital movements and their effects. According to MacDougall (1951) international capital flows are driven by differences in interest rates and expected profit rates across countries. He posited that national markets for products and factors of production operate within a perfectly competitive framework, allowing capital to flow freely from capital-abundant countries to those with capital scarcity. For instance, these factors underpinned the substantial capital export from Britain during the 19th century (Kindleberger, 1969). The international mobility of capital leads to a convergence of the marginal productivity of capital across countries, thereby increasing global output and enhancing the welfare of all participating nations (Helpman, 1984; Lucas, 1990).

The international capital flow channel provides a robust explanation for the linkage between foreign exchange markets and stock markets. The international capital channel transmits external shocks from international sources directly or indirectly to the stock market the foreign exchange market experiences them (Fratzscher, 2012). For instance, if a country's exchange rate declines due to an external shock, leading to an appreciation of the local currency, this fluctuation creates temporary arbitrage opportunities and generates exchange gains. These gains reduce the risk for international investors, thereby enhancing the attractiveness of the domestic investment market and leading to a continuous inflow of external capital (Froot & Ramadorai, 2008). The stock market receives some of this capital, which amplifies market stimuli and contributes to rising stock yields. Simultaneously, other portions of international capital are invested in the real economy, such as through foreign direct investment (FDI) in real enterprises, whose revenues and profits contribute to economic growth and, indirectly, to stock market prosperity (Alfaro, Chanda, Kalemli-Ozcan, & Sayek, 2004; Reinhart & Rogoff, 2004).

2.4.3. Theory of Investors' Psychological Expectations

Investor psychological expectation, often called investor sentiment (Stein, 1996) refers to the systematic deviation in investors' future expectations. It is a complex concept to quantify, representing the willingness or outlook of market participants to invest (Baker & Wurgler, 2007). In an era of increasingly interconnected national financial markets, investor psychological expectations play a pivotal role in driving movements in exchange rates, stock prices, and bond yields. These expectations act as a transmission medium through which these financial variables influence each other (Barberis, Shleifer, & Vishny, 1998). Additionally, investor sentiment is highly contagious; some investors tend to follow the dominant players or the herd, often without sufficient analysis, thereby amplifying price movements (De Long, Shleifer, Summers, & Waldmann, 1990).

In the late 1990s, rapid social and economic development, coupled with the intensification of international commodity flows and capital interactions, led to closer integration of global markets. The advent of advanced technological and information tools facilitated the swift dissemination of information, further enhancing the interconnectedness of financial markets. The international flow of capital and information transmission contributed to the formation of a linkage mechanism in prices across major markets, reflecting the collective influence of investor psychological expectations (Shiller, 2000).

2.5. BEKK-GARCH in Volatility Spillover Effects

Caporin and McAleer (2012) point out that it is routine to manage and monitor enormous portfolios of financial assets using either BEKK-GARCH or DCC-GARCH. Where BEKK is often applied to interaction shocks between two variables, DCC（Dynamic Conditional Correlation） is applied to interaction shocks between more variables. Türkyılmaz and Balıbey (2013) investigated the conditional variance of monthly interest rates, stock exchange prices, and exchange rates in Turkey using the BEKK-MGARCH model technique, and their results suggest that there were significant volatility spillovers between these three financial sectors before the global economic crisis hit Turkey. This study highlights significant volatility spillovers, but it does not thoroughly examine how macroeconomic policies or external shocks could intensify these impacts during times of crisis, indicating a knowledge gap regarding how policy responses can reduce such risks.

Liu (2016) investigates cross-border stock market spillovers between the US, UK, Hong Kong, and Japan. According to Liu's BEKK-GARCH model's conclusions, shocks have had a greater impact on the US market in the wake of the crisis. This analysis does not account for trade conflicts or other potential external factors that could significantly alter the spillover effects. Furthermore, the study does not investigate how volatility spillovers would be increased or decreased by the integration of local markets with the global financial system. The earlier shocks had less of an effect on East Asian markets, but they persisted longer.

Studies of several market shocks, including those to oil and stock prices, have also made extensive use of the BEKK-GARCH model (Yu, Zha, Stafylas, He, & Liu, 2020). Xie, Liu, Qian, and Li (2021) discover, based on the empirical findings of BEKK, that while events like the shale oil boom and reductions in crude oil production assist in stabilizing the stock market, external shocks to oil supply and demand put pressure on China's stock market. The BEKK-GARCH model does not directly look at how these shocks affect bigger economic variables like inflation or interest rates. This means that market volatility may spread to other markets even more. Despite this, these results provide a useful framework for figuring out how events in other countries affect the stock market.

2.6. Hypothesis

2.6.1. Foreign Exchange Market

Kavli and Kotzé (2014) examined the effects of exchange rate volatility and returns on spillover effects for both developed and emerging market currencies. According to their findings, exchange rate returns have seen a gradual increase in spillover effects over time and have a moderate response rate to economic events, especially abrupt shocks. Ben Omrane and Hafner (2015) provide more support for this conclusion. In his investigation into the relationship between macroeconomic news and exchange rate volatility, he identified two primary drivers of currency price fluctuations: the direct shock effects of news and the volatility spillover effects between currencies.

Expanding on the theme of volatility spillovers in currency markets, Qin, Zhang, and Zhang (2018) demonstrated volatility spillovers between the RMB (Renminbi)foreign exchange and equity markets, revealing that RMB exchange rate volatility contributes to broader financial market spillovers. Similarly, Su (2021) examined the extent and drivers of volatility spillovers in the foreign exchange market using HAR (Heterogeneous Autoregressive) models, confirming both inter-regional and intra-regional spillovers and highlighting the interconnectedness of global currency markets.

Based on the statement above, the foreign exchange market should be considered. Therefore, this study proposes the following hypothesis:

H_1: There is a volatility spillover effect in the foreign exchange market between the US and China after the trade war.

2.6.2. Stock Market

The stock market facilitates the issuance and trading of stocks, encompassing both primary and secondary markets. Through stock issuance, companies can quickly raise large amounts of capital to scale operations, while individual investors use surplus capital to invest in these companies, aiming to grow their wealth.

Yilmaz (2010) finds that East Asian equity markets experienced significant volatility spillovers during major crises, such as the East Asian crisis. Similarly, Sun, Hsiao, and Li (2015) observe similar stock market volatility spillover patterns between the US/UK and US/Canada markets.

Joshi, Mehta, Patel, and Patel (2021) applied T-GARCH and E-GARCH models to the Indian and European stock markets, finding strong volatility effects between them. Ahmed, Zhao, and Habiba (2022) looked into return linkages and volatility spillovers in emerging Asian markets. They found that there were significant one-way spillovers between a number of market pairs and significant two-way spillovers in most cases. Oh and Kim (2024) analyzed risk contagion between stock markets, highlighting that each market can act as an overnight risk factor for the other, particularly during the US-China trade war.

Based on the statement above, the stock market should be considered.

This study proposes the following hypothesis:

H_2: There is a volatility spillover effect in the stock market between the US and China after the trade war.

2.6.3. Bond Market

The financial market relies heavily on the bond market for the issuance and trading of bonds. The bond yield curve serves as a benchmark for returns on all financial instruments, making the bond market a crucial channel for transmitting central bank monetary policy.

Christiansen (2007) looked into volatility spillovers from the US and European bond markets to certain European markets using a GARCH model. Kim (2017) found evidence of risk spillovers between the US stock and bond markets when she found that short- and long-term bond market volatility is asymmetrically impacted by stock market volatility.

Balli, Hu, and Rana (2020) used volatility and yield spillover models to assess the impact of developed markets (US, UK, and Japan) on emerging bond markets, finding that spillovers are asymmetric and largely explained by bilateral trade volumes. O'Sullivan and Papavassiliou (2021) examined return and volatility spillovers in European sovereign bonds, noting that bonds amplify volatility during key macroeconomic events like credit rating downgrades and financial assistance programs.

Based on the statement above, the bond market should be considered. Therefore, this study proposes the following hypothesis:

H_3: There is a volatility spillover effect in the bond market between the US and China after the trade war.

3. DATA AND METHODOLOGY

3.1. Data

Daily data from different sources. The sample period spans from 4 January 2016 to 31 December 2021. The sample period is further divided into two sub-periods: 4 January 2016 to 23 March 2018 and 23 March 2018 to 31 December 2021. Taking the escalation of US-China trade friction as a demarcation point, this paper will explore the volatility spillover effects between the foreign exchange market, stock market, and bond markets in China and the US. Table 1 shows the variables used in this research.

Table 1. List of variables.

Variables	Descriptions	Unit	Sources
FXC	Log-difference of the exchange rate of USD to RMB	Percent	PBOC
SSEI	SSE composite index	Percent	SSE
GCNY	Yield of Chinese government bonds (10 years)	Percent	CBVC
USDX	US dollar index	Percent	Wind
DJIA	Dow Jones industrial average	Percent	DJ
TYUS	Treasury yield of the US government (10 years)	Percent	Feds

Note: PBOC denotes the People's Bank of China.
SSE denotes the Shanghai Stock Exchange.
CBVC denotes China Bond Valuation Centre.
DJ denotes Dow Jones & Company.
Feds denote the Federal Reserve Board.

To meet the requirements of the econometric model, this study excluded data with missing dates. To ensure the stationary of time series data, the variables will be subject to logarithmic yield treatment as follows: $R = \ln (P_t / P_{t-1})$.

Table 2. Descriptive statistics of financial markets.

Variables	FXC	SSEI	GCNY	USDX	DJIA	TYUS
Panel A: Before the trade war break: 04/Jan/2016 to 23/Mar/2018						
Mean	-0.005	-0.010	0.050	-0.020	0.066	0.046
Median	-0.004	0.075	0.000	-0.007	0.075	0.000
Maximum	0.907	4.174	3.448	2.495	2.805	10.098
Minimum	-0.926	-7.305	-2.803	-1.723	-4.714	-10.281
Standard deviation	0.230	1.093	0.783	0.452	0.754	2.037
Skewness	-0.173	-1.755	0.480	0.362	-1.195	0.080
Kurtosis	4.783	13.827	5.420	6.267	10.057	6.131
Jarque-Bera	71.910	2822.800	147.669	244.073	1209.938	214.216
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Sum	-2.869	-5.057	26.194	-10.410	34.452	24.084
Sum of squared deviations	27.637	624.032	319.683	106.468	296.490	2165.385
Observations	523	523	523	523	523	523
ADF test	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Panel B: After trade war break: 23/Mar/2018 to 31/Dec/2021						
Mean	0.001	0.017	-0.034	0.008	0.046	-0.071
Median	0.003	0.016	0.000	0.000	0.099	0.000
Maximum	0.898	7.548	4.698	1.775	10.764	34.175
Minimum	-0.996	-8.039	-5.851	-1.526	-13.842	-31.508
Standard deviation	0.225	1.196	0.851	0.368	1.458	4.220
Skewness	-0.018	-0.332	-0.227	0.435	-1.057	0.161
Kurtosis	4.611	8.713	8.701	5.036	23.278	19.865
Jarque-Bera	95.266	1212.880	1199.329	179.734	15240.460	10433.230
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Sum	0.889	14.970	-29.580	7.457	40.641	-62.861
Sum of squared deviations	44.551	1258.172	636.368	119.143	1867.486	15651.010
Observations	880	880	880	880	880	880
ADF test	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Note: ***denote statistical significance at 10%, respectively.

In Table 2, ADF test results show that all series are stationary at the original level, allowing for the direct use of these variables in the model's construction.

Table 3. Result of the ARCH-LM test.

Variables	F-statistic	LM-statistic	P-value
FXC	9.66	9.60	0.00***
SSEI	3.68	3.67	0.05**
GCNY	29.65	29.08	0.00***
USDX	18.36	18.15	0.00***
DJIA	215.46	186.99	0.00***
TYUS	700.84	467.71	0.00***

Note: **,***denote statistical significance at 10%, 1% respectively.

As shown in Table 3, the P-values of the six stock indexes are all less than 5%, and the p-values of FXC, GCNY, USDX, DJIA, and TYUS are less than 1%, supporting the null hypothesis that there is no heteroscedasticity, so the result shows that the null hypothesis should be rejected.

3.2. ARCH Model

High-frequency financial data analysis now widely uses the ARCH model, which Engle (1982) developed under autoregressive conditions, to analyze financial time series fluctuations and asymmetry.

The variance of the random disturbance term μ_t at moment *t* depends on the magnitude of the squared error of the disturbance term before moment *t*. The following are the formulations for Equations 1 and 2:

$$y_t = \lambda x_t + \mu_t, \frac{\mu_t}{\varphi_t} \sim N(0,1) \qquad (1)$$

$$\sigma^2 = \omega_0 + \sum_{i=1}^{p} \alpha_i \cdot \mu_{t-i}^2 \qquad (2)$$

The model is the p-order autoregressive conditional heteroskedasticity model, i.e., the ARCH (*p*) model, where *p* is the lag order, y_t and x_t are the dependent and independent variables, respectively, μ_t is the random error term, $\alpha_i > 0$ and ω_0 are the constants. It is required $\sum_{i=1}^{p} \alpha_i < 1$ in order to ensure the smoothness of the ARCH process.

Despite some limitations, early research widely utilized the ARCH model, which effectively captures financial time series volatility. To address these, Bollerslev introduced the GARCH model in 1986, a generalized version of the ARCH model.

3.3. GARCH Model

The GARCH model, like the ARCH model, has a time-varying heteroskedastic error term.

Equations 3 and 4 express the basic equation of the GARCH model as follows:

$$y_t = \lambda x_t + \mu_t, \frac{\mu_t}{\varphi_t} \sim N(0,1) \qquad (3)$$

$$\sigma^2 = \omega_0 + \sum_{i=1}^{p} \alpha_i \cdot \mu_{t-i}^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2 \qquad (4)$$

The GARCH model has an additional term $\sum_{i=1}^{q} \beta_i \sigma_{t-i}^2$ compared to the ARCH model, which is called the GARCH term.

Similarly, $\sum_{i=1}^{p} \alpha_i \cdot \mu_{t-1}^2$ is called the ARCH term. *p* is the ARCH term lag order, *q* is the GARCH term lag order, $\omega_0 > 0$, $\sum_{i=1}^{q} \alpha_i > 0$, $\sum_{i=1}^{q} \beta_i \geq 0$, and $\sum_{i=1}^{p} \alpha_i + \sum_{i=1}^{q} \beta_i < 1$ is required to ensure the requirement of the GARCH model.

The GARCH (1, 1) model is the most often used GARCH model, and Equations 5 and 6 provide the fundamental statement of this model:

$$y_t = \lambda x_t + \mu_t, \frac{\mu_t}{\varphi_t} \sim N(0,1) \quad (5)$$

$$\sigma^2 = \omega_0 + \alpha_1 \mu_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (6)$$

The GARCH model is more accurate in predicting financial market changes and can represent the ARCH model's higher rank, allowing for more concise and explicit model identification and prognosis.

3.4. BEKK-GARCH Model

The binary BEKK-GARCH model is first expanded by constructing the $R_t = (R_{1t}, R_{2t})'$. The two-dimensional vector is:

Mean value equation:

$$R_t = a_0 + \sum_{i=1}^{p} a_i R_{t-i} + \varepsilon_t \quad (7)$$

Covariance equation:

$$\mathrm{H_t = C'C + A'\varepsilon_{t-1}\varepsilon_{t-1}'A + B'H_{t-1}B} \quad (8)$$

In the function:

$$H_t = \begin{pmatrix} h_{11,t} & h_{12,t} \\ h_{12,t} & h_{22,t} \end{pmatrix} \quad (9)$$

$$A_t = \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{pmatrix} B_t = \begin{pmatrix} b_{11} & b_{12} \\ b_{12} & b_{22} \end{pmatrix} C_t = \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} \quad (10)$$

a_{i} is the matrix of autoregressive coefficients lagged to order i. ε_t is a two-dimensional column vector of residuals. $\mathrm{H_t}$ is the return series between the two markets' conditional variance-covariance matrix. $h_{11,t}$ and $h_{22,t}$ are the conditional variances and $h_{12,t}$ is the conditional covariance.

The coefficient matrices that need to be estimated are A and B, where A represents the GARCH effect and B is the ARCH effect. The diagonal members of both matrices represent the effect of squared-lagged residuals on current fluctuations. The ARCH and GARCH effects are absent if the A and B coefficients are not significant.

a_{ij}, $\mathrm{b_{ij}}$ (ij, i≠j) indicates the change in conditional volatility of variable i from past anomalous shocks to variable j and the volatility spillover from i to j. To determine whether there is volatility spillover, it is a matter of determining whether a_{ij}, $\mathrm{b_{ij}}$ (ij, i≠j) is equal to zero.

When applying the BEKK-GARCH model, the significance of the estimated coefficients (A and B) is crucial for determining the presence of ARCH and GARCH effects. Finding insignificant coefficients would suggest a lack of volatility clustering in the data. To mitigate these risks, we conducted a Wald test after estimation to ensure that the model adequately captures conditional heteroscedasticity.

3.5. Wald Test

The basic idea of the Wald test construction is that if the Hypothesis H_0 is true, the $R\beta - r$ vector should converge to the zero vector when random sampling is performed; since $R\beta - r$ is a random vector, and the equivalent proposition for a random variable to converge to zero is that its measure converges to zero, its measure $\|R\beta - r\|$ can be calculated in E^q space first, and then the hypothesis H_0 can be ascertained by testing whether this measure is statistically significantly different from zero is true or false. The specific construction method involves the following steps:

Since $\beta = (X'X)^{-1}X'yX$ is non-random, β is a linear function of the sample observation *y*. Furthermore, the distribution of *y* depends on the distribution of *u*. Under the assumption of $u \sim N(0, \sigma^2 I)$. Since the linear combination of normally distributed variables is still normally distributed, β follows the normal distribution $\beta \sim N[\beta, \sigma^2(X'X)^{-1}]$.

Because $E(\beta) = \beta$, then $E(R\beta) = R\beta$, and then we get:

$$\text{var}(R\beta) = E\left[R(\beta - \beta)(\beta - \beta)' R'\right] = \text{Rvar}(\beta)R' = \sigma^2 R\left(X'X\right)^{-1} R'$$

$$R\beta \sim N[R\beta, \sigma^2 R(X'X)^{-1}R'] \quad (11)$$

$$R(\beta - \beta) \sim N[0, \sigma^2 R(X'X)^{-1}R']$$

If the virtual assumption $R\beta - r = 0$ holds, then we have:

$$R\beta - r \sim N[0, \sigma^2 R(X'X)^{-1}R'] \quad (12)$$

$$\|R\beta - r\| = (R\beta - r)'[\sigma^2 R(X'X)^{-1}R']^{-1}(R\beta - r)$$

Since β follows a normal distribution, its linear combination $(R\beta - r)$ still follows a normal distribution, so its measure follows $\chi 2$ with the number of degrees of freedom as the number of constraints.

$$\| R\beta - r \| = (R\beta - r)'[\sigma^2 R(X'X)^{-1}R']^{-1}(R\beta - r) \sim \chi^2(q) \quad (13)$$

where $\sigma 2$ is the variance of the overall is can not observable. Therefore, replacing the value of $\sigma 2$ in the above equation with a consistent estimate $\sigma^2 = e'e/n$ of the sample $\sigma 2$. Then $\|R\beta - r\|$ follows an asymptotic normal distribution. Defining $\|R\beta - r\|$ in terms of the Wald statistic:

$$W = \| R\beta - r \| = \frac{(R\beta - r)'[R(X'X)^{-1}R']^{-1}(R\beta - r)^a}{\sigma^2} \sim \chi^2(q) \quad (14)$$

The study can prove the assumption about the dummy variables by looking at how significant the Wald test is. This makes the BEKK-GARCH model more stable.

4. RESULT

This chapter shows the statistical results of the BEKK-GARCH model and Wald test before and after the trade war.

Table 4. Regression result of BEKK-GARCH model (Before the trade war).

Variables	a_{11}	b_{11}	a_{12}	b_{12}
FXC→SSEI	-0.207*** [-5.226]	0.958*** [58.921]	0.255** [2.429]	0.140*** [3.720]
SSEI→FXC	0.233*** [9.014]	0.965*** [137.260]	-0.008 [-1.189]	0.001 [0.102]
FXC→GCNY	-0.066 [-0.513]	0.829*** [7.846]	-0.252* [-1.683]	-0.346** [-2.244]
GCNY→FXC	0.240*** [4.875]	0.946*** [41.570]	-0.061*** [-3.104]	0.028** [2.984]
FXC→USDX	-0.152*** [-2.601]	-0.229* [-1.714]	0.181 [1.345]	0.496 [1.831]
USDX→FXC	0.052 [0.915]	0.517* [1.783]	0.372*** [12.997]	0.303*** [6.211]
FXC→DJIA	0.198*** [2.940]	-0.515* [-1.689]	-0.257* [-1.905]	0.824*** [2.732]
DJIA→FXC	0.471*** [9.027]	0.825*** [19.706]	-0.049*** [-2.668]	0.013 [0.428]
FXC→TYUS	0.154** [2.389]	0.786*** [6.309]	-1.174** [-2.030]	1.500 [-1.201]
TYUS→FXC	0.161*** [4.446]	0.984*** [166.269]	-0.049*** [-4.067]	0.007** [2.340]
SSEI→GCNY	0.229*** [8.504]	0.967*** [150.717]	-0.009 [-0.555]	0.002 [0.417]
GCNY→SSEI	0.294*** [8.521]	0.941*** [65.240]	0.000 [0.004]	-0.001 [-0.174]
SSEI→USDX	0.274*** [8.631]	0.958*** [101.331]	0.050* [1.927]	0.012 [0.333]
USDX→SSEI	-0.102 [-1.229]	-0.446 [1.279]	-0.195*** [-2.842]	-0.228 [-1.355]
SSEI→DJIA	0.174*** [4.540]	0.941*** [81.552]	0.138*** [4.219]	-0.021* [-1.652]
DJIA→SSEI	0.229*** [8.000]	0.910*** [68.147]	-0.220*** [-3.829]	-0.137*** [-4.713]
SSEI→TYUS	0.258*** [9.491]	0.955*** [112.491]	0.082 [2.543]	-0.038*** [-4.954]
TYUS→SSEI	0.445*** [5.301]	-0.197 [-0.777]	-0.056*** [-3.375]	0.041 [1.248]
GCNY→USDX	0.262*** [5.556]	0.933*** [41.698]	0.129** [2.120]	-0.030 [-1.373]
USDX→GCNY	0.124** [2.440]	0.675*** [44.308]	-0.123* [-1.826]	0.284*** [20.910]
GCNY→DJIA	0.279*** [8.166]	0.946*** [64.315]	-0.032 [-1.006]	0.003 [0.190]
DJIA→GCNY	0.479*** [9.915]	0.806*** [23.191]	-0.001 [-0.028]	0.016 [0.903]
GCNY→TYUS	0.221*** [6.983]	0.958*** [100.005]	0.186 [1.127]	-0.018 [-0.186]
TYUS→GCNY	0.474*** [5.961]	0.106 [0.343]	0.059** [2.168]	-0.020 [-0.353]
USDX→DJIA	0.222*** [3.033]	-0.101 [-0.252]	-0.288*** [-3.867]	0.156 [0.156]
DJIA→USDX	0.451*** [9.347]	0.853*** [30.022]	-0.112** [-2.516]	-0.061 [-0.992]
USDX→TYUS	0.144*** [3.038]	0.944*** [37.970]	-0.474*** [-4.890]	0.033 [1.246]
TYUS→USDX	0.129*** [5.019]	0.986*** [155.428]	-0.029*** [-3.374]	0.009*** [3.401]
DJIA→TYUS	0.484*** [8.778]	0.859*** [24.400]	0.382** [2.482]	-0.049 [-0.274]
TYUS→DJIA	0.448*** [6.711]	0.166 [0.962]	-0.022 [-1.281]	-0.069* [-1.677]

Note: The asterisk ***, **, and * denotes statistical significance at 1%, 5%, and 10 % levels.

Table 5. Wald test result of BEKK-GARCH model (Before the trade war).

Variables	Null hypothesis	P-value
FXC→SSEI	$a_{12} = b_{12} = 0$	0.001***
	$a_{21} = b_{21} = 0$	0.068*
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.001***
FXC→GCNY	$a_{12} = b_{12} = 0$	0.001***
	$a_{21} = b_{21} = 0$	0.049**
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.004***
FXC→USDX	$a_{12} = b_{12} = 0$	0.079*
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
FXC→DJIA	$a_{12} = b_{12} = 0$	0.011**
	$a_{21} = b_{21} = 0$	0.022**
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.004***
FXC→TYUS	$a_{12} = b_{12} = 0$	0.059*
	$a_{21} = b_{21} = 0$	0.001***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.001***
SSEI→GCNY	$a_{12} = b_{12} = 0$	0.854
	$a_{21} = b_{21} = 0$	0.958
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.981
SSEI→USDX	$a_{12} = b_{12} = 0$	0.139
	$a_{21} = b_{21} = 0$	0.003***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
SSEI→DJIA	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
SSEI→TYUS	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.001***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
GCNY→USDX	$a_{12} = b_{12} = 0$	0.063*
	$a_{21} = b_{21} = 0$	0.032**
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.043**
GCNY→DJIA	$a_{12} = b_{12} = 0$	0.536
	$a_{21} = b_{21} = 0$	0.330
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.467
GCNY→TYUS	$a_{12} = b_{12} = 0$	0.526
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
USDX→DJIA	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.023**
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
USDX→TYUS	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.004***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.000***
DJIA→TYUS	$a_{12} = b_{12} = 0$	0.045**
	$a_{21} = b_{21} = 0$	0.009***
	$a_{12} = a_{21} = b_{12} = b_{21} =0$	0.008***

Note: The asterisk ***, **, and * denotes statistical significance at 1%, 5%, and 10 % levels.

Table 6. Regression result of BEKK-GARCH model (After the trade war).

Variables	a_{11}	b_{11}	a_{12}	b_{12}
FXC→SSEI	0.218*** [4.966]	0.955*** [45.766]	-0.186 [-0.676]	0.118 [0.783]
SSEI→FXC	0.362*** [9.682]	0.893*** [46.705]	-0.010 [-0.692]	0.006 [1.081]
FXC→GCNY	-0.296*** [-5.299]	0.931*** [33.204]	0.023 [0.146]	0.102 [1.443]
GCNY→FXC	0.283*** [4.573]	0.929*** [30.852]	0.010 [0.892]	-0.000 [-0.019]
FXC→USDX	0.234*** [7.690]	0.922*** [50.114]	0.259*** [5.602]	-0.213*** [-8.780]
USDX→FXC	0.147*** [5.699]	0.965*** [101.850]	-0.118*** [-5.112]	0.083*** [7.605]
FXC→DJIA	-0.177*** [-6.037]	0.977*** [118.490]	0.035 [0.240]	0.010 [0.138]
DJIA→FXC	0.470*** [12.191]	0.849*** [40.528]	0.004 [0.704]	-0.002 [-0.645]
FXC→TYUS	-0.185*** [-5.162]	0.972*** [75.203]	0.525** [2.039]	0.218** [2.079]
TYUS→FXC	0.326*** [11.824]	0.944*** [101.226]	0.005*** [3.692]	0.001 [0.129]
SSEI→GCNY	0.306*** [7.874]	0.911*** [45.281]	0.128*** [5.342]	-0.046*** [-2.894]
GCNY→SSEI	0.352*** [7.586]	0.879*** [25.970]	-0.021 [-0.408]	0.051 [1.528]
SSEI→USDX	0.326*** [7.822]	0.912*** [45.388]	0.024** [2.504]	-0.015*** [-3.114]
USDX→SSEI	0.185*** [6.703]	0.967*** [112.232]	-0.066 [-0.453]	0.028 [0.583]
SSEI→DJIA	0.328*** [8.571]	-0.938*** [-44.286]	0.047 [1.533]	-0.221*** [-3.687]
DJIA→SSEI	0.434*** [11.428]	0.890*** [43.241]	-0.023 [-0.699]	0.184*** [2.877]
SSEI→TYUS	0.342*** [8.908]	-0.912*** [-42.598]	0.022 [0.535]	-0.335*** [-2.945]
TYUS→SSEI	0.375*** [10.351]	0.940*** [74.575]	-0.003 [-0.393]	0.054*** [2.818]
GCNY→USDX	0.335*** [6.837]	0.899*** [32.784]	0.039*** [2.941]	0.003 [0.664]
USDX→GCNY	0.121*** [4.398]	0.981*** [122.130]	0.101 [1.128]	-0.168*** [-3.861]
GCNY→DJIA	0.225*** [4.840]	-0.961*** [-50.305]	0.129*** [3.531]	-0.246** [-2.346]
DJIA→GCNY	0.429*** [12.435]	0.863*** [37.766]	-0.102*** [-3.924]	0.120*** [5.019]
GCNY→TYUS	0.093 [1.573]	0.978*** [76.285]	-0.081 [-0.736]	0.144*** [4.097]
TYUS→GCNY	0.319*** [12.650]	0.955*** [71.546]	0.021** [2.271]	0.003 [0.168]
USDX→DJIA	0.047 [1.237]	-0.934*** [-34.525]	0.640*** [5.993]	1.168*** [5.347]
DJIA→USDX	0.470*** [11.102]	0.850*** [30.858]	0.054*** [5.794]	-0.038*** [-6.261]
USDX→TYUS	0.150*** [3.009]	0.863*** [26.070]	0.595*** [2.958]	-0.410*** [-3.282]
TYUS→USDX	0.357*** [10.889]	0.935*** [88.998]	0.016*** [4.956]	-0.005*** [-5.237]
DJIA→TYUS	0.433*** [10.809]	0.867*** [46.723]	0.014 [0.195]	-0.025 [-0.818]
TYUS→DJIA	0.338*** [11.768]	0.949*** [118.463]	0.020 [1.451]	-0.001 [-0.150]

Note: The asterisk *** and ** denotes statistical significance at 5%, and 10 % levels.

Table 7. Wald test result of BEKK-GARCH model (After the trade war).

Variables	Null hypothesis	P-value
FXC→SSEI	$a_{12} = b_{12} = 0$	0.725
	$a_{21} = b_{21} = 0$	0.364
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.544
FXC→GCNY	$a_{12} = b_{12} = 0$	0.085*
	$a_{21} = b_{21} = 0$	0.146
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.047**
FXC→USDX	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
FXC→DJIA	$a_{12} = b_{12} = 0$	0.971
	$a_{21} = b_{21} = 0$	0.507
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.837
FXC→TYUS	$a_{12} = b_{12} = 0$	0.087*
	$a_{21} = b_{21} = 0$	0.081*
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.083*
SSEI→GCNY	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.208
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
SSEI→USDX	$a_{12} = b_{12} = 0$	0.007***
	$a_{21} = b_{21} = 0$	0.826
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.0432**
SSEI→DJIA	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
SSEI→TYUS	$a_{12} = b_{12} = 0$	0.010**
	$a_{21} = b_{21} = 0$	0.008***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
GCNY→USDX	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
GCNY→DJIA	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.972
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
GCNY→TYUS	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
USDX→DJIA	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
USDX→TYUS	$a_{12} = b_{12} = 0$	0.000***
	$a_{21} = b_{21} = 0$	0.000***
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.000***
DJIA→TYUS	$a_{12} = b_{12} = 0$	0.540
	$a_{21} = b_{21} = 0$	0.111
	$a_{12} = a_{21} = b_{12} = b_{21} = 0$	0.268

Note: The asterisk ***, **, and * denotes statistical significance at 1%, 5%, and 10 % levels.

Firstly, as observed in Table 5, before the trade war, the Wald test p-value of the null hypothesis $a_{12} = b_{12} = 0$is 0.079 > 0.05, which illustrates that there is no unidirectional volatility spillover effect of China's foreign exchange market on the US dollar index. As observed in Table 7, after the trade war, the p-values of Wald tests are all 0, which shows there is a volatility spillover effect between China's foreign exchange market and the US dollar index (H1 cannot be rejected).

Table 4 and Table 6 illustrate this point. The a_{12} and b_{12} of FXC→USDX was insignificant before the trade war but significant after the trade war. This finding suggests that with the internationalization of the RMB, China's foreign exchange market has increased its influence on the USD. This observation suggests that the internationalization of the RMB has enhanced China's foreign exchange market's impact on the USD, which aligns with studies highlighting the growing global role of the RMB post-inclusion in the SDR. Moreover, the USDX impact on the FXC is significant both before and after the trade war, reflecting the US dollar's status as a world currency, and fluctuations in the dollar's exchange rate will significantly impact the RMB. The USDX influence on FXC remains significant throughout, underscoring the global dominance of the US dollar and its persistent effect on the RMB, consistent with existing literature on global currency dynamics (Froot & Ramadorai, 2008).

Secondly, as observed in Table 5 and Table 7, both the SSEI and DJIA Wald tests are significant before and after the trade war, suggesting that there is a volatility spillover effect between the Chinese and US stock markets (H2 cannot be rejected).

As observed in Table 4 and Table 6. After the trade war, a_{12} of SSEI and DJIA are no longer significant. The reason for this is that trade between the US and China has been affected, resulting in a reduction in the scale of trade and a decrease in the ARCH effect of volatility linkage between their stock markets. But b_{12} still significant means there is still a GARCH effect between the US and Chinese stock markets. However, the fact that the GARCH term is still important suggests that the longer-term volatility linkage exists, even though the short-term effects are weaker. This finding is in line with what other research on trade shocks has found (Gong et al., 2020).

Institutional investors dominate the US stock market, with their participation reaching over 80%. These large numbers and structure of the rich level of institutional investors involved in stock market investment, then retail investors, have more professional investment judgment, multi-channel information sources, clearer investment objectives, and other advantages compared to institutional investors, who are more rational and conducive to external shocks brought about by the fluctuations quickly stabilized.

Thirdly, as observed in Table 5, before the trade war, the Wald test p-value of the null hypothesis $a_{12} = b_{12} = 0$is 0.526 > 0.05, demonstrating that there is no unidirectional volatility spillover impact between the US and Chinese bond markets. Table 7 demonstrates that there is a volatility spillover effect between the US and Chinese bond markets following the trade war, with all of the Wald tests' p-values being zero (H3 cannot be rejected).

As observed in Table 4. Before the trade war, the b_{12} is not significant on GCNY→TYUS and TYUS→GCNY, showing there is no GARCH effect between China and the US bond market. The a_{12} is only significant on TYUS→GCNY, which also illustrates there is no unidirectional volatility spillover effect of China's bond market on the US bond market, as Wald's test result shows.

As observed in Table 6. After the trade war, a_{12} is only significant on TYUS→GCNY, not significant of GCNY→TYUS. The b_{12} is not significant on GCNY→TYUS but significant on TYUS→GCNY. There is a volatility spillover effect between the Chinese bond market and the US bond market, but their effects are not as strong as the volatility spillover effect in the US and China foreign exchange markets.

The inclusion of RMB in the SDR has steadily increased its international influence. Simultaneously, fluctuations in China's exchange rate have impacted trade volumes between China and the US. China uses the profits from its trade surplus to build foreign exchange reserves, with a significant portion invested in US Treasury bonds. This interconnection explains why the onset of the trade war has affected both nations' exchange and debt markets. This finding supports the view that China's growing role in global financial markets, alongside its substantial foreign exchange reserves (composed largely of US Treasury), has intensified the impact of trade tensions on both the exchange and bond markets, consistent with the existing understanding of macroeconomic imbalances between the US and China (Sharma et al., 2020).

5. DISCUSSION

The primary contribution of this paper lies in uncovering the dynamic shifts in volatility spillovers between the foreign exchange, stock, and bond markets of China and the United States during the US-China trade war, offering a fresh perspective on the interconnection between the two nations' financial markets. As many studies, such as Tam (2020) and Steinbock (2018) have noted, global economic integration is an irreversible trend that no country can resist. The objective existence of trade frictions between China and the US will still not change the direction of continued cooperation between China and the US in the economic field. However, as highlighted by Kapustina et al. (2020) this close connection also facilitates the contagion of risks. China should actively cooperate with the US and other countries to jointly resist financial risks and keep the world economic order.

China's regulators must strengthen their control over the financial sector to prevent financial risks from accumulating and brewing into large-scale risks that could seriously interfere with the macroeconomy. At present, China's financial system is relatively not very mature, and many internal problems of the target system still need to be dealt with and coordinated. The establishment of an early warning system for financial risks and the strengthening of a financial stability assessment will help prevent systemic risks.

The US foreign exchange market significantly influences the volatility of the Chinese exchange market. Hence, the Chinese government must factor in foreign exchange market volatility when formulating economic policies, particularly in the context of the impossible Trinity theory, as it can prevent the further transmission of financial risks to the domestic market. According to the Impossible trinity theory, a certain amount of capital control, although impeding the free flow of international capital, is conducive to China's maintenance of an independent and autonomous monetary policy and a more flexible exchange rate system (Krugman, Rogoff, Fischer, & McDonough, 1999; Mundell, 1963).

Furthermore, with the majority of China's foreign exchange reserves currently denominated in US dollars, the intensification of the US-China trade war or a deterioration in the international economic situation could easily trigger large-scale foreign exchange risks, leading to asset losses. In this regard, the People's Bank of China should enrich the currency of foreign exchange reserves and increase its holdings in the international currency basket, such as the euro, the British pound, and other major currencies, to diversify foreign exchange risks while ensuring the stability of China's foreign exchange reserves. As highlighted by Wijaya et al. (2022) trade policy uncertainty can escalate systemic risks in regional markets, but diversifying foreign exchange reserves helps mitigate concentration risks associated with a single currency, thus reducing the impact of trade policy uncertainties and ensuring greater stability in China's foreign exchange reserves.

Baker and Wurgler (2007) highlighted the need to strengthen the Chinese stock market mechanism and related laws and regulations, particularly in managing investor sentiment, to reduce irrational stock price fluctuations caused by market overreaction. After the US-China trade frictions occurred, the Chinese stock market was hit and damaged more compared to the US, which mainly came from the negative reaction of investors' emotions to the US-China trade frictions events. To prevent the market from being overly emotional and generating irrational stock price fluctuations, policy institutions should effectively utilize monetary policy instruments to mitigate the effects of significant negative news by injecting liquidity into the market. In addition, China's news media should also increase the transparency of relevant economic information to help investors form correct investment expectations and release some positive news to neutralize market sentiment while huge negative news is happening.

For the bond market, supervision and enforcement should continue to be strengthened, a unified bond market enforcement mechanism should be established and improved, relevant regulatory authorities should strengthen coordination and communication, and clues found to be involved in illegal bond activities should be promptly transferred to the SFC for processing. In line with Alfaro et al. (2004) improved regulatory frameworks in the bond market would enhance market stability and investor confidence by mitigating the risks associated with international capital movements. Further, improve the information disclosure system and strictly regulate the disclosure standards of bond issuers.

On the one hand, before information disclosure, we can explore the development of a bond investor cognitive test to assess whether the information provided by bond issuers is true and reliable through a small-scale investor assessment and adjust and optimize the relevant disclosure information based on the results of the test and assessment. Legislation can strengthen the enforcement effect of information disclosure, and we can design punitive compensation rules in the field of bond investor protection to impose civil compensation liability on market players who disclose inaccurate information.

The impact of the US-China trade war on our financial markets has been significant, and China's financial markets have been impacted to some extent. Although the US-China trade friction has caused some pressure on China's economic growth, the risks are manageable, and the impact on China's macroeconomy is limited through the adjustment of the Chinese government's monetary and fiscal policies and the improvement of relevant laws and regulations in the financial market. In addition, China's domestic financial and economic environment will mature with increased transparency, advancements in media and public opinion, and the education of investors on relevant financial investment knowledge.

The study of US-China trade friction has yielded several important lessons. First, although globalization has promoted economic growth, it has also increased the transmission of risks between countries, so policy coordination is particularly important. Second, the sensitivity of financial markets to external shocks and investor sentiment reminds us that information transparency and market supervision must be strengthened to reduce volatility. Finally, diversification and risk dispersion are key to coping with future uncertainties, especially in supply chain and foreign exchange reserve management. Through these experiences, we can put forward more effective policy recommendations to help improve the existing economic environment and enhance the resilience of the global economy.

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