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The empirical research of cross-listed shares: The case of AH shares

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Declaration of Authorship

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Prague, July 27, 2021 _______________________

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Abstract

This thesis analyzes the information transmission and correlation of the AH share and its listed stock markets and uses the Shanghai-Hong Kong Stock Connect (refer as "the Connect") as a breakthrough to study its development trend. The dataset includes the daily returns of Shanghai and Hong Kong stock markets, AH share markets, and eight AH bank shares during 2010-2018. Using DCC GARCH and VAR models, we find persistent correlations for Shanghai and Hong Kong stock markets, the AH share market, and AH bank stocks. However, for AH bank shares, we do not find a growing trend of dynamic correlation. Moreover, the Connect has an insignificant effect on the correlation of cross-listed shares. We also find Granger causality for the SSE index as the Hang Seng index, but for the AH share market and AH bank shares, it is Granger causality for the H stocks as the A stocks.

Keywords	information transmission, DCC GARCH, AH shares

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List of Abbreviations

ABC	Agricultural Bank Of China
ADF	Augmented Dickey-Fuller test
AHXA	Hang Seng Stock Connect China AH (A) Index
AHXAH	Hang Seng Stock Connect China AH (A+H) Index
AHXH	Hang Seng Stock Connect China AH (H) Index
AIC	Akaike information Criterion
ARCH	AutoRegressive Conditional Heteroskedasticity
ARIMA	Auto Regressive Integrated Moving Average Model
ARMA	Auto Regressive Moving Average) Model
BOC	Bank Of China Limited
BOCM	Bank Of Communications
CCB	China Construction Bank Corporation
CEB	China Everbright Bank
CITIC	Citic Bank Corporation Limited
CMB	China Merchants Bank
CMBC	China Minsheng Banking Corporation
CSRC	China Securities Regulatory Commission
DCC GARCH	Dynamic Conditional Correlation -GARCH
GARCH	Generalized AutoRegressive Conditional Heteroskedasticity
HQ	Hannan Quinn Criterion
HSAHP	Hang Seng China AH Premium Index
HSCAHSI	Hang Seng Stock Connect China AH Smart Index
HSI	Hang Seng Index
ICBC	Industrial and Commercial Bank Of China
IPO	Initial Public Offering
RMB	Renminbi
SC	Schwarz Criterion
SSE	SSE Composite Index
The Connect	the Shanghai-Hong Kong Stock Connect
VAR	Vector Autoregression Model

Chapter 1 Introduction

The AH share refers to the cross-listed of Mainland China companies on both the Shanghai and Hong Kong stock exchanges. According to the law of one price principle, when investors purchase cross-listed shares with the same management voting and dividend rights, the share prices with the same cash flow in different markets should be the same after exchange rate adjustment. Therefore, the location of a company's listing should not affect the share price.

However, in the reality, it is common in the world that listing a company's shares on different stock markets or the participation of different investors can lead to different stock prices. Usually, the share price of a cross-listed company in the domestic market is lower than the share price in the overseas market. However, the AH share premium is a unique phenomenon; H shares[1] consistently discount A shares. Roosenboom and Dijk (2009) analyzed 526 cross-listed shares from 44 countries and summarized four reasons for prices difference for cross-listed shares: market segmentation, share liquidity, information disclosure, and market price discovery function.

After three decades of development, China's stock market has become the second largest in the world, but it is still not fully integrated with international financial markets. Capital from outside the mainland is not allowed to invest directly in the Shanghai and Shenzhen stock markets. This capital control makes it impossible for mainland and foreign investors to invest in each other's markets, and the listed markets for cross-listed stocks are practically segmented. Many researchers argue that market segmentation is the main cause of price differences in cross-listed stocks, while investor behavior and trading mechanisms also impact price differences. Chakravarty, Sarkar, and Wu (1998) analyze A shares and B shares and point out that information asymmetry and market segmentation are the main reasons for the price difference in A share and B share. Zhao and Wang (2002) analyze the

[1] Chinese stocks can be divided into five types according to the location of listing and investors: A-shares, B-shares, H-shares, S-shares, and N-shares. Among them: A shares are common stocks issued by companies in China for domestic institutions, organizations, or individuals (excluding Taiwan, Hong Kong, and Macau investors) to subscribe and trade in RMB. B shares are those special stocks registered in mainland China and listed in mainland China to subscribe or trade in foreign currencies. H shares are registered in mainland China and listed in Hong Kong to subscribe and trade in Hong Kong dollars.

policy change (B-share reform in 2001) and volatility spillover effects of market integration. It shows that the B-share market reform has a positive impact on stock market integration. Hu and Wang (2008) study A and H shares and argue that information asymmetry and liquidity risk can explain the AH premium. According to their study, if the market is less segmented and capital flows are freer, the share prices of cross-listed A and H shares should converge, and the AH share premium phenomenon should be improved. It provides policymakers with ideas to promote stock market integration in mainland China and Hong Kong.

Based on the financial market globalization and two-way opening-up political strategy, the Chinese government launched the Shanghai-Hong Kong Stock Connect (refer as "the Connect") program on 17th November 2014 to healthy develop the capital market of Mainland China. With the Shanghai-Hong Kong Stock Connect launch, qualified investors in both markets can trade shares through local brokers and clearing houses. According to the Shanghai-Hong Kong Stock Connect design intent, the implementation of this policy should reduce the market segmentation of AH shares and increase capital liquidity between the Shanghai and Hong Kong stock markets. This should lead to a convergence of cross-listed AH share prices, an easing of the AH share premium phenomenon, and the correlation between the Shanghai and Hong Kong stock markets should become higher. However, since the launch of the Shanghai-Hong Kong Stock Connect in November 2014, the spread between A and H shares has not decreased gradually as expected but has instead shown a significant trend of increasing. As a result, the AH premium index rose to about 120 after the Shanghai-Hong Kong Stock Connect.

Many investors and researchers are confused about the market performance of AH shares after the Shanghai-Hong Kong Stock Connect. Has the Shanghai-Hong Kong Stock Connect promoted the correlation between Shanghai and Hong Kong stock markets? Some researchers have gone beyond the analysis of the factors influencing the AH share premium and have gradually turned their research to the role of the Shanghai-Hong Kong Stock Connect on AH shares and the two stock markets and the information transmission and market correlation between the markets.

This thesis will mainly study the information transmission and dynamic correlation between Shanghai and Hong Kong stock markets and AH share markets before and after the Shanghai-Hong Kong Stock Connect. However, it is worth mentioning that we will add AH bank shares to the research object in this thesis. The reason for adding banking stocks as research objects is based on the following 2 reasons: 1. AH bank shares occupy more than 60% of the market capitalization of AH shares, and the AH premium of banking shares is relatively low. Therefore, as a traditional industry, the investment philosophy and valuation methods of banking shares are more mature, and the difference in investment preferences between the two markets is relatively small. 2. Due to regulatory requirements, the banking industry has a high level of information disclosure. Therefore, information asymmetry can be reduced for investors. Overall, by including banking stocks, we can eliminate sector speculation (e.g., pharmaceuticals, IT sector) and dramatic volatility of small-cap companies from our analysis, thus truly understanding the effect and impact of the Connect on cross-listed shares.

For the above study, we used the following data: the Shanghai and Hong Kong stock market indexes; the AH stock market indexes; and daily closing prices of the eight cross-listed AH stock bank shares. The study period is from 2010 to 2018. In the study of information transmission, we divide the sample into before November 2014 and after November 2014, and then explore the changes in information transmission between the two markets and these cross-listed stocks. Regardless of the AH premium index increase, we should see the real impact of the interconnection on the market correlation between the two markets and the cross-listed shares, so we will use the DCC GARCH model to explore the dynamic correlation. This thesis also provides a perspective for investors looking for arbitrage opportunities in AH stocks. They can better understand the correlation between the two stock markets and stock returns. The results of Granger causality and dynamic correlations will provide further reference and direction for investors' trading strategies.

The structure of this thesis is in five parts: Background review; Literature review; Data and methodology; Empirical evidence, and Conclusion. In the background review, we will introduce the basic information of China stock market and AH and the differences between them and introduce the trading mechanism of Shanghai-Hong Kong Stock

Connect and the policy meaning. In the literature review, we will review the analysis of cross-listed stocks in China and the global analysis of cross-listed stocks and inter-market correlations from the perspective of the AH share premium. In the Data and Methodology section, we will detail the scope of data selection and data processing and introduce the models that will be used in this thesis. In the empirical evidence part, we will present the results from models and compare the results with previous studies. Finally, we will summarize our output from thesis and suggest further extension points.

Chapter 2 AH share background review

The Chinese stock market is an emerging market with a relatively short history. In the early 1990s, two stock exchanges opened in the People's Republic of China: the Shanghai Stock Exchange and Shenzhen Stock Exchange[2]. Since then, the Chinese stock market has been developing in quick progression. However, based on the special national conditions and nature of state for China, the structure and management are different from many other mature capital markets.

In mainland China, shares are classified by investor and by place of listing. Depending on the type of investor, there are A shares and B shares. A shares are shares of mainland Chinese companies traded on the Chinese stock exchanges (Shanghai Stock Exchange and Shenzhen Stock Exchange). A-shares are quoted in RMB, and until 2001, the A-share market was only open to investors resident in mainland China. For foreign investors, China introduced the Qualified Foreign Institutional Investor (QFII) system in 2001, allowing qualified foreign institutions to invest in A shares within a certain quota. In 2011, China also introduced the Renminbi Qualified Foreign Institutional Investor (RQFII), allowing foreign institutions to invest directly in the mainland using foreign RMB within a certain quota limit, which relaxes existing restrictions on currency settlement. In September 2018, the revised Measures for the Administration of Securities Registration and Settlement and Measures for the Administration of Share Incentives of Listed Companies came into effect, allowing eligible foreign natural person[3] investors to open A-share accounts and invest directly in the A-share market.

On the other hand, companies listed on the Chinese stock exchange can also issue B shares. B shares are quoted in foreign currency and were only available to foreign investors until 2001. After 2001, the B share market was reformed and opened to both domestic and foreign investors.

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[2] Source: SSE Introduction (http://www.sse.com.cn/aboutus/sseintroduction/introduction/)

[3] only two types of foreign natural persons can open A-share accounts: first, foreigners working in mainland China; and second, foreign employees of A-share listed companies who work abroad and participate in share incentives.

According to the listing place, there are H-share, N-share, and S-shares. H-share is the share of Mainland China-based company that listed on the Hong Kong Stock Exchange. Similarly, N-share represents the share listed on the New York Stock Exchange, and S-share is the share listing on Singapore Stock Exchange. H-share is regulated by Chinese law, but they are quoted in Hong Kong dollars and trade like other shares on the Hong Kong Stock Exchange.

This thesis will mainly focus on Shanghai and Hong Kong stock markets and those AH cross-listed banking shares. The background and development of two stock markets and cross-listed shares are following:

1. The AH cross-listed shares development and stock market background

Hong Kong's stock market has a more extended history and complete system relative to China's stock market. The first official Association in Hong Kong was established in 1891, and then Association renamed the Hong Kong Stock Exchange in 1914[4].

With the opening up and the increasing degree of global economic and financial integration, cross-listing has become a widespread phenomenon worldwide. Affected by geopolitical, cultural, economic, and policy factors, Hong Kong is the first place for Chinese companies to list overseas. It is also the most concentrated market for Chinese companies to issue cross-listed shares. The cross-listed Chinese companies began in 1993[5]. At present, "A+H" is the primary choice for cross-listed Chinese companies.

In the initial stage, the A-share market has limited capacity and insufficient experience to meet the financing demand of domestic companies. In 1993, under the promotion by the Chinese government, after pre-selection, six companies, including Tsingtao Brewery and Sinopec issued H-share. Due to unfamiliarity with the rules and regulations of the Hong Kong Stock Exchange, those H-share had a lousy performance in the Hong Kong stock market and faced refinancing issues. Therefore, returning to A-shares had become their common choice. Based on this background, Tsingtao Brewery issued H

[4] Source: History of HKEX and its Market(https://www.hkexgroup.com/About-HKEX/Company-Information/About-HKEX/History-of-HKEX-and-its-Market?sc_lang=en)
[5] Source: Development of AH share (http://finance.sina.com.cn/focus/ahliandong/)

shares in Hong Kong in July 1993 and returned to the A-share market in August of the same year, becoming the first case of "A+H" listing.

In 1997, the return of Hong Kong inspired Chinese companies to raise capital overseas. As a result, 16 Chinese companies issued H-shares, and 4 achieved cross-listing in the same year. However, in 1998 the China Securities Regulatory Commission stipulated that companies issuing B or H shares were no longer allowed to issue A shares and vice versa, which put the process of cross-listing and financial market development in China on hold. However, with the trend of globalization, in 2001, the Chinese Ministry of Foreign Trade and Economic Cooperation and the CSRC jointly issued the "Certain Opinions on Issues Related to Foreign Investment in Listed Companies", which relaxed the restrictions on cross-listing and foreign investment. As a result, the number of AH companies continues to increase. As of the end of December 2019, there were 119 AH companies.

According to the primary industry classification, the finance and real estate, energy, and information technology sectors ranked the top three in terms of number of companies and market capitalization, with the three sectors together accounting for more than 70% of the total number of AH shares

2. Differences between the Mainland China and Hong Kong stock markets

AH's A shares and H shares are respectively listed in Mainland China and Hong Kong. These two markets have differences in investor structure, investment products, trading systems, IPO systems, and market supervision. The investment channels in the Mainland China market are narrow, and the trading products are mainly stocks and funds. On the other hand, the Hong Kong market is diversified in investment products, including stocks, funds, and various derivatives. Also, the investor structure is different in that the proportion of individual investors in A-shares is relatively high. However, for the Hong Kong market, nearly 60% of the total transaction amount comes from overseas and Hong Kong local institutional investors.

In terms of the market trading system, there are many differences between Hong Kong and mainland China. First, the A-share market does not allow direct short-selling of stocks, and investors can only do so through stock index futures or securities financing. In contrast, most stocks in Hong Kong can be sold short after being designated by the exchange. Secondly, the A-share market imposes a one-day limit (10%) on listed stocks, but the Hong Kong market has no limit on ups and downs. Finally, the A-share market uses a "T+1" trading system where stocks bought on the same day can only be sold the following day, while the Hong Kong stock market uses a "T+0" system where stocks bought can be sold on the same day.

For the IPO system in both markets, the stock market in mainland China is still being explored and reformed and is gradually moving towards marketization. However, the perfect IPO system is not yet complete. On the other hand, the Hong Kong market is one of the international financial centers, with a regulated market, well-developed regulations, and international alignment. Therefore, the IPO system in Hong Kong is more completed, and the degree of marketization is relatively higher than that in the mainland China market.

In terms of market regulation, there are specific differences between Hong Kong and mainland China. Hong Kong has been influenced by the British and American legal systems in terms of securities market regulation and is more internationalized. On the other hand, mainland China's securities market has borrowed and absorbed some foreign experience in its development process. As a result, the difference between the regulatory systems of the two markets is not too significant. However, the different levels of development of the two markets have affected the formulation and implementation of market regulatory policies.

3. AH Premium

In contrast to cross-listed stocks in developed markets such as Europe and the US, the premium of cross-listed stocks in China has the opposite phenomenon, with B and H shares trading at a significant discount to A shares. On July 9, 2007, Hang Seng Indexes launched the Hang Seng China AH Premium Index (HSAHP), which tracks the average price difference between A shares and H shares of the largest and the most liquid Chinese companies listed on both A shares and H shares, and measure this price difference. Its purpose is to calculate the weighted average premium (or discount) of A-share prices relative to H-share prices based on the free-float adjusted market capitalization of AH companies. There are currently 130 constituent shares included in this index, which varies according to the eligibility of the constituent stocks. When the AH premium index is less than 100, A shares are trading at a discount relative to H shares; when the AH premium exceeds 100, A shares are trading at a premium relative to H shares.

Figure 1. Hang Seng China AH Premium Index (HSAHP)

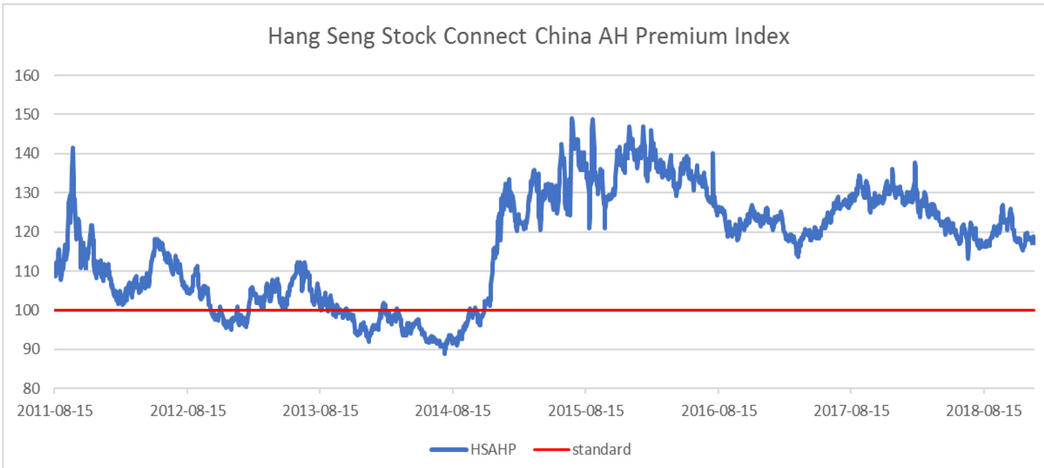


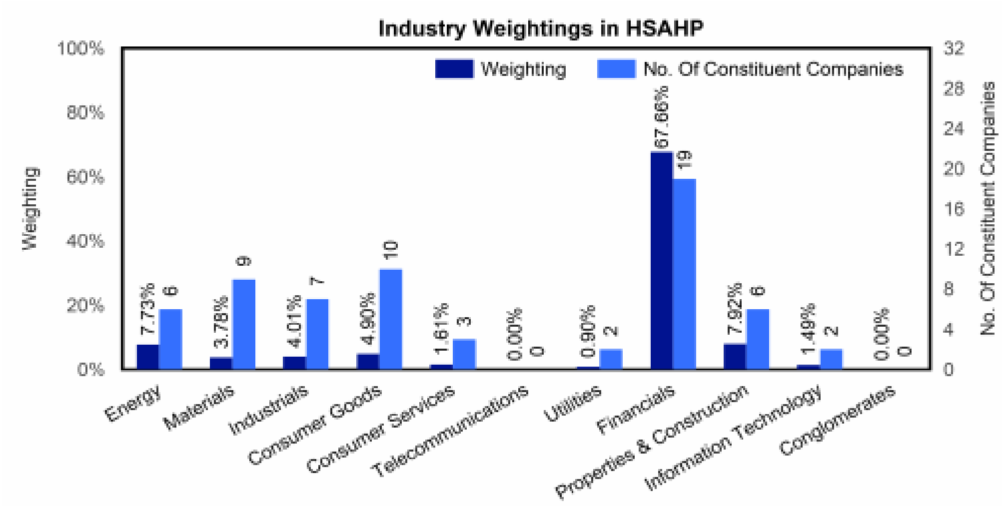
Figure 1 is the Hang Seng China AH Premium Index from August 2011 to December 2018.[6] Observing the historical performance of the index, most of the time A shares are at a premium relative to H shares, accounting for 82% of the entire trading day from August 2011 to December 2018. According to the industry classification standard, the AH Premium of each industry was different. The industries such as medicine, health, information technology, and consumption were consistently higher. For the industries such as the utilities, financial, real estate, raw materials, and other industries were not that high. The premium of the traditional cyclical industry is low, and the premium of the emerging technology industry is high. The characteristics of the industry will affect the premium level of AH shares.

The number of constituents for each industry and weighting in the AH Premium Index are in Figure 2[7] that we could see that the financial industry occupied over 65% in total weight, and banks are the main part of the financial industry.

[6] Source: https://www.hsi.com.hk/schi/indexes/all-indexes/ahpremium

[7] Source: https://www.hsi.com.hk/static/uploads/contents/zh_cn/dl_centre/factsheets/ahpremiumc

Figure 2. Industry Weighting in Hang Seng China AH Premium Index (HSAHP)



4. The Shanghai and Hong Kong Stock Exchange Connect

Mainland China and Hong Kong have long been exploring mechanisms for their connectivity. On November 17, 2014, the Shanghai-Hong Kong Stock Connect was officially launched, a unique collaboration establishing a trading link between two different stock exchanges. It is also an essential step in the opening up of China's capital markets, as it expands the scope of investment for domestic investors while providing a channel for foreign investment institutions to participate in China's domestic market.

Investors can be divided into northbound and southbound, investing in the Shanghai Stock Exchange and the Hong Kong Stock Exchange. Northbound trading allows all Hong Kong and international investors to purchase eligible stocks listed on the Shanghai Stock Exchange through their local brokers. Southbound trading allows eligible mainland Chinese investors, institutional investors, and individual investors with RMB 500,000 cash in their investment accounts to purchase eligible stocks listed on the Shanghai-Hong Kong Stock Exchange through their local brokers. The Shanghai-Hong Kong Stock Connect has a total annual quota as well as a daily quota. In the beginning, the total annual and daily quotas for the northbound direction were RMB 300 billion and RMB 13 billion, respectively. And the total annual and daily quotas for the southbound direction were RMB 250 billion and RMB 10.5 billion, respectively. Since May 1, 2018, the daily quota for northbound has been increased to RMB 52 billion, and the daily quota for southbound has been increased to RMB 42 billion. As a result, the Shanghai-Hong Kong Stock Connect has significantly increased the two-way capital flow between the Shanghai and Hong Kong stock markets.

The highlight for this Connect is in four points it is mutual market access with closed-loop capital flows; trades are controlled by quotas; quoted and settled in RMB to minimize currency risk; and clearing and settlement arrangements for prudent risk management and main market rules applicable to shares. Until 2018, for northbound trading, the eligible shares were 795, and for southbound trading, the eligible shares were 385. All AH shares are included in the Connect. Thus, the Connect removes the liquidity barrier for AH cross-listed stocks and also provides liquidity channels for both stock markets. The connection should result in improved market correlation and integration. This is why we used the Shanghai and Hong Kong Connect as a breakthrough to study the development of the two stock markets and AH cross-listed stocks.

Chapter 3 Literature Review

Cross-listed premiums are common, and as mentioned in the introduction, foreign-listed stocks are generally priced higher than domestic ones. However, for stocks cross-listed in mainland China and Hong Kong, the share price performance is the opposite. This premium phenomenon is also seen in the A and B share price differential.

Since the issuance of B shares, A shares have always had a premium over B shares. The most significant difference between A-shares and B-shares is quoted currency and investor structure. Before 2001, mainland Chinese investors could not invest in B-shares, and foreign investors could not invest in A-shares, and the two stock markets were split. To study A and B share premiums, domestic and foreign researchers mainly analyze them from the following points: information asymmetry, demand differences, liquidity differences, and risk differences.

The information asymmetry mainly refers to the discounted B-shares by foreign investors due to language differences, differences in accounting standards, and the lack of reliable information in the market. Chakravarty, Sarkar, and Wu (1998) include information asymmetry and market segmentation into the model and derive the relative pricing equations for A and B shares. Based on the pricing model, they find that if foreigners can trade A-shares, it will increase the liquidity of B-shares and thus reduce the B-share discount. Therefore, information asymmetry has strong explanatory power for the B-share discount. Chen, Lee, and Rui (2001) also support this opinion.

The demand difference refers to the fact that the demand for stocks is different between foreign investors and Chinese investors. Foreign investors have numerous investment opportunities, and therefore the price elasticity of demand for B-shares is higher. On the other hand, Chinese investors have narrower investment channels and therefore have less price elasticity of demand for A-shares. Stulz and Wasserfallen (1995) develop a model with a different demand function for domestic and foreign investors for domestic stocks. They find that domestic entrepreneurs maximize firm value by differentiating between domestic and foreign investors, which leads to differences in the prices of cross-listed shares.

On the other hand, the liquidity differences refer to the fact that when a stock is less liquid and has higher transaction costs, investors are less willing to buy, and the stock price decreases. For AB shares, B shares are always at a discount to A shares because the market for B shares is smaller and less liquid and because transaction costs also include exchange rate costs. Chen, Lee, and Rui (2001) found that the primary reason for price differences is the illiquid B share market. Due to the less liquid in the B share market, the investors have a higher expected return and lower share price to compensate for increased transaction costs. The Risk differences are analyzed mainly based on the risk preferences of investors and the structure of investors in different markets. The A-share market is mainly composed of individual investors, with a relatively small percentage of institutional investors. Generally speaking, individual investors have less capacity to analyze company valuation, market assessment, and industry future development, and are more sensitive to policies, and have a higher risk preference, with solid speculative characteristics. The B-share market is only open to foreign investors, who are mainly institutional investors. Institutional investors have better valuation mechanisms in evaluating companies, focusing on companies' medium and long-term development and are less affected by short-term policy incentives, and have lower risk preferences. Ma (1996) found price differences between A and B shares are correlated with investors' attitudes toward risk, and price differences between B and foreign stocks are also correlated.

There are also many studies to examine the price difference between A and B shares in terms of trading mechanism, market efficiency, and the effect of exchange rate changes. However, the main opinion is that the price difference between A and B shares is due to market segmentation and capital control. If investors in the A and B share markets could invest in each other, the price difference would gradually decrease under the market's action. Therefore, the Chinese government launched the B-share market reform in 2001, and the B-share prices increased significantly after the reform.

With the progress of global international development, China's capital market opening to the outside world has entered a new stage. In April 2000, the Chinese government relaxed the policy restrictions on the types of shares issued by listed companies.

As a result, more and more large companies adopted AH listing to improve the financing for companies.

As with the premium for AB shares, there was also a significant premium for AH shares. With the decline of the B-share market and the development of the H-share market, the AH-share premium has become a popular research topic for cross-listed Chinese companies. Most A-share prices are always higher than H-share prices, and the highest A-share price of individual companies even exceeds 100% of the H-share price.

Many researchers analyze the reasons for AH share premium based on the research model of AB share premium. Hu and Wang (2008) build a regression model based on the historical data of 51 AH listed companies to verify the effects of information asymmetry, demand difference, liquidity difference, and risk difference on AH premium. Based on this model, they further validate the effects of market volatility, interest rate changes, investor structure, and corporate governance on AH share prices. Through empirical tests, liquidity and information asymmetry have better explanatory power on the AH share premium. They argue that the market segmentation of the two stock markets and the limitation of capital flows are the root causes of the AH share price premium and addressing these two points is the best starting point to narrow the AH share price premium. However, the AH premium index has risen rapidly since the linkage and remained above 120 points. Market segmentation and capital restrictions are not the root cause to explain the AH share premium

With the AH share and AH share premium development, many researchers have gradually moved away from the micro-level studies of the one-price theorem. Instead, they study the information transmission and correlation between cross-listed stocks and returns in different financial markets at the market level from the perspective of investors and policymakers.

The literature on correlation and information transmission in financial markets dates back to the 1980s. A large literature uses the study of financial markets and financial instruments to determine the degree of integration between different markets within a geographic region and the linkages between international markets. In terms of cross-market studies, Theodossiou and Lee (1993) studied volatility spillovers and interdependence in the U.S., Japanese, U.K., Canadian, and German stock markets by implementing a multivariate GARHC model. They did not find a relationship between market volatility and expected returns. However, they found strong time-varying conditional volatility of returns in all markets, which supports the view that the conditional volatility of returns in these markets is influenced by foreign equity markets, especially the study that the U.S. market has significant volatility spillover effects on all other countries' equity markets. Xu and Fung (2005) used a bivariate asymmetric GARCH model to study the volatility spillover effects of returns traded in cross-market information flow patterns for precious metal futures contracts traded in the U.S. and Japanese markets. They find robust pricing transmission between the two markets, but in terms of returns, the information flow exists only from the U.S. market to the Japanese market. Moreover, this information transfer is usually rapid and can be absorbed within one trading day. There are also strong spillovers between the two markets, and the effects are comparable and similar. Chan, Lien, and Weng (2008) examine the causal relationship between Hong Kong and U.S. financial markets using band spectrum regressions to examine the dynamic nature of the interaction between these two capital markets. They find a unidirectional causal relationship from the U.S. market to the Hong Kong market.

Back to Mainland China, the Chinese stock market rapidly developed after 2001. The linkage between the Mainland China stock market and other important international stock markets started to be followed by researchers and investors. Many researchers studied the correlation between the Mainland China stock market with the Hong Kong stock market or with the United States stock market, which is based on the economic level, market segmentation, and cross-listed for those markets. Li (2007) used a four-variable asymmetric GARCH in line with the BEKK model to examine the linkages between the stock markets in Mainland China, Hong Kong, and the United States. Similar to Theodossiou and Lee (1993), he did not find the directional linkage between the stock market in Mainland China and the United States, but he found the volatility spillover from the Hong Kong to the Mainland China stock market and weak integration of the Mainland China stock market with the developed stock markets. The weak integration of markets could benefit overseas investors to diversify their investment risk by investing shares in multiple stock markets. Hou, Li (2016) used the asymmetric DCC GARCH model to find the volatility transmission and volatility spillover effect between the United States and China stock markets. Based on the model, they found out a two-way volatility spillover to opening prices between the United States and Mainland China market, but for the daily trading, there is the only one-way volatility spillover effect from the United States to Mainland China. Therefore, the United States market is more efficient in impounding information from other markets.

Overall, in studies of market correlation and information transmission for cross markets, many researchers have found spillover effects are usually from developed country markets to developing country markets. Thus, there is not always two-way causal relationship between developed country stock markets and developing country stock markets. However, stock markets with similar economic levels and relatively close geographical backgrounds have shown higher correlations and effective information transmission. Correlation and information transmission between stock markets also affect the information transmission and price differences of cross-listed shares. With the globalization of financial markets, cross-listed stocks are becoming more common in the capital markets. Since 2000, the phenomenon of premiums and information transmission regarding cross-listed stocks has received more attention from researchers and investors. Cross-listing usually exists between the domestic stock market and the U.S. stock market in the European and American stock markets. As a result, many studies examine the correlation between cross-listed stocks and stock markets between U.S. and other countries' stock markets.

T. Alaganar and Bhar (2002) examine the information flow between stocks using a bivariate GARCH model using cross-listed stock trades in Australia and the United States. They find no directional information flow from the United States stock market to the Australian stock market for either cross-listed stocks or stock indices. However, the effect of the United States stock market on the average return and volatility levels of stock markets in other countries is more significant. Eun and Sabherwal (2003) studied the relationship and price discovery for cross-listed Canadian shares in the United States market. They applied the Harris et al. (1995) permanent and transitory test to find the price discovery contributions for the cross-listing shares. They found out that the shares listed in the domestic market (Canada) have more contribution to price discovery than those listed in the United States market. The price adjustment is general according to the changes that happened in domestic. Even the price adjustment for shares in the United States market is following the changes in Canada, and the price adjustment is still quick. In research of emerging countries, Yaseen, Lam, and Barkoulas (2014) studied the cross-listed shares of Israeli firms, which cross-listed in their domestic markets and the United States. By implement the bivariate GARCH model, they found unidirectional mean return and volatility spillover effect from the United States to the Israeli market, but not vice versa. Therefore, the domestic market dominates the overseas market in the price discovery process with cross-listing cases, providing new evidence to support the home bias hypothesis. They also found that external shocks come from the Middle East peace process have no impact on the conditional correlation between the two markets. However, external shocks come from the world and other regional markets impact the conditional correlation positively. Su and Chong (2007) studied the price discovery between Chinese companies cross-listed on the Hong Kong and New York stock markets, and they implement both Gonzola and Granger (1995)'s permanent–transitory decomposition and Hasbrouck (1995)'s information share methods for the examination. They found out the shares from both markets are co-integrated, but the shares listed in Hong Kong have better price discovery than the shares listed in New York. The conclusion of this type of research is similar, and even though the correlation varies across markets, mature capital markets have a stronger influence on share prices, and information transmission is not necessarily a two-way street.

The market background for cross-listed stocks in China is constantly changing. The B-share market reform in 2001 was an initial attempt to open up China's capital market. After that, the Chinese government gradually introduced various policies to provide domestic and foreign investors with broader investment channels and a platform for the opening up of China's financial markets and the internationalization of the RMB. Each of these new policies has had an impact on cross-listed stocks.

Lou (2005) analyzed the price differences between A and H shares and A and B shares using a panel data model based on Fame and French's (1996) concept of dynamic portfolios. Based on the cointegration test and Granger causality test, he finds that cointegration exists in most cross-listed companies, and most of them have causality from B shares to A shares. After the B share market opening to domestic investors in 2001, the cointegration improves significantly, and the price adjustment function of A shares to B shares is improved. However, the opening of the B-share market did not affect the cross-listed stocks in the A-share and H-share markets, and the segmentation between the A-share and H-share markets did not improve. Lu, Wang, Chen, and Chong (2007) investigated the effectiveness and influence of regulatory policies on Chines A share and B share markets. The opening of the B share market to domestic investors increases market efficiency, which also significantly reduces the price differential between A shares and B shares. Veiga, Chan, and McAleer (2008) also studied the regulation influence on stock markets and cross-listing shares. Based on the B share market reform background, they analyzed the conditional correlation and information transmission between A and B shares. They found out that the reform significantly impacted volatility spillovers and volatility transmission between A share and B share markets. And all pairs of conditional correlations increased, and information transmission mechanisms have been improved after the reform. Tan, Chiang, Mason, and Nelling (2008) applied three models to discover the correlation between A and B share markets: basic correlation method, dynamic conditional correlation model (VGARCH-DCC), and GARCH based Cholesky decomposition method. They found a consistent positive trend of correlation between cross-listed A shares and B shares. Moreover, when the government announced a new policy to improve the integration of A share and B share markets, the barriers of trading decreased, which further enhances the co-movement between A share and B share markets. Chen, Jiang, Li, and Sim (2010) focus on the volatility spillover effect between Chinese A-shares and B-shares markets with the structural changes of B share market after 2001. They used the bivariate GARCH model to test the volatility changes in both markets after reform and found the volatility in A shares has more significant increases than B shares, enhancing the risk for the whole stock market. Cai, McGuinness, and Zhang (2011) used daily price data and implemented a non-linear Markov error correction model to test the cointegration relationship between cross-listed Chinese state-owned companies' A- shares and H- shares. They found a tendency in line with Chinese government policies that aim to reform China's capital account regime and exchange rate system. They also found out that the cross-listed H shares would increase the price transparency in the Mainland and Chinese governance reformation had significantly positive impacts on both Mainland China and Hong Kong markets. Chen, Buckland, and Williams (2011) applied the VECM-MV-GARCH model to examine the response of various industries in Hong Kong, Mainland China (A share and B share) markets when the regulatory changed from the Chinese government. They did not find much significant evidence of cointegration between Hong Kong and the Mainland market before the deregulation in Mainland China. However, after implementing stock market deregulation, they found a consistently increasing conditional correlation between two markets both in the short-term and long-term.

Before the Shanghai-Hong Kong Stock Connect launch, there have been many studies on the information transmission and correlation between A and H shares. And since the implementation of the Shanghai-Hong Kong Stock Connect in 2014, researchers have paid more attention to the impact of the Shanghai Stock Connect on cross-listed stocks and the stock markets in Shanghai and Hong Kong while studying the results of market correlation presentation.

Buckle, Chen, McMillan, and Tong (2017) find that regulatory changes have an impact not only on the mainland market but also on cross-listed H-shares. Furthermore, as the number of cross-listed stocks increases, policies in the mainland market are likely to affect the entire Hong Kong stock market. When the Chinese government opens up the mainland market and provides a higher freedom level for capital movements between the two markets in mainland China and Hong Kong, cross-listed stocks will benefit from both markets.

Huo and D. Ahmed (2017) use high-frequency data and GARCH models to find that the Shanghai-Hong Kong Stock Connect does boost the influence of stock markets and economic activity in mainland China. The Shanghai stock market leads to the Hong Kong stock market's mean and volatility spillover effects after the Shanghai-Hong Kong Stock Connect. Due to the enhanced volatility spillover effect of the Shanghai stock market on the Hong Kong stock market, the opening of the mainland China stock market can enhance the dominance of the mainland China stock market, influence the risk level and improve the market efficiency.

Lin (2017) applies the ARMA-BEKK-AGARCH model to study the volatility link between Shanghai and Hong Kong stock markets before and after implementing the Shanghai-Hong Kong Stock Connect. He finds that it is always the Hong Kong market that transmits shocks to the Shanghai market regarding the spillover of shocks. The transmission of volatility changes from significant before the Shanghai-Hong Kong Stock Connect to insignificant afterward.

Hui and Chan (2018) investigate how the Shanghai-Hong Kong pass-through affects the stock markets of both places and the pricing dynamics of cross-listed stocks. By using linear regressions to examine the rise in AH share prices using the stock AH premium as a dummy variable, they find that trading activity in the Chinese mainland market has a more pronounced effect on the AH premium than trading activity in the Hong Kong market, implying that the Chinese mainland financial market plays a dominant role in the Shanghai-Hong Kong stock interconnection.

Ma, Deng, Cai, and Zhai (2019) use DCC, ADCC, and GO-GARCH models to investigate whether the Shanghai-Hong Kong Stock Connect facilitates market flows between Shanghai and Hong Kong. By comparing time-varying correlations between Shanghai and Hong Kong, Shenzhen and Hong Kong markets, and distinguishing between market turbulence caused by policy announcements, the models show that market correlations between Shanghai and Hong Kong do not increase significantly after implementing the program. As a result, the researchers concluded that the Shanghai-Hong Kong Stock Connect program is not a major potential force to boost market flows between Shanghai and Hong Kong in the short term.

Cheng, Chow, Chui, and Wong (2019) study the sustainability of financial integration between the Chinese (Shanghai and Shenzhen) stock markets and the Hong Kong stock market before and after the launch of the Connect. They use cointegration and linear and nonlinear causality to investigate whether the Shanghai-Hong Kong Stock

Connect has an impact on both market capitalization and market indices in Hong Kong, Shanghai, and Shenzhen. Using cointegration tests and linear Granger causality testing techniques, they find that the stock market in mainland China has an increasing impact on Hong Kong stocks.

Throughout the literature review, we review the analysis of China's cross-listed share premiums and the analysis of Shanghai and Hong Kong stock market correlations and information transmission. We found that different researchers have different conclusions on AH correlation and information transmission based on different hypothetical conditions. Therefore, we include the more stable AH bank shares to analyse the Shanghai-Hong Kong Stock Connect impact on cross-listed AH shares in the Shanghai-Hong Kong stock market and the development of information transmission and correlation between AH shares and two stock markets.

Chapter 4 Methodology of empirical research

This chapter describes the data collection and processing, and the models that will be applied in the empirical analysis section. First, we will present the background of data collection and the data collation process. Then, based on the literature review, we will introduce and describe the econometric model: VAR model and DCC GARCH model, which we will use to find out the causality and dynamic correlation between the two stock markets, AH share market and cross-listed AH bank shares.

4.1 Data collection and description

Since the purpose of this thesis is to analyze the development of the information transmission and dynamic correlation between Shanghai and Hong Kong stock markets, AH share market, and cross-listing AH bank shares, we extracted 2 types of data into our data collection, which are stock market indexes and daily closing price of shares.

For the stock market index, we used Shanghai Stock Exchange Composite Index (SSE) for the Shanghai stock market and Hang Seng Index (HSI) for the Hong Kong stock market. The SSE Composite Index[8] includes all A- and B-shares listed in Shanghai Stock Exchange and is calculated bases on the total market capitalization of those listed shares. The Hang Seng Index[9] uses free float-adjusted market-capitalization to include in 50 constituents' companies represent about 58% of the capitalization of the Hong Kong Stock Exchange. Thus, those two indexes are the primary index to reflect the performance of the general stock market.

We already introduced Hang Seng Stock Connect China AH Premium Index (HSAHP) in the background part regarding the cross-listed AH shares market. The HSAHP belongs to Hang Seng Stock Connect China AH Index Series (AH Series)[10] ,which includes in 5 indexes: The Hang Seng Stock Connect China AH Premium Index (HSAHP), the Hang Seng Stock Connect China AH (A+H) Index (AHXAH), the Hang Seng Stock Connect China AH (A) Index (AHXA), the Hang Seng Stock Connect China AH (H) Index

[8] Source: http://english.sse.com.cn/markets/indices/overview/
[9] Source: https://www.hsi.com.hk/schi/indexes/all-indexes/hsi
[10] Source: https://www.hsi.com.hk/schi/indexes/all-indexes/chinaah

(AHXH) and the Hang Seng Stock Connect China AH Smart Index (HSCAHSI). Bases on each index's different constituents reflect the price performance of those cross-listed shares in the Mainland China and Hong Kong stock market. In this thesis, we want to analyze the information transmission and correlation of AH cross-listed stocks in their respective markets and compare them with the Shanghai and Hong Kong stock markets, so we will use the AHXA and AHXH indices for further analysis. The frequency of the SSE and HSI is daily, and the period is from January 2010 to December 2018. AHXA and AHXH are also daily, but due to missing information, the period is from November 2011 to December 2018. So, we have 4 indexes data with almost 8 years research period.

The second type of data is the daily closing price of cross-listed AH bank shares. Currently, there are nine cross-listed AH bank shares in the market, but we exclude China Everbright Bank (CEB) because it was listed on the Hong Kong Stock Exchange in December 2013, too close to the launch of the Shanghai-Hong Kong Stock Connect, which may lead to biased analysis. Agricultural Bank Of China (ABC) was listed in mid-July 2010, again later than the research period. However, we did not exclude ABC stock due to its large market capitalization and the that only six months of data are missing. There are 8 AH bank shares, and 4 market indexes are selected for this thesis.[11]

Table 1. Summary of data in the research

Data Type	Code	A/H code	Name	Industrial Sector
Index	SSE	SSE	SSE Composite Index	
	HSI	HSI	Hang Seng Index	
	AH_A	AHXA	Hang Seng Stock Connect China AH (A) Index	
	AH_H	AHXH	Hang Seng Stock Connect China AH (H) Index	
Price	ABC	601288/1288	Agricultural Bank Of China	Financial Sector
	BOC	601988/3988	Bank Of China Limited	Financial Sector
	BOCM	601328/3328	Bank Of Communications	Financial Sector
	CCB	601939/939	China Construction Bank Corporation	Financial Sector
	CITIC	601998/998	Citic Bank Corporation Limited	Financial Sector
	CMB	600036/3968	China Merchants Bank	Financial Sector
	CMBC	600016/1988	China Minsheng Banking Corporation	Financial Sector
	ICBC	601398/1398	Industrial and Commercial Bank Of China	Financial Sector

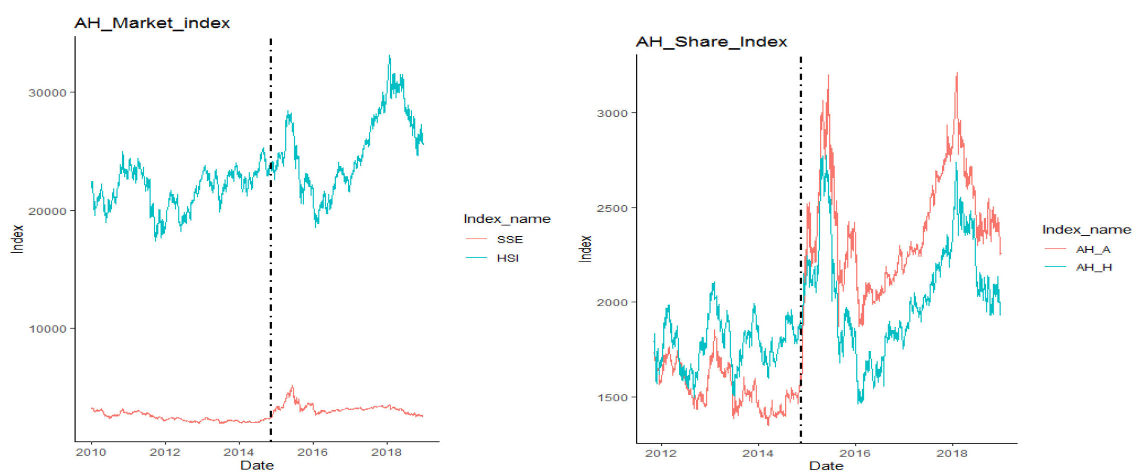
[11] All the data for market indexes and shares price came from Yahoo Finance.

Since the trading dates of the Shanghai and Hong Kong stock markets are not exactly the same, we need to clean up the data beforehand. Therefore, we manually exclude the data with mismatched trading days in both markets. As a result, the total average number of observations for each index and share price during the research period is around 2220. After excluding the mismatched trading days, the average number of observations for each index and share is around 2100.

On the other hand, the Connect is quote and settled in RMB, and HKD/CNY is changing bases on the foreign exchange market. Therefore, we used the daily foreign exchange rate of HKD/CNY provided by the Shanghai Stock Exchange to exchange all H shares to RMB. Based on those prior data processes, we aimed to decrease the influence of the exchange rate on share price and return.

From Figure 3, we could see the trend of the two stock markets and cross-listed share market. The vertical lines are the days of the implementation of the Shanghai-Hong Kong Stock Connect to distinguish the market performance before and after the implementation. We could see that the trend of index changes in Shanghai and Hong Kong stock markets are not similar, especially after 2016, when the SSE had a significant rise, while the overall trend of changes in the HSI is more stable. And the trend of stock indexes in A and H stock markets is more similar.

Figure 3. The SSE, HSI and AH share market index



For AH bank stocks, the price trend for each stock is also very different. This can be seen in detail in Figure 4.

Figure 4. AH bank shares' price

In table 2, we summary some key indicator for AH bank share from end of 2019, the number of A shares issued by most bank share is higher than the number of H shares.

Table 2. Key indicators for AH bank shares

				Unit: Millions USD
Bank	**ABC**	**BOC**	**BOCM**	**CCB**
Total assets	3,293,104.95	3,071,963.19	1,388,230.02	3,382,421.70
Total shareholders' equity	231,643.53	220,409.57	93,002.75	276,275.83
Return on Shareholders' Equity	12.45%	12.26%	11.20%	13.27%
Total Capital Ratio	14.11%	14.27%	13.96%	16.13%
Non-performing Loan Ratio	1.59%	1.41%	1.49%	1.46%
Total number of shares	349,983	294,388	74,263	250,011
Total number of A shares	319,244	210,766	39,251	9,594
Total number of H shares	30,739	83,622	35,012	240,417
Bank	**CITIC**	**CMB**	**CMBC**	**ICBC**
Total assets	883,626.42	982,526.02	875,156.50	4,034,481.49
Total shareholders' equity	58,509.11	73,707.41	61,324.67	326,834.84
Return on Shareholders' Equity	10.96%	15.64%	12.94%	13.11%
Total Capital Ratio	12.31%	15.00%	11.75%	14.56%
Non-performing Loan Ratio	1.81%	1.36%	1.75%	1.52%
Total number of shares	48,935	25,220	43,782	356,406
Total number of A shares	34,053	20,629	35,462	269,612
Total number of H shares	14,882	4,591	8,320	86,794

Source: https://finance.sina.com.cn/

When considering the Shanghai-Hong Kong Stock Exchange Connect impact, we used 17th November 2014 as the break point and divided each group into two subgroups: The “Before November 2014” and “After November 2014”. This subgroup will apply to VAR and Granger Causality test. Furthermore, in correlation development between two stock markets and shares, we use whole period observation in the DCC GARCH model, which will provide a dynamic correlation of research objects.

4.2 The methodology for empirical research

Based on the literature on information transmission and dynamic correlation between financial markets and cross-listed shares, two models will be used in this thesis: the VAR model and the DCC GARCH model. The VAR model is one of the most commonly used models to analyze multiple regression time series, and it has the advantage of explaining the past and causality of multiple objects in a time-varying manner. We will build the VAR model to determine the causal relationship between different stock markets and between AH shares by Granger causality test. The DCC GARCH model was proposed by Engle (2002), and since then the model has been widely used in correlation studies of financial markets. Using the DCC GARCH model, we will find out the actual dynamic correlation coefficients of two markets and AH shares.

4.2.1 The Stationary of data collection

The first and the most important things time series analysis is stationary, so we need to ensure data is stationary. If the unit root exists in the time series data, it will show a systematic pattern, and the data will not be predicted. Therefore, in statistics, the unit root test is a mandatory test before any modeling, it will test whether a time series variable is non-stationary and possesses a unit root.

This thesis will use the Augmented Dickey-Fuller test (ADF), which is the most common and practical test for a unit root in a time series data. The producer for the ADF test is applied in the equation below:

$$\Delta y_t = c + \beta t + \gamma y_{t-1} + \delta \Delta y_{t-1} + \cdots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t$$

Where c is a constant, β is the coefficient on a time trend and p is the lag order of the autoregressive process. The null hypothesis is a unit root is present in a time series data. The ADF statistic result in the test is typically a negative number. If the data is not stationary, differencing will be necessary. The common transformation way is logarithms, which is widely used in financial time series study and will also result in the daily return rate of our research objects. So, we will first test the stationary for the original market index and share price. If data is not stationary. We will apply the daily return rate for the index and shares.

4.2.2 VAR model with Granger Causality

As we mentioned at the beginning of the methodology part, the vector autoregression (VAR) model is a flexible and commonly used model for multivariable time series study.

A multivariate time series $u_1, u_2, \ldots u_m$, where for each time t u_t is a real valued n-dimensional vector with components $u_{1t}, u_{2t}, \ldots u_{nt}$. A *p*th order vector autoregressive model for VAR(*p*) is following:

$$U_t = \sum_{k=1}^{P} A_k U_{t-k} + \varepsilon_t$$

The n × n real-valued matrices A_k are the regression coefficients, and the n-dimensional stochastic process ε_t is the residuals with a white noise process, which are independently and serially uncorrelated.

The efficacy of the VAR model has been proved by many empirical analyses of financial time series, which describe the dynamic behavior of financial time series. It is also widely used as the foundation for structural inference and analysis, such as the Granger causality test. The Granger causality test is more efficient and accurate for forecasting when one object is causing the others, and it provides an efficient way to determine the relationship between two or more objects. Granger proposed this test in 1969. There are two time series Xt and Yt in the two-variable models, and both are stationary time series with zero means. In our thesis, the two-time series will be the return of market index or shares price in different stock markets. The Xt represents the return of A share, and Yt represents return of H shares. The casual model is:

$$U_t = \begin{pmatrix} X_t \\ Y_t \end{pmatrix}$$

$$X_t = \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + \varepsilon_t$$

$$Y_t = \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + \eta_t$$

The ε_t and η_t are two uncorrelated white-noise series, and *m* is the given research period. An F-test is applied in the Granger causality test to check the model fitted into our share return and market return.

When the information in A share in time t could provide statistically significant information about future values of H shares in time t through a series of t-tests and F-tests on lagged values of A share in time t-j, we call time series A share is causing H share, vice versa. According to the above formulas, the definition of causality relation could be implied by the parameters. So, when H share is causing A share, then bj is not zero; when A share is causing H share, then cj is not zero. The null hypothesis is not rejected if and only if no lagged values of A share are retained in the regression, which is rejected if the F statics value calculated from the data is greater than the critical value of the F-test at some level of confidence.

To test whether there was a change in the causal relationship of two stock markets and AH cross-listed bank shares after the Connect launched in 2014, we will apply the subgroup of data into model. And compare the causal relationship between different times of the same objects.

4.2.3 DCC GARCH model

DCC GARCH is one of the most famous and commonly used models in multivariate GARCH model family. Engle proposed this model in 2002, which mainly focused on the dynamic correlation of multiple financial variables. The DCC estimator have more flexibility than univariate GARCH, and less complexity of conventional multivariate GARCH model. However, the data should firstly fit in the Auto Regressive Integrated Moving Average (ARIMA) model to eliminate the autocorrelation. If the residual is a white noise and has ARCH effect, we will then apply the GARCH model to residual and estimate the actual financial time series data volatility.

The ARIMA model can be written as:

$$y'_t = c + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} + \varepsilon_t$$

This is the equation for ARIMA (p,d,q) model, which p is order of autoregressive part(AR), d is degree of first differencing involved, and q is the order of the moving average part(MA). The y'_t is the differenced series, the predictor on the right-hand side includes both lagged value of y_t and lagged error ε_t.

The DCC GARCH model developed from Bollerslev (1990) constant conditional correlation (CCC) GARCH model. The difference is DCC allowing correlation matrix $\boldsymbol{R}$ to be time varying.

Suppose the returns $\boldsymbol{r}_t$ from n objects with expected value 0 and covariance matrix $\boldsymbol{H}_t$. Then the formula of DCC GARCH model is defined as:

$$\boldsymbol{H}_t = \boldsymbol{D}_t \boldsymbol{R}_t \boldsymbol{D}_t$$

$\boldsymbol{H}_t$ is $n \times n$ matrix of conditional variances of $\boldsymbol{\varepsilon}_t$ at time *t*. The $\boldsymbol{D}_t$ is $n \times n$ diagonal matrix of conditional standard deviations of $\boldsymbol{\varepsilon}_t$ at time *t*. And $\boldsymbol{R}_t$ is $n \times n$ conditional correlation matrix of $\boldsymbol{\varepsilon}_t$ at time *t*.

The elements in the diagonal matrix $\boldsymbol{D}_t$ are standard deviations from univariate GARCH models.

$$\begin{bmatrix} \sqrt{h_{1,t}} & 0 & \cdots & 0 \\ 0 & \sqrt{h_{2,t}} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sqrt{h_{n,t}} \end{bmatrix}$$

Where

$$h_{i,t} = \omega_i + \sum_{p=1}^{P_i} \alpha_{i,p} \gamma_{i,t-p}^2 + \sum_{q=1}^{Q_i} \beta_{i,q} h_{i,t-q}$$

Where α and β are non-negative parameter and α+β<1, which is restriction of GARCH for non-negativity and stationary. The univariate GARCH models could have different orders. The specification of the univariate GARCH models is not limited to the standard univariate GARCH(p, q), and can include in any GARCH process with Gaussian distributed errors that satisfies appropriate stationarity conditions that ensures the unconditional variance to exist.

$\boldsymbol{R}_t$ is the conditional correlation matrix of the standardized disturbances ε_t, i.e:

$$\boldsymbol{\varepsilon}_t = \boldsymbol{D}_t^{-1} r_t \sim N(\boldsymbol{0}, \boldsymbol{R}_t)$$

Since $\boldsymbol{R}_t$ is a correlation matrix it is symmetric.

$$R_t = \begin{bmatrix} 1 & \rho_{1,2,t} & \rho_{1,3,t} & \cdots & \rho_{1,n,t} \\ \rho_{1,2,t} & 1 & \rho_{23,t} & \cdots & \rho_{2,n,t} \\ \rho_{1,3,t} & \rho_{2,3,t} & 1 & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \rho_{n-1,n,t} \\ \rho_{1,n,t} & \rho_{2,n,t} & \cdots & \rho_{n-1,n,t} & 1 \end{bmatrix}$$

The elements of $\boldsymbol{H}_t = \boldsymbol{D}_t \boldsymbol{R}_t \boldsymbol{D}_t$ is:

$$[\boldsymbol{H}_t]_{ij} = \sqrt{h_{ij} h_{jt} \rho_{ij}}$$

Where $\rho_{ii} = 1$.

There are two requirements need to be considered when we are specifying a form of $\boldsymbol{R}_t$. Firstly, the $\boldsymbol{H}_t$ must be positive definite since it is a covariance matrix. So $\boldsymbol{R}_t$ must be positive definite. Secondly, all the elements in the correlation matrix $\boldsymbol{R}_t$ must be equal to or less than one by definition.

To ensure all of these requirements in the DCC-GARCH model, $\boldsymbol{R}_t$ is decomposed into:

$$\boldsymbol{R}_t = \boldsymbol{Q}_t^{*-1} \boldsymbol{Q}_t \boldsymbol{Q}_t^{*-1}$$

where $\overline{\boldsymbol{Q}} = \mathrm{Cov}[\boldsymbol{\varepsilon}_{t-1} \boldsymbol{\varepsilon}_t^T] = \mathrm{E}[\boldsymbol{\varepsilon}_{t-1} \boldsymbol{\varepsilon}_t^T]$ is the unconditional covariance matrix of the standardized errors $\boldsymbol{\varepsilon}_t$. $\overline{\boldsymbol{Q}}$ can be estimated as:

$$\overline{\boldsymbol{Q}} = \frac{1}{T} \sum_{t=1}^{T} \boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t^T$$

The parameters a and b are scalars, and $\mathbf{Q}_t^*$ is a diagonal matrix with the square root of the diagonal elements of $\boldsymbol{Q}_t$ at the diagonal:

$$Q_t^* = \begin{bmatrix} \sqrt{q_{11,t}} & 0 & \cdots & 0 \\ 0 & \sqrt{q_{22,t}} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sqrt{q_{ii,t}} \end{bmatrix}$$

$\boldsymbol{Q}_t^*$ rescales the elements in $\boldsymbol{Q}_t$ to ensure the second requirement $|\rho_{ij}| = \left|\frac{q_{ijt}}{q_{iit} q_{jjt}}\right| \leq 1$. Further $\boldsymbol{Q}_t$ has to be positive definite to ensure $\boldsymbol{R}_t$ to be positive definite.

In order to guarantee $\boldsymbol{H}_t$ to be positive definite, the scalars a and b must satisfy:

$$a \geq 0\ ,\ b \geq 0 \text{ and } a + b < 1$$

And in additional for $\boldsymbol{Q}_0$ the starting value of $\boldsymbol{Q}_t$, has to be positive definite to guarantee $\boldsymbol{H}_t$ to be positive definite.

The correlation structure can be extended to the general DCC(M,N)-GARCH model:

$$\boldsymbol{Q}_t = \left(1 - \sum_{m=1}^{M} a_m - \sum_{n=1}^{N} b_n\right)\overline{\boldsymbol{Q_t}} + \sum_{m=1}^{M} a_m \boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}_{t-1}^T + \sum_{n=1}^{N} b_n \boldsymbol{Q}_{t-1}$$

And DCC (1,1)-GARCH model is:

$$\boldsymbol{Q}_t = (1 - a_m - b_n)\overline{\boldsymbol{Q}} + a_m \boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}_{t-1}^T + b_n \boldsymbol{Q}_{t-1}$$

When the parameters in $\boldsymbol{D}$ be denoted $\theta$and the additional parameters in $\boldsymbol{R}$ be denoted ϕ.The log likelihood can be written as the sum of a volatility part and a correlation part:

$$L(\theta, \phi) = L_V(\theta) + L_C(\theta, \phi)$$

The volatility term is

$$L_V(\theta) = -\frac{1}{2}\sum_t (n \log(2\pi) + \log|D_t|^2 + r_t' D_t^{-2} r_t)$$

And the correlation component is

$$L_C(\theta, \phi) = -\frac{1}{2}\sum_t (\log|R_t| + \varepsilon_t' R_t^{-1} \varepsilon_t - \varepsilon_t' \varepsilon_t)$$

According to many researches, the DCC-GARCH (1,1) is sufficient to find the volatility and correlation, the higher differencing is not so effective. So, we will apply DCC-GARCH (1,1) model in our empirical analysis. The market index and cross-listed share price will be modelled in pair, so we observe accrued volatility and correlation between each stock markets and cross-listed AH bank shares.

Chapter 5 Empirical evidence and analysis

In this chapter, we will present the empirical evidence from the model in this thesis. In the beginning, we will describe the statistical summary of data we used in empirical research. Then the VAR model will be applied to data for the Granger Causality test to describe the changes of information transmission and causal relationship before and after the Connect. Last but not least, the DCC GARCH model will be used for the paired data to observe the conditional correlation in the whole period. Finally, we will compare whether the trend of correlation between the markets and shares is the same as our expectation. In the end, we will summarize empirical results and discuss previous literature.

5.1 Data summary and stationary test

In this sector, we provide the basic summary and statistical description for our data collection. The summary represents three subgroups: the "Whole Period", the "Before November 2014" and the "After November 2014". From 2010 to 2018, even the Shanghai and the Hong Kong stock market experienced varying changes, but there was no financial crisis. The fundamental market introduction and data collection have been introduced in chapter 2 and chapter 4.

To see the whole picture with general information for the markets and shares, we will start from the "Whole Period" summary in table 3. We could see that both share price and market index have a massive gap between the minimum value and maximum value and the share price of A shares is consistently higher than H shares. When we look for the mean and median value, in the H-shares market, most of the mean value is higher than the median value (8 in a total of 10), and half of A-share market shares have a higher mean value than the median value. It means more observations have a higher value, and there is a positive skew. The general market has a strong performance, especially for the H-share market. For the standard deviation, usually, A-shares have a higher standard deviation than H-shares, which presents the higher volatility in A shares market. Regarding the unconditional Correlation coefficients, except for the share ABC and the market index SSE&HSI has the lowest correlation in general, the correlation for the rest of paired data is higher than 0.5. Based on the correlation in Table 3, we can see that the cross-listed stocks have a high correlation, and the two markets have a low correlation

Table 3. The summary of data for whole period from 2010 –2018

Whole period	ABC_A	ABC_H	BOC_A	BOC_H	BOCM_A	BOCM_H	CCB_A	CCB_H	CITIC_A	CITIC_H
nbr.val	1996	1996	2115	2115	2117	2117	2115	2115	2115	2115
min	2.29	2.115342	2.45	1.93166	3.63	3.606278	3.78	3.774915	3.41	2.634126
max	4.75	3.97194	5.6	4.442775	9.4	7.392229	9.81	7.392672	10.28	5.874855
median	2.92	2.967321	3.36	3.000712	5.52	4.906231	4.93	5.078974	5.54	4.142
mean	3.02981	2.957114	3.395058	3.036052	5.43277	5.023007	5.322922	5.122863	5.504391	4.054949
var	0.2512284	0.1362688	0.3350078	0.1919549	1.053079	0.6618197	1.222984	0.5022561	1.502478	0.3332258
std.dev	0.5012269	0.3691461	0.5787986	0.4381265	1.026197	0.813523	1.105886	0.7087003	1.225756	0.5772571
Jarque Bera Test (p value)	213.2381 (< 2.2e-16)		372.4845 (< 2.2e-16)		281.3242 (< 2.2e-16)		1011.1648 (< 2.2e-16)		645.365 (< 2.2e-16)	
Whole period	CMB_A	CMB_H	CMBC_A	CMBC_H	ICBC_A	ICBC_H	SSE	HSI	AH_A	AH_H
nbr.val	2121	2121	2120	2120	2116	2116	2120	2120	1695	1695
min	9.39752	8.993829	3.43056	2.674341	3.23	3.132018	1950.012	17407.8	1346.5	1461.75
max	34.89	31.58016	9.25	7.71807	7.75	6.030864	5166.35	33154.12	3213.82	2777.08
median	14.2392	15.08144	6.03	4.903526	4.36	4.361467	2798.543	22901.25	2066.02	1878.25
mean	16.32381	16.25529	5.904548	4.949063	4.524204	4.43072	2787.181	23344.96	2037.393	1931.354
var	38.2014	25.65797	2.363005	0.804488	0.5722537	0.3720647	307916.2	9409608	233017.2	72202.05
std.dev	6.180728	5.06537	1.537207	0.8969325	0.7564746	0.6099711	554.902	3067.508	482.7186	268.7044
Jarque Bera Test (p value)	865.7918 (< 2.2e-16)		284.0652 (< 2.2e-16)		572.0411 (< 2.2e-16)		572.4277 (< 2.2e-16)		227.4746 (< 2.2e-16)	
Correlation	ABC_A	ABC_H	BOC_A	BOC_H	BOCM_A	BOCM_H	CCB_A	CCB_H	CITIC_A	CITIC_H
Whole period	1	0.4060396	1	0.7280616	1	0.5963087	1	0.7425646	1	0.8248601
	0.4060396	1	0.7280616	1	0.5963087	1	0.7425646	1	0.8248601	1
Correlation	CMB_A	CMB_H	CMBC_A	CMBC_H	ICBC_A	ICBC_H	SSE	HSI	AH_A	AH_H
Whole period	1	0.9507555	1	0.887498	1	0.6814646	1	0.492705	1	0.7948377
	0.9507555	1	0.887498	1	0.6814646	1	0.492705	1	0.7948377	1

The Connect launched on 17th November 2014, to see the difference in market performance after the Connect, we split the whole period data into "Before November 2014" and "After November 2014". The summary report for subgroup "Before November 2014" is in Appendix table 1.1. From that table, we could see the gap between the minimum value and the maximum value is smaller than the whole period, and the difference between the median and mean also gets smaller. Same as the whole period, the median value is smaller than the mean value for most of A shares (8 in a total of 10), and it's the same for most of H shares (7 in a total of 10). Therefore, the correlation of the paired data is smaller than the whole period.

The summary report for subgroup "After November 2014" is in Appendix table 1.2. The minimum and maximum values did not change much compared with the whole period, but the median and mean values increased. Most A shares have a higher mean value than the median value, and half of H shares have the same result. After the Connect, the A shares have higher prices, and the market performance in A share market improved. From beginning to end, the market index and share price are in a positive skew. Compared with the subgroup "Before November 2014", the standard deviation increased for market index and share, which means the market index and share prices have changed more widely, and the risk has increased.

However, when we compare the correlation for each market index and share between 3 subgroups of data, we could not find a unified trend for the correlation changes. The correlation is time-varying for each object, in order to accurately capture the correlation between markets and AH share, we have to work with other methods to find the real dynamic correlation for them during the whole period.

The stationary test is the foundation for time series analyses. We plot the indexes and share prices for whole research objects, which have a trend in the graph. (All the plot of market index and share price is in Appendix). We also applied ADF test for three subgroups data, and the result is in Table 4, which we could easily see that all data are not stationary.

Table 4. Stationary Test for the share price/market index						
	Whole Period		Before November 2014		After November 2014	
	ADF	P-Value	ADF	P-Value	ADF	P-Value
ABC_A	0.066	0.97	-0.222	0.74	0.193	0.93
ABC_H	-0.320	0.08	-0.280	0.24	-0.104	0.35
BOC_A	-0.648	0.48	-1.356	0.28	-0.106	0.61
BOC_H	-0.707	0.66	-0.714	0.69	-0.258	0.91
BOCM_A	-1.164	0.31	-2.390	0.04	-0.088	0.50
BOCM_H	-0.903	0.32	-1.142	0.52	0.061	0.12
CCB_A	-0.386	0.58	-1.320	0.42	0.097	0.73
CCB_H	-0.419	0.89	-0.729	0.61	0.158	0.94
CITIC_A	-0.990	0.13	-1.461	0.23	-0.330	0.07
CITIC_H	-0.982	0.15	-1.068	0.10	-0.228	0.16
CMB_A	0.218	0.61	-1.219	0.32	0.518	0.51
CMB_H	0.116	0.25	-0.903	0.28	0.561	0.48
CMBC_A	0.927	0.93	-0.045	0.72	-0.227	0.72
CMBC_H	-0.389	0.61	-0.059	0.99	-0.370	0.36
ICBC_A	-0.360	0.93	-1.313	0.34	0.195	0.66
ICBC_H	-0.658	0.56	-0.975	0.60	0.096	0.64
SSE	-0.752	0.30	-1.158	0.48	-0.284	0.06
HSI	-0.007	0.65	0.037	0.88	0.021	0.76
AH_A	0.016	0.40	-0.406	0.90	0.130	0.49
AH_H	-0.220	0.23	-0.031	0.96	-0.172	0.25
Comments: The ADF Critical values at 1% is -2.58, at 5% is -1.95 and at 10% is -1.62						

To overcome the issue of stationary and eliminate the trend of data, we calculate the market and shares returns as the first difference of the natural logarithm of each market index and share price. The formula for return rate is following:

$$return\ rate = \ln\left(\frac{p_t}{p_{t-1}}\right)$$

Where the p_t is close price/index at time t, p_{t-1} is close price/index at time t-1. We made a summary of the daily return for the whole period[12] in table 5, and the plotted the daily return for each index and share looks more stationary than the daily close price (All the plots will be present with a correlation graph in chapter 5.4).

[12] The market and share return summary also has three subgroups: the whole period, Before November 2014, and After November 2014. The rest two subgroup summaries are in Appendix table 1.3 and 1.4.

Table_5: The summary of return rate for whole period from 2010 –2018										
Whole period	**ABC_A**	**ABC_H**	**BOC_A**	**BOC_H**	**BOCM_A**	**BOCM_H**	**CCB_A**	**CCB_H**	**CITIC_A**	**CITIC_H**
nbr.val	1995	1995	2114	2114	2116	2116	2114	2114	2114	2114
min	-0.10423	-0.08956	-0.11629	-0.08317	-0.106	-0.08356	-0.10577	-0.09646	-0.10564	-0.08966
max	0.096414	0.124872	0.096581	0.096993	0.096247	0.092481	0.095661	0.079582	0.096129	0.100399
median	0	-0.00025	0	-0.00013	0	-0.00025	0	8.7E-05	0	-2.1E-05
mean	0.000146	2.36E-05	-6.7E-05	-9.1E-05	-0.00017	-0.00012	1.89E-05	-3.6E-06	-0.00016	-0.00014
var	0.000215	0.000296	0.000231	0.000248	0.0003	0.000293	0.000272	0.000254	0.000449	0.000331
std.dev	0.014658	0.017209	0.015191	0.015762	0.017316	0.017103	0.016485	0.015952	0.0212	0.01818
Jarque Bera Test (p value)	7180.4983 (< 2.2e-16)		9465.511 (< 2.2e-16)		7268.977 (< 2.2e-16)		6100.6481 (< 2.2e-16)		3406.0687 (< 2.2e-16)	
Whole period	**CMB_A**	**CMB_H**	**CMBC_A**	**CMBC_H**	**ICBC_A**	**ICBC_H**	**SSE**	**HSI**	**AH_A**	**AH_H**
nbr.val	2120	2120	2119	2119	2115	2115	2119	2119	1694	1694
min	-0.1044	-0.10282	-0.10525	-0.11794	-0.10583	-0.09045	-0.08906	-0.06018	-0.09843	-0.07996
max	0.095542	0.222361	0.095437	0.095222	0.09531	0.099702	0.063691	0.069869	0.096549	0.09848
median	0	-0.00013	0	-0.00047	0	-0.00012	0.000498	0.000527	0.00014	-0.00031
mean	0.000201	0.000207	0.000105	1.75E-05	2.93E-06	-6.5E-05	-0.00012	7.36E-05	0.000157	4.68E-05
var	0.000341	0.000446	0.000325	0.000366	0.000213	0.000277	0.000202	0.000136	0.000219	0.000229
std.dev	0.018478	0.021108	0.01804	0.019119	0.0146	0.016632	0.014218	0.011654	0.014788	0.015119
Jarque Bera Test (p value)	8425.0642 (< 2.2e-16)		3380.192 (< 2.2e-16)		6519.9322 (< 2.2e-16)		5749.5399 (< 2.2e-16)		4126.9044 (< 2.2e-16)	
Correlation	**ABC_A**	**ABC_H**	**BOC_A**	**BOC_H**	**BOCM_A**	**BOCM_H**	**CCB_A**	**CCB_H**	**CITIC_A**	**CITIC_H**
Whole period	1	0.385871	1	0.390484	1	0.455519	1	0.423264	1	0.49013
	0.385871	1	0.390484	1	0.455519	1	0.423264	1	0.49013	1
Correlation	**CMB_A**	**CMB_H**	**CMBC_A**	**CMBC_H**	**ICBC_A**	**ICBC_H**	**SSE**	**HSI**	**AH_A**	**AH_H**
Whole period	1	0.560932	1	0.517011	1	0.393334	1	0.553859	1	0.668137
	0.560932	1	0.517011	1	0.393334	1	0.553859	1	0.668137	1

To ensure the stationary of daily return, we applied the ADF test again for each subgroup. The ADF output for daily return of markets and shares is in Table 6, and all ADF values are lower than -2.58, all series reject the null hypothesis that there is a unit root.

Table 6. Stationary Test for share/market daily return						
	Whole Period		**Before November 2014**		**After November 2014**	
	ADF	**P-Value**	**ADF**	**P-Value**	**ADF**	**P-Value**
ABC_A	-34.9599	< 2.2e-16	-22.5192	< 2.2e-16	-25.5583	< 2.2e-16
ABC_H	-31.4512	< 2.2e-16	-22.6143	< 2.2e-16	-21.6747	< 2.2e-16
BOC_A	-35.7075	< 2.2e-16	-23.6351	< 2.2e-16	-25.342	< 2.2e-16
BOC_H	-32.2809	< 2.2e-16	-23.3373	< 2.2e-16	-22.3027	< 2.2e-16
BOCM_A	-33.7598	< 2.2e-16	-23.753	< 2.2e-16	-23.5707	< 2.2e-16
BOCM_H	-32.7817	< 2.2e-16	-23.887	< 2.2e-16	-22.4784	< 2.2e-16
CCB_A	-36.3903	< 2.2e-16	-24.1365	< 2.2e-16	-25.7599	< 2.2e-16
CCB_H	-33.3094	< 2.2e-16	-24.7777	< 2.2e-16	-22.2075	< 2.2e-16
CITIC_A	-32.734	< 2.2e-16	-23.44	< 2.2e-16	-22.7203	< 2.2e-16
CITIC_H	-31.6036	< 2.2e-16	-23.0623	< 2.2e-16	-21.5495	< 2.2e-16
CMB_A	-34.2355	< 2.2e-16	-24.1441	< 2.2e-16	-23.9622	< 2.2e-16
CMB_H	-33.3623	< 2.2e-16	-24.1776	< 2.2e-16	-22.9256	< 2.2e-16
CMBC_A	-33.8764	< 2.2e-16	-24.5181	< 2.2e-16	-23.365	< 2.2e-16
CMBC_H	-33.3824	< 2.2e-16	-24.276	< 2.2e-16	-22.99	< 2.2e-16
ICBC_A	-35.7969	< 2.2e-16	-24.8697	< 2.2e-16	-25.0553	< 2.2e-16
ICBC_H	-33.1285	< 2.2e-16	-24.0743	< 2.2e-16	-22.7672	< 2.2e-16
SSE	-33.5699	< 2.2e-16	-24.0859	< 2.2e-16	-23.0871	< 2.2e-16
HSI	-32.5064	< 2.2e-16	-23.7356	< 2.2e-16	-22.1828	< 2.2e-16
AH_A	-30.898	< 2.2e-16	-18.644	< 2.2e-16	-24.0238	< 2.2e-16
AH_H	-28.9759	< 2.2e-16	-19.0279	< 2.2e-16	-21.8621	< 2.2e-16
Comments: The ADF Critical values at 1% is -2.58, at 5% is -1.95 and at 10% is -1.62						

Therefore, the daily return of all indexes and shares are stationary, and we could use the daily return for VAR and DCC-GARCH in the following empirical study.

5.2 The empirical result for VAR and Granger Causality test

The VAR model is used to study multivariate financial time series behavior, and it could explain the past information and causal relationship for multiple objects. Moreover, it overcomes the estimation bias caused by the endogeneity of the traditional static analysis, which could obtain the dynamic relationship between all endogenous variables.

To examine the changes of information transmission and causal relationship of the stock markets and cross-listed AH bank shares after the Connect, we applied the VAR model to subgroups "Before November 2014" and "After November 2014". The model has been present in chapter 4, and the optimal numbers of lag in the VAR model are determined by information criteria (AIC, HQ, and SC) and likelihood ratio. In Table 7, we can see the average lag order for the VAR model for subgroup Before the Connect is 1 (except ICBC). Nevertheless, after the Connect, the number of lag orders changed for many pairs at a different level. The AH share index and 6 shares changed to higher lag order, the Shanghai and Hong Kong market index and other 2 shares remain the lag order as 1.

Table 7. VAR select for shares and markets index

		Before November 2014	After November 2014
ABC	ABC_A ABC_H	1	2
BOC	BOC_A BOC_H	1	2
BOCM	BOCM_A BOCM_H	1	1
CCB	CCB_A CCB_H	1	5
CITIC	CITIC_A CITIC_H	1	2
CMB	CMB_A CMB_H	1	6
CMBC	CMBC_A CMBC_H	1	1
ICBC	ICBC_A ICBC_H	2	6
A&H Index	SSE HSI	1	1
AH	AH_A AH_H	1	2

Based on the VAR model, we estimate the autoregression and linkage between Shanghai and Hong Kong stock markets and cross-listed AH bank shares in two periods. To observe our result in an appropriate visual table, we separated the results into two tables according to the variation of the number of lag orders. Table 8 summarizes the shares and market index with a relatively small range of change in the lag order after the Connect. As we could see, the significance of estimators is quite different between the two periods. In general, there are more significant estimators appearing after the Connect. It seems like, before the Connect, many cross-listed AH bank shares and two stock markets did not have lots of mutual influence according to their previous return. Only one banking share ABC presents strong one-way information transmission from A shares to H shares. There are 2 other shares, and AH market index presents weak one-way information transmission from A share to H shares, but the coefficient is relatively small. The AH share index was the only pair representing one-way information transmission from H shares to A shares.

After the Connect, the average lag order increased to 2 for the shares and market index in Table 8. There were more significant estimators shown in lag 2, and some mutual influence started to appear. For the shares, the A share of BOCM and CMBC is always unaffected by any own lagged term, while H-shares are affected by A shares in lag 1, both before and after the Connect. For BOC, the A share and H share are only affected by their own lagged item. The shares of ABC and CITIC show some mutual influence. For the market index, in lag 1 SSE has a negative effect on HSI, conversely there is no. The AH share index has mutual influence after the Connect.

Based on the significance of estimators, we assumed for cross-listed shares the return of A shares had a higher autoregressive and was impacted by its historical return after the Connect. It was also occasionally affected by H shares return at t-2. Meanwhile, the H shares are not influenced by its historical return, and the return of A shares at t-1 could impact H shares. This view will be specifically demonstrated in the Granger Causality Test.

Table 8. VAR Estimation results_1				
	Before November 2014		After November 2014	
	A share	H share	A share	H share
ABC_A.l1	-0.03477	0.1219 (**)	0.00068	-0.04479
ABC_H.l1	0.00958	0.01773	0.02151	0.05720
ABC_A.l2			-0.1784(***)	-0.0558(*)
ABC_H.l2			0.0803(**)	0.02676
BOC_A.l1	-0.02361	0.05432	0.02076	-0.06034(**)
BOC_H.l1	-0.00161	0.00412	-0.00307	0.02884
BOC_A.l2			-0.1695(***)	-0.04567
BOC_H.l2			0.06790	0.01245
BOCM_A.l1	-0.01908	0.07409(*)	0.04643	-0.05361(*)
BOCM_H.l1	0.01496	0.05089	0.01236	-0.01822
CITIC_A.l1	0.02413	0.01592	0.07932(**)	0.01440
CITIC_H.l1	0.01663	0.02952	0.00518	0.04603
CITIC_A.l2			-0.1142(***)	-0.02615
CITIC_H.l2			0.1342(**)	0.01385
CMBC_A.l1	0.00101	0.06704(*)	-0.01572	-0.07351(**)
CMBC_H.l1	0.01153	-0.02297	-0.00506	0.00234
SSE.l1	-0.00369	-0.06125(*)	0.01531	-0.05649(**)
HSI.l1	0.00226	0.03920	0.07767	0.05938
AH_A.l1	0.06112	0.08996	-0.00827	-0.08195(**)
AH_H.l1	-0.07285(*)	-0.04155	0.06075	0.08811(**)
AH_A.l2			-0.1893(***)	-0.04905
AH_H.l2			0.1417(***)	0.03042
Comments:				
Equation for A share: rA = rA.l1 + rH.l1 + const + trend				
Equation for H share: rH = rA.l1 + rH.l1 + const + trend				

In Table 9, we present the VAR result for shares: CCB, CMB, and ICBC. Those 3 shares lag order for the VAR model had massive changes after November 2014. After comparing the data for those 3 shares with other shares and the market index, it seems like the development of the original share price might be the main reason. The CMB is a young bank that has grown rapidly since 2014, and the share price tripled from 2014 to 2018, which is very different from other banks' shares. The ICBC and CCB are the first and second of the four largest state-owned joint-stock commercial banks in Mainland China. The difference between their price changes and other shares is that price peak points, and the premium level are not high. Most other shares prices rapidly increased and peaked in 2015, then share price dropped down after 2015. However, for those 3 shares, the share price increased in 2015, but the peak point was at the beginning of 2018.

From Table 9, we could see that before the Connect, the return of those 3 H shares were still not easily affected by the lagging information of A shares and their own lagging information. The return of A shares could be affected by their own lagging information (only ICBC A shares show a significant coefficient at its own lag order 1). This summary result is slightly different from the previous Table 8. After the Connect, we could find A shares have a more significant coefficient in the long term. All those 3 A shares are affected by their own lagging information and the lagging information of H shares in specific lag order. All those 3 H shares were not easily affected by any lagging information.

In general, the Shanghai-Hong Kong Stock Connect has a positive impact on the information transmission of AH shares, but this impact has little effect on the stock market indexes. For those cross-listed AH bank shares, the shares in the Shanghai market are affected by information from the local market and the information from the Hong Kong market. However, the Hong Kong market shares have a faster absorption of information from the local market, but there are sometimes affected by information from the Shanghai market.

With a suitable VAR model for each share and market index, we could obtain the statistic for Granger causalities and compare the causal relationship before and after the Connect. The Granger causalities results are summarized in Table 10.

Table 9. VAR Estimation results_2				
	Before November 2014		After November 2014	
	A share	H share	A share	H share
CCB_A_A.l1	0.02073	0.02079	0.04169	-0.009153
CCB_H_A.l1	0.03829	0.01253	-0.006698	-0.002097
CCB_A_A.l2			-0.2154(***)	-0.04378
CCB_H_A.l2			0.2005(***)	0.03293
CCB_A_A.l3			0.05309	0.06957(**)
CCB_H_A.l3			0.04377	0.0483
CCB_A_A.l4			0.08885(**)	0.02257
CCB_H_A.l4			0.01619	-0.05519
CCB_A_A.l5			-0.1004(***)	0.002964
CCB_H_A.l5			-0.0854(*)	-0.03228
CMB_A_A.l1	-0.03603	0.04161	-0.054	0.02819
CMB_H_A.l1	0.00653	0.04346	0.07255(*)	-0.0002933
CMB_A_A.l2			-0.1267(***)	0.03425
CMB_H_A.l2			0.04538	-0.06458
CMB_A_A.l3			-0.08528(**)	-0.03234
CMB_H_A.l3			0.1303(***)	0.05536
CMB_A_A.l4			-0.02136	-0.001854
CMB_H_A.l4			0.05763	-0.03913
CMB_A_A.l5			-0.1694(***)	-0.03213
CMB_H_A.l5			0.0503	-0.02799
CMB_A_A.l6			-0.1004(**)	0.02433
CMB_H_A.l6			0.07186(*)	0.04128
ICBC_A_A.l1	-0.09156(***)	-0.01286	-0.01433	-0.01967
ICBC_H_A.l1	0.02205	0.008704	0.04003	0.05968(*)
ICBC_A_A.l2	-0.03847	0.003497	-0.1669(***)	-0.04523
ICBC_H_A.l2	0.0517	-0.01667	0.08988(**)	-0.03312
ICBC_A_A.l3			0.04993	0.07759(**)
ICBC_H_A.l3			0.03366	0.03767
ICBC_A_A.l4			-0.0478	-0.04826
ICBC_H_A.l4			0.04724	-0.02733
ICBC_A_A.l5			-0.09445(**)	0.01729
ICBC_H_A.l5			-0.01402	-0.007738
ICBC_A_A.l6			-0.1418(***)	0.01308
ICBC_H_A.l6			0.08956(**)	-0.02228

From Table 10, we get some interesting results, which are similar to our assumption. From a market perspective, before the Shanghai-Hong Kong Stock Connect launch, the Shanghai stock market return is not affected by its own lagged term and the lagged term of Hong Kong stock market return. The Shanghai stock market return has faster absorption information. Hong Kong stocks also have faster information absorption of the local market but are affected by lagged terms of the Shanghai stock market; however, the significant impact is relatively small. After the Shanghai-Hong Kong Stock Connect launch, Shanghai stocks remain unaffected by their own and Hong Kong stock returns, but their impact on Hong Kong stock returns becomes more significant. Granger causality tests indicate that after the launch of the Connect, the Shanghai stocks market begin to have a unidirectional Granger causality on Hong Kong stocks market, and information transmission between markets is enhanced, which is consistent with our findings in Table 9. The AH share market index returns have the opposite results of the Granger causality test as the returns of the Shanghai-Hong Kong market. In the AH share market, H shares have a weak but not significant influence on A shares even before the launch of the Connect. After the Connect, H-shares have a significant one-way influence on A-shares; that is, cross-listed H-shares have Granger causality on A-shares. Moreover, A shares have had no influence and Granger causality on H shares since the beginning.

From the cross-listed bank shares perspective, before the Shanghai-Hong Kong Stock Connect, two shares (ABC and CMBC) showed one-way Granger causality from A-share to H-share, one share (ICBC) showed one-way Granger causality from H-share to A-share, and the remaining shares did not find any Granger causality. However, after the Shanghai-Hong Kong Stock Connect, more shares (CCB, CITIC, CMB, and ICBC) started to have Granger causality from H shares to A shares, and only one share (BOC) newly produced a one-way Granger causality from A shares to H shares. Thus, the enhanced information transmission from H-share to A-share for overall bank stocks is consistent with the overall trend of the AH share market, where bank shares are more representative of the overall AH share market.

In conclusion, for cross-listed stocks, H-share returns play a "leading role" in the information transmission of the AH share market. They are more significant in internal and external information absorption and transmission, indirectly or directly affecting cross-listed A-share returns. As a connecting mechanism, the Shanghai-Hong Kong Stock Connect has an essential role in promoting Granger causality from H-shares to A-shares in a unidirectional way. However, the impact of this policy on the information transmission between the two stock markets is relatively small, and the Shanghai stock market plays only a weak "leading role" in the Hong Kong stock market after the Shanghai-Hong Kong Stock Connect. We will discuss this result with previous literature in the summary section.

Table 10. Granger Causality Test						
	Before November 2014			After November 2014		
Hypothesis	**F-Test**	**p-value**	**Conclusion**	**F-Test**	**p-value**	**Conclusion**
ABC_A do not Granger-cause ABC_H	4.27340	0.0388	Reject H0	2.92180	0.0541	Fail to reject H0
ABC_H do not Granger-cause ABC_A	0.22802	0.6330	Fail to reject H0	2.13320	0.1187	Fail to reject H0
BOC_A do not Granger-cause BOC_H	1.35770	0.2441	Fail to reject H0	3.46010	0.0080	Reject H0
BOC_H do not Granger-cause BOC_A	0.00513	0.9429	Fail to reject H0	1.25960	0.2838	Fail to reject H0
BOCM_A do not Granger-cause BOCM_H	3.12570	0.0772	Fail to reject H0	3.50650	0.0613	Fail to reject H0
BOCM_H do not Granger-cause BOCM_A	0.31565	0.5743	Fail to reject H0	0.07208	0.7884	Fail to reject H0
CCB_A do not Granger-cause CCB_H	0.24202	0.7851	Fail to reject H0	1.87870	0.0809	Fail to reject H0
CCB_H do not Granger-cause CCB_A	1.48930	0.2257	Fail to reject H0	4.43110	0.0002	Reject H0
CITIC_A do not Granger-cause CITIC_H	0.20559	0.6503	Fail to reject H0	0.67432	0.5096	Fail to reject H0
CITIC_H does not Granger-cause CITIC_A	0.23838	0.6254	Fail to reject H0	3.21080	0.0405	Reject H0
CMB_A do not Granger-cause CMB_H	0.93798	0.3329	Fail to reject H0	0.41823	0.8673	Fail to reject H0
CMB_H do not Granger-cause CMB_A	0.05655	0.8121	Fail to reject H0	3.14380	0.0045	Reject H0
CMBC_A do not Granger-cause CMBC_H	3.35500	0.0351	Reject H0	4.51000	0.0338	Reject H0
CMBC_H do not Granger-cause CMBC_A	0.09590	0.9086	Fail to reject H0	0.01748	0.8948	Fail to reject H0
ICBC_A do not Granger-cause ICBC_H	0.04027	0.9605	Fail to reject H0	1.76980	0.1015	Fail to reject H0
ICBC_H do not Granger-cause ICBC_A	3.47370	0.0312	Reject H0	2.22770	0.0380	Reject H0
SSE do not Granger-cause HSI	3.04410	0.0812	Fail to reject H0	4.27510	0.0388	Reject H0
HSI do not Granger-cause SSE	0.00379	0.9509	Fail to reject H0	2.03660	0.1537	Fail to reject H0
AH_A do not Granger-cause AH_H	1.78380	0.1819	Fail to reject H0	2.98800	0.0506	Fail to reject H0
AH_H do not Granger-cause AH_A	3.04240	0.0813	Fail to reject H0	5.96710	0.0026	Reject H0

Comments:
Fail to reject H0: There is no Granger-cause relationship from A to B
Reject H0: There is a Granger-cause relationship from A to B

5.3 The empirical result for DCC-GARCH

DCC-GARCH model is commonly used in financial time series studies for the dynamic conditional correlations between financial markets or financial assets. To investigate the transmission process of return and volatility between two stock markets and cross-listed shares in Shanghai and Hong Kong, and to find an accurate correlation for them, we applied the DCC-GARCH model bases on the literature review and Engle's (2002) research.

Many studies have shown that using the GARCH family model with the first-order lag is sufficient to capture the stock market's volatility. Therefore, this thesis uses DCC-GARCH (1,1) model for all stock markets and shares. However, due to the autocorrelation within the variable, the ARMA (0,0) is not applicable for most shares and market indexes. So we add ARMA (p,q) into DCC-GARCH to remove the dependence in returns share's return and use likelihood ratio to determine the proper lag order for each share and market index. After determining the appropriate ARMA lag term and testing that the residuals have heteroskedasticity (ARCH effect), we estimate the parameters of the DCC-GARCH model for Shanghai and Hong Kong stock market returns and cross-listed share returns, respectively. We separated our results into two tables to analyze the difference in volatility between stock markets and cross-listed AH bank shares. Table 11 summarizes the parameters of ARMA-DCC-GARCH model for the stock market, and Table 12 is the summary parameters for the cross-listed AH bank shares. The number of p and q for each share are different in the ARMA model. We added the ARMA model detail above the tables for each object, and the full ARMA-DCC-GARCH results are in Appendix.

As we have known from chapter 4, there are 5 critical parameters in DCC-GARCH model. The parameter ω is a long-term variance. The ARCH parameter α is the residual square lag coefficient, reflecting the size of the external information's impact on the object, precisely the impact of existing information on later fluctuations. And the GARCH parameter β is the coefficient of the lagging term of the conditional variance itself, which reflects the fluctuation degree of the object is affected by their previous information. Finally, the correlation parameters a and b reflect the dynamics and persistence of the correlation coefficients for objects. All parameter α and β are greater than 0, and the sum of α and β is less than one, which satisfy the corresponding assumption for DCC-GARCH model. Moreover, it ensures that the conditional covariance matrix of the standardized residual term is positive definite. Table 11 and Table 12 show the parameter α is generally low and close to zero, whereas the parameter β is extremely high and close to 1. Thus, the conditional correlations between the indices are dynamic. Furthermore, parameter a is always lower for all markets and shares than parameter α, and parameter b is always higher than parameter β, indicating relatively high persistence in correlations between each pair.

From Table 11, we could see the SSE has a bigger ARCH parameter α, but a smaller GARCH parameter β compare with HSI, which indicating compare with the Hong Kong stock market, the Shanghai stock markets have a higher reflection for the external new information but a lower reflection from its own previous performance. The general trend is the same for the AH share index. However, when we compare the α and β parameters of the two groups of markets, we find that A shares in the AH share index have a higher α parameter relative to the SSE, which indicates that A shares in the AH share market are more sensitive to new information from the external sources, but at meanwhile this fluctuation is quick and easy to be absorbed. And the α parameter of H-shares in the AH share index is similar to the value of the α parameter of the HSI, which is basically consistent with the information flow we found in Granger causality.

Table 11. The Estimation of ARMA-DCC-GARCH model for Market Index

AH Market Index				AH Share Index			
ARMA(2.3)-DCC-GARCH				ARMA(1.1)-DCC-GARCH			
	Estimate	Std._Error			Estimate	Std._Error	
[SSE].ω	0.000001	0.000001		[AH_A].ω	0.000001	0.000002	
[SSE].α1	0.053364	0.009352	***	[AH_A].α1	0.063822	0.022691	**
[SSE].β1	0.945636	0.009095	***	[AH_A].β1	0.930677	0.022321	***
[HSI].ω	0.000001	0.000001		[AH_H].ω	0.000005	0.000003	
[HSI].α1	0.044067	0.00599	***	[AH_H].α1	0.047829	0.008544	***
[HSI].β1	0.946149	0.007707	***	[AH_H].β1	0.93181	0.015767	***
[Joint]dcca1	0.006684	0.001975	***	[Joint]dcca1	0.020958	0.007159	**
[Joint]dccb1	0.989104	0.002639	***	[Joint]dccb1	0.96387	0.01443	***

From Table 12, we can see that after applying the suitable ARMA model, the ARCH parameter and GARCH parameter of most shares are significant within the confidence interval of 1%; CCB is more special, its ARCH parameter is significant within the confidence interval of 5%; while the ARCH parameter of CMB is not significant. The ARCH parameters for most AH shares are larger than those of ARCH parameters of SSE and HSI, and AH share market indicates that cross-listed AH shares are more influenced by new external information and A shares are more likely to receive external information than H shares. The GARCH parameters of all the AH shares are significant, but the overall GARCH parameter values are smaller than the GARCH parameter values of the Shanghai and Hong Kong market and the AH shares market, which suggests that cross-listed stocks are less sensitive to local volatility and volatility persistence is not so strong.

To sum up the DCC-GARCH regarding the volatility changes between markets and shares, we would like to say the Shanghai stock market and A shares have less market efficiency than Hong Kong stock market and H shares, the share in Hong Kong market is more stable.

For the DCC correlation parameters a and b, the positive correlation parameters for all stock markets and the AH share are significant within the confidence interval, and the restriction that $a+b<1$ is satisfied, which indicates that the standardized residual product over a period has a significant effect on the dynamic correlation coefficient. Moreover, the parameter b is significant, but the parameter value is very close to 1, reflecting the robust persistence characteristic of the correlation. Therefore, we can conclude that there must be correlation coefficients between Shanghai and Hong Kong stock markets as well as between AH shares under dynamic conditions, and We will discuss them in detail in the next section.

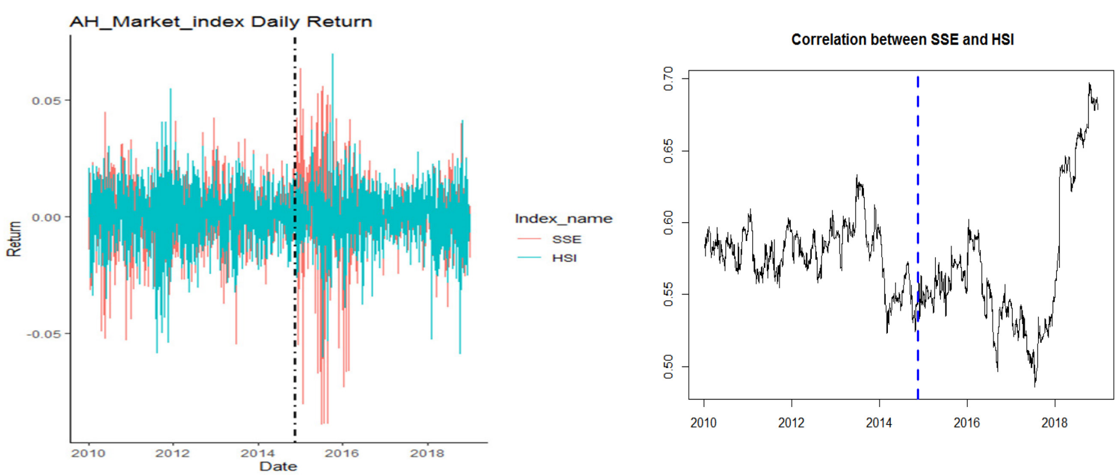
Table 12. The Estimation of ARMA-DCC-GARCH model for Shares							
ARMA(0.0)-DCC-GARCH				ARMA(1.1)-DCC-GARCH			
	Estimate	Std._Error			Estimate	Std._Error	
[CMBC_A].ω	0.000005	0.000005		[ABC_A].ω	0.000005	0.000003	*
[CMBC_A].α1	0.118536	0.025125	***	[ABC_A].α1	0.077489	0.018459	***
[CMBC_A].β1	0.875086	0.028115	***	[ABC_A].β1	0.896812	0.026671	***
[CMBC_H].ω	0.00001	0.000003	***	[ABC_H].ω	0.000015	0.000002	***
[CMBC_H].α1	0.100437	0.012212	***	[ABC_H].α1	0.082224	0.008129	***
[CMBC_H].β1	0.872748	0.012657	***	[ABC_H].β1	0.866145	0.010267	***
[Joint]dcca1	0.011061	0.003469	**	[Joint]dcca1	0.019676	0.011185	*
[Joint]dccb1	0.981273	0.005447	***	[Joint]dccb1	0.947767	0.032648	***
ARMA(2.2)-DCC-GARCH							
	Estimate	Std._Error			Estimate	Std._Error	
[BOCM_A].ω	0.00001	0.000003	***	[CITIC_A].ω	0.000011	0.000003	***
[BOCM_A].α1	0.127853	0.022701	***	[CITIC_A].α1	0.076466	0.008341	***
[BOCM_A].β1	0.839318	0.018414	***	[CITIC_A].β1	0.897972	0.016954	***
[BOCM_H].ω	0.000009	0.000002	***	[CITIC_H].ω	0.000003	0.000007	
[BOCM_H].α1	0.075424	0.009126	***	[CITIC_H].α1	0.062127	0.012299	***
[BOCM_H].β1	0.893758	0.008956	***	[CITIC_H].β1	0.931104	0.021264	***
[Joint]dcca1	0.014161	0.008396	*	[Joint]dcca1	0.008764	0.005143	*
[Joint]dccb1	0.94384	0.031629	***	[Joint]dccb1	0.956946	0.014106	***
ARMA(4.4)-DCC-GARCH							
	Estimate	Std._Error			Estimate	Std._Error	
[BOC_A].ω	0.000008	0.000002	***	[CCB_A].ω	0.000014	0.000008	*
[BOC_A].α1	0.116002	0.018734	***	[CCB_A].α1	0.140521	0.064311	**
[BOC_A].β1	0.843056	0.020256	***	[CCB_A].β1	0.804919	0.040308	***
[BOC_H].ω	0.000012	0.000001	***	[CCB_H].ω	0.000022	0.000009	**
[BOC_H].α1	0.072821	0.004668	***	[CCB_H].α1	0.078314	0.023998	**
[BOC_H].β1	0.876032	0.008088	***	[CCB_H].β1	0.834789	0.045105	***
[Joint]dcca1	0.022607	0.013725	*	[Joint]dcca1	0.016251	0.009174	*
[Joint]dccb1	0.815135	0.084503	***	[Joint]dccb1	0.938827	0.028666	***
ARMA(4.4)-DCC-GARCH				ARMA(6.6)-DCC-GARCH			
	Estimate	Std._Error			Estimate	Std._Error	
[CMB_A].ω	0.000004	0.000007		[ICBC_A].ω	0.000007	0.000005	
[CMB_A].α1	0.051996	0.035379		[ICBC_A].α1	0.179397	0.040182	***
[CMB_A].β1	0.938473	0.041428	***	[ICBC_A].β1	0.803409	0.027931	***
[CMB_H].ω	0.000004	0.00001		[ICBC_H].ω	0.000015	0.000002	***
[CMB_H].α1	0.029993	0.02095		[ICBC_H].α1	0.074478	0.007036	***
[CMB_H].β1	0.960321	0.005114	***	[ICBC_H].β1	0.867801	0.011723	***
[Joint]dcca1	0.006166	0.003421	*	[Joint]dcca1	0.011385	0.006929	*
[Joint]dccb1	0.984511	0.011392	***	[Joint]dccb1	0.961494	0.010089	***

5.4 Dynamic correlation of markets and cross-listed shares

We use the implementation of the Shanghai-Hong Kong Stock Connect policy as a time split to study the changes in the dynamic correlations between the Shanghai and Hong Kong stock markets, the AH share market, and the cross-listed AH shares before and after the Connect. In addition, we will combine the results of the previous VAR model with the DCC GARCH model to further analyze the impact of the Connect on the correlations of each market and cross-listed shares.

As we mentioned in section 5.3, based on table 11, all the correlation coefficients a and b are significant, and coefficient b value is close to 1, reflecting the persistence and relative stability of the stock markets. In Figure 5, we can see the development of conditional correlations for the Shanghai and Hong Kong stock markets. The vertical line in the figure represents the time Split Point on 17th November 2014 for the Connect.

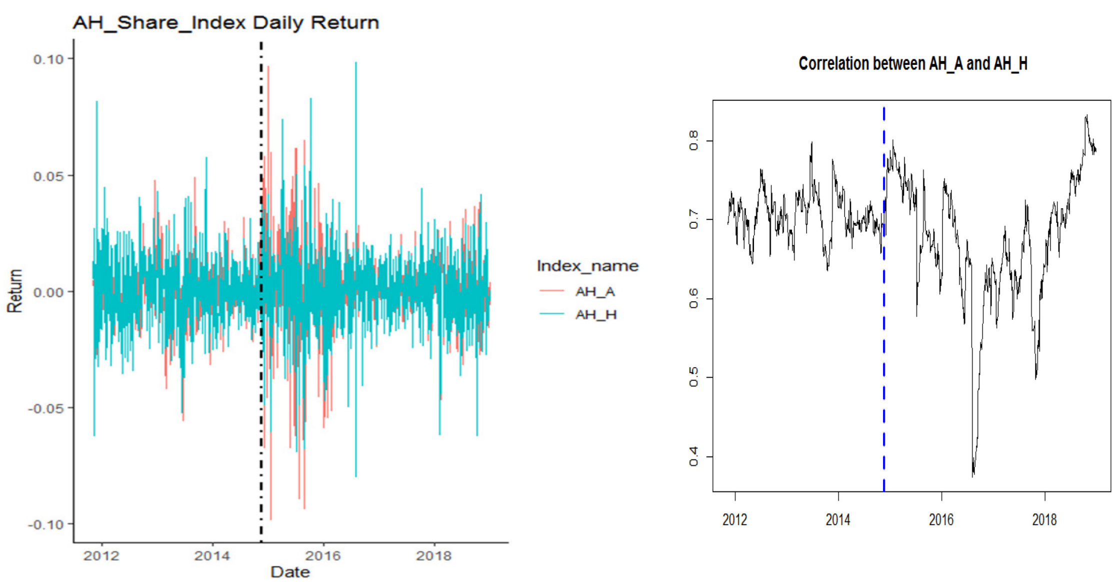
Figure 5. The Shanghai and Hong Kong stock market return and correlation



From Figure 5, we can see that the dynamic correlation coefficient between Shanghai and Hong Kong stock markets remained between 0.47 and 0.7 from 2010 to 2018. After the implementation of the Shanghai-Hong Kong Stock Connect, the returns of Shanghai and Hong Kong stock markets were more volatile, but the correlation between Shanghai and Hong Kong stock markets did not increase significantly and showed a downward trend after 2016 until the end of 2017 when it started to increase significantly and reached its peak value in 2018.

On the other hand, when we look at Figure 6 to analyze the correlation coefficients of the AH share indexes, we see a different trend of correlation. Before the connection, the correlation between AH_A and AH_H stays relatively high (about 0.7). The components of the index determine this. After the Connect, the correlation increases slightly at the beginning of 2015, then the correlation shows a significant downward trend and drops to its lowest point in the middle of 2016. The downward trend soon returned to its original average level, and the correlation coefficient started to rise from the end of 2017. the correlation coefficient between the AH market indices peaked in 2018 and was higher than the peak of the correlation between the Shanghai and Hong Kong stock markets.

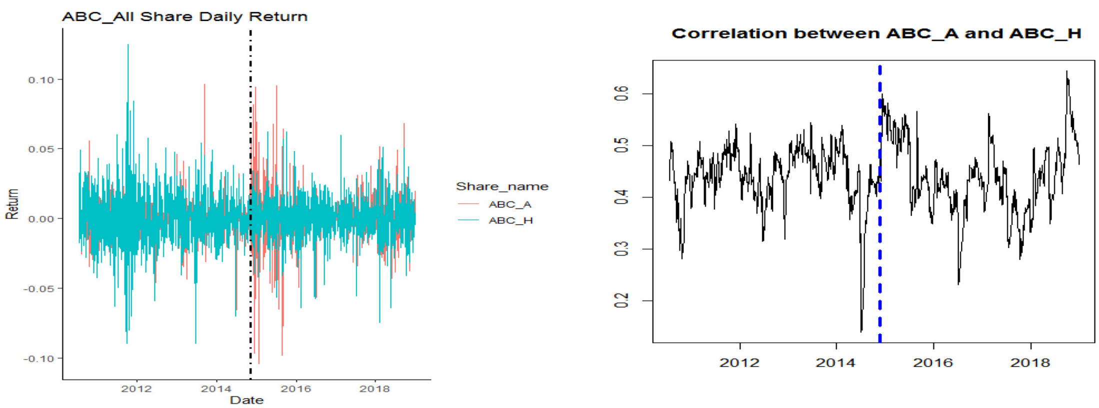
Figure 6. The AH share index daily return and correlation



The estimated results of the correlation coefficients a and b of the DCC GARCH for the cross-listed AH bank shares are summarized within Table 12, and the correlation coefficients a and b are significant for all cross-listed AH bank shares. In general, the adjustment of the conditional correlation coefficient a between A shares and H shares is relatively small, while the coefficient b value is above 0.90(except share BOC), which reflecting the persistence and relative stability of correlation between the A share return and H share return for each cross-listed AH shares. Figures 7 to 14 show the dynamic correlation coefficients among the cross-listed AH bank stocks.

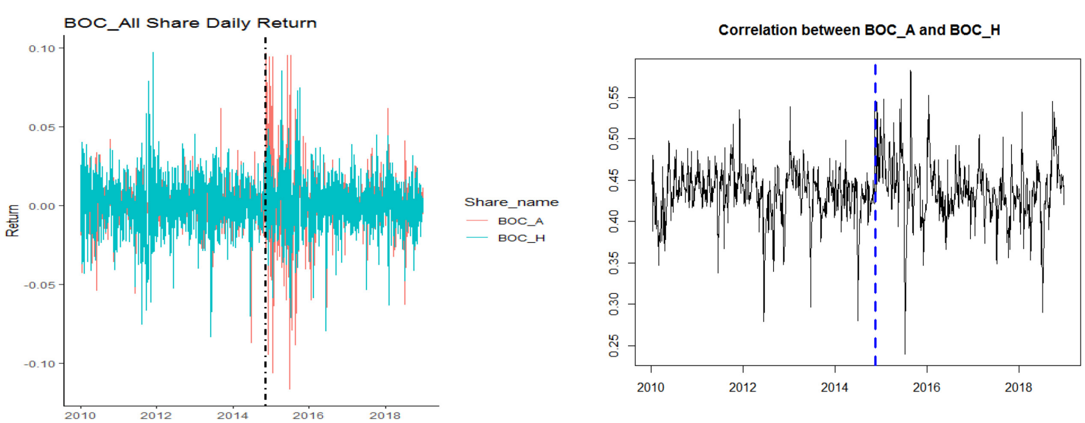
For stock ABC, the range of correlation coefficient between A shares and H shares is 0.16 to 0.63, with a large overall change. Its correlation coefficient had a significant rise when the Shanghai-Hong Kong Stock Connect was launched, but that upward trend did not last, and like the overall AH shares, its correlation coefficient gradually declined since middle of 2015, fell to its lowest point in middle of 2016, and slowly rebounded in early 2018, reaching its peak in middle of 2018.

Figure 7. The ABC shares daily return and correlation



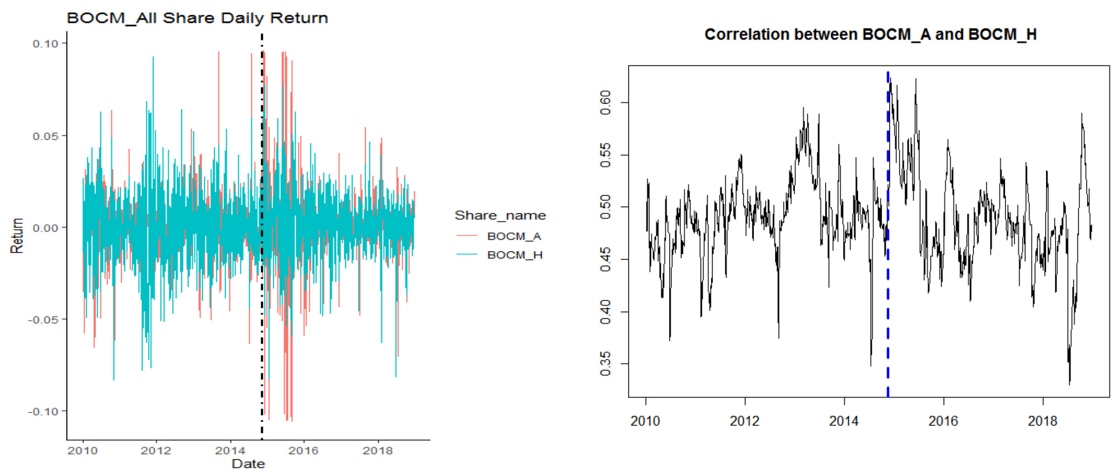
According to Table 12, the correlation parameter b for shares BOC is relatively small, and his dynamic correlation is lower than other AH bank shares. In Figure 8, we can see that the correlation coefficient between the A and H shares of BOC does not have a significant, long-term trend change. However, we still found that after the Shanghai-Hong Kong Stock Connect launched, the correlation coefficient of the share increased in early 2015, just not in a persistent way. The overall correlation coefficient varies between 0.24 and 0.57, and the overall correlation is low when compared to other AH bank shares.

Figure 8. The BOC shares daily return and correlation



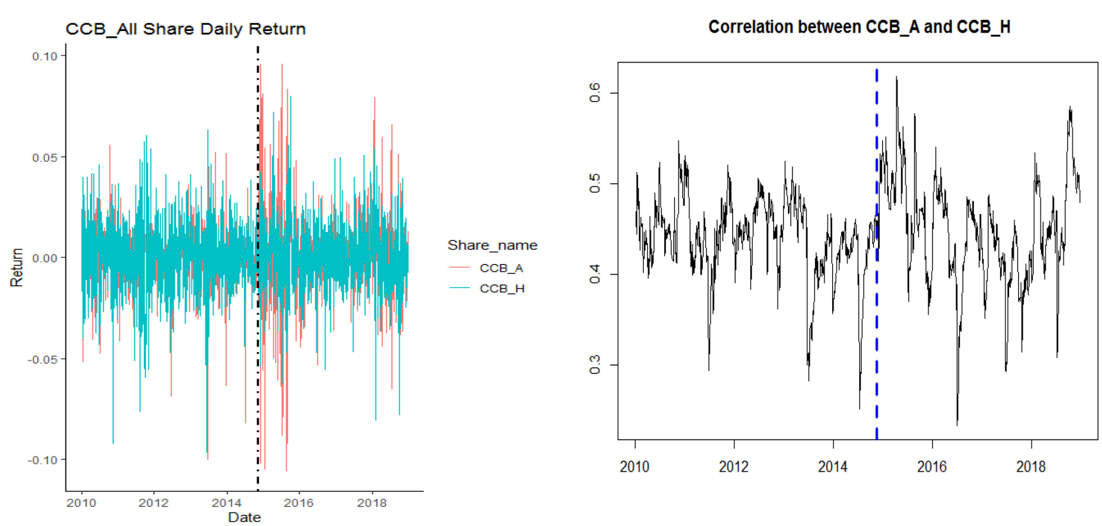
The correlation coefficient between A and H shares of the stock BOCM moves between 0.32 and 0.62. It can be seen that there was a significant increase in the correlation coefficient when the Shanghai-Hong Kong Stock Connect was launched and peaked in early 2015, but as with other AH bank shares, the correlation coefficient did not continue to rise, but declined since 2016 until it rose again in the first half of 2018.

Figure 9. The BOCM shares daily return and correlation



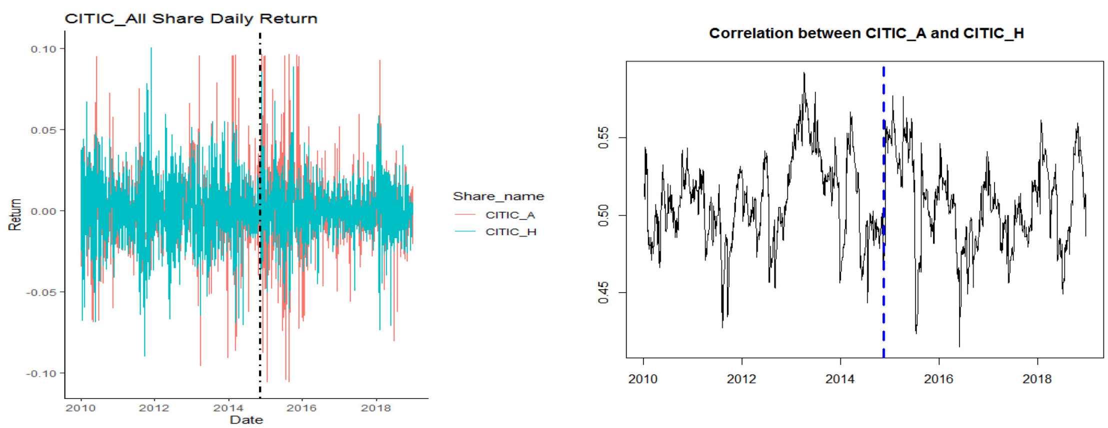
The dynamic correlation coefficient of the stock CCB moves up the range of 0.22 to 0.61, with its peak appearing in the middle of 2015. From Figure 10 we can see that there is a short-term positive impact on the correlation of CCB AH shares when the Shanghai-Hong Kong Stock Connect implemented, but in the medium to long term, the dynamic correlation is not significant affected by the Connect.

Figure 10. The CCB shares daily return and correlation



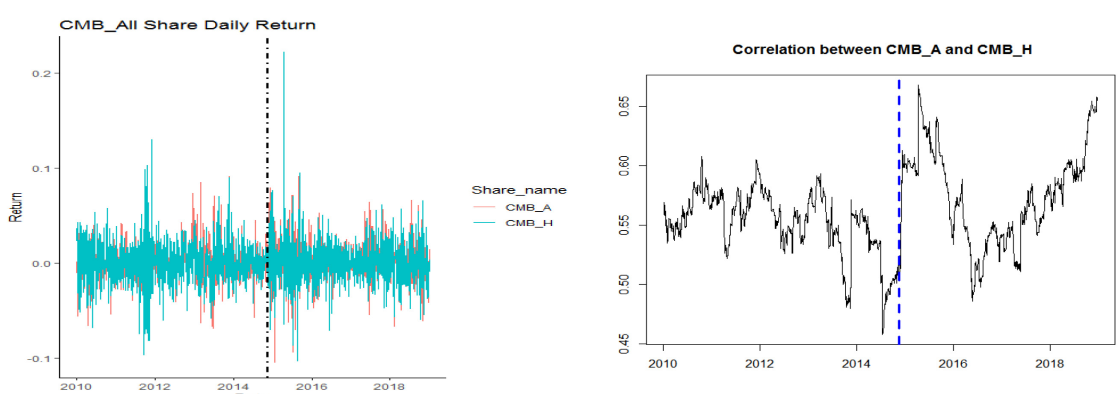
For CITIC shares, its dynamic correlation coefficient varies between 0.4 and 0.6, which is less volatile than other AH bank shares. The correlation coefficient peaked before the Connect, and there was a downward trend of correlation before the Connect. After implementing the Connect, the correlation coefficient increased significantly, but the upward trend did not last.

Figure 11. The CITIC shares daily return and correlation



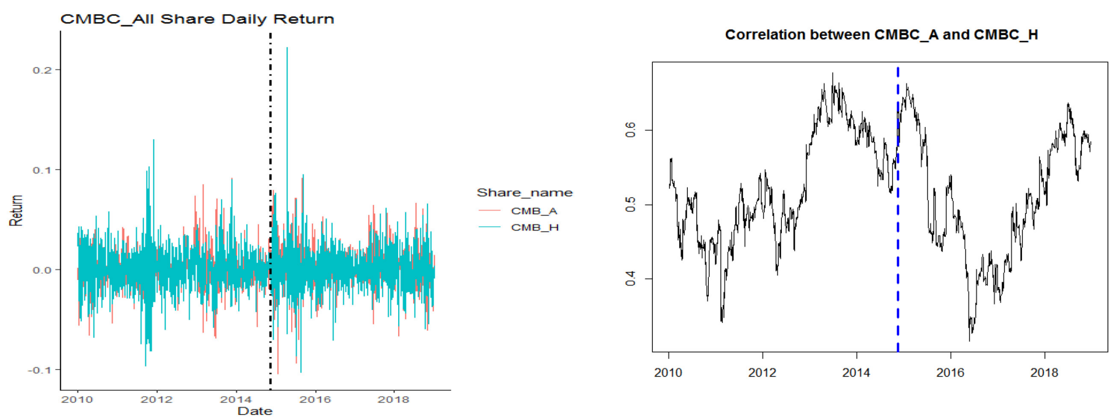
CMB is a relatively special bank share, with a consistently low premium between A and H shares, and with both A and H share prices continuing to rise after the Connect in 2014 and reaching a share price peak in early 2018 (between 2010 and 2018). CMB's price trend and correlation are very similar, with the correlation ranging between 0.45 and 0.66. After the implementation of the Connect, the correlation had a significant increase and peaked in mid-2015. Due to the short-term crash of Shanghai and Shenzhen stocks markets in the second half of 2015, the correlation declined significantly from the second half of 2015 to the beginning of 2016. After 2016, the CMB AH shares resumed a significant upward trend of correlation until the end of our study period.

Figure 12. The CMB shares daily return and correlation



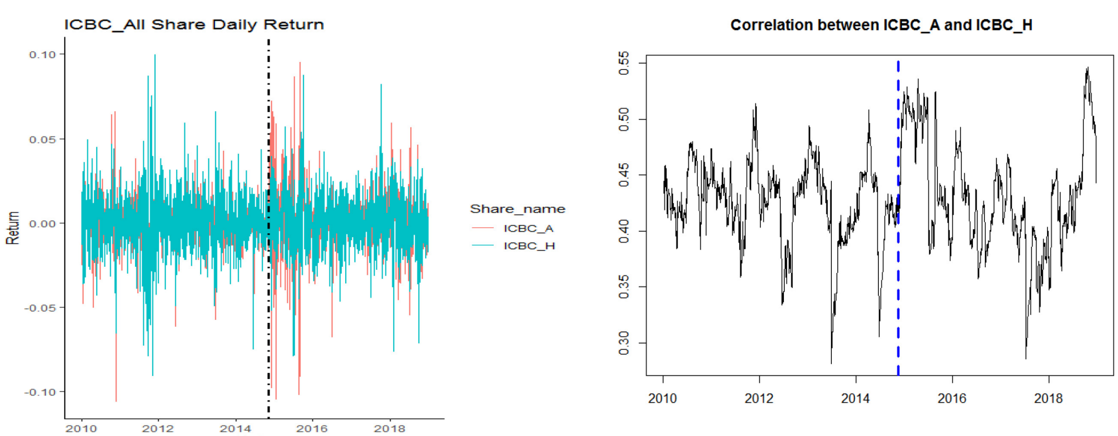
CMBC's shares had a relatively high correlation before the Connect peak occurring in 2013. However, as with most AH bank shares, the correlation declined in the first half of 2014, but had a significant upward trend after the implementation of the Shanghai-Hong Kong Stock Connect. However, since mid-2015, there has been a V-shaped trend in the correlation coefficient, with correlation fluctuations ranging from 0.31 to 0.67.

Figure 13. The CMBC shares daily return and correlation



The correlation of ICBC's AH shares is lower than that of other banking shares, with its correlation varying between 0.28 and 0.55, with its peak appearing in the second half of 2018. As with all other AH bank shares, the correlation has had a significant upward trend after the implementation of the Shanghai-Hong Kong Stock Connect, but the trend has not lasted.

Figure 14. The ICBC shares daily return and correlation



In general, correlations are positive for all stock markets and cross-listed shares, with the AH share index showing the highest average correlation for other stock markets and AH shares (~0.7), followed by average correlations for Shanghai and Hong Kong stock markets (~0.6). The average correlation of all AH bank shares is about 0.45-0.55, and its correlation moves steadily within a certain range. When we analyze the impact of Shanghai-Hong Kong Stock Connect on the two markets and cross-listed AH bank stocks, we can see that Shanghai-Hong Kong Stock Connect has a significant positive impact on the AH share market and the correlation of AH bank stocks in a short period, but the impact is not long-lasting. In particular, the correlation between the AH share market and the AH bank shares declined significantly from the middle of 2015 to the middle of 2016, which was caused by the 2015 stock market crash in Shanghai and Shenzhen. It suggests that the conditions of the listing market more influence the volatility of cross-listed share prices and that cross-listed A and H shares remain as two relatively more independently operating shares. The Shanghai-Hong Kong Stock Connect is only the initial stage of the interconnection mechanism between the two financial markets, and it will still take a long process to enhance the linkage between the two stock markets and the A and H shares.

5.5 The summary of empirical research

Based on the empirical results of the VAR and DCC-GARCH models, we have three main conclusions.

1. After 2010, the information transmission between the Shanghai and Hong Kong stock markets and cross-listed bank shares has increased and has been dynamically correlated.

According to the literature on the information transmission of stock markets and cross-listed stocks, information transmission is usually from developed to developing markets. Many studies examining the correlation and information transmission between mainland China, Hong Kong, and U.S. stock markets point out that information transmission was mainly one-way from Hong Kong to mainland China and there was no significant information transmission from the U.S. to mainland China. However, based on the empirical results of the VAR model, we find that this relationship has changed after 2010. From the perspective of cross-listed shares, A-shares are usually affected by their own lagged information, and sometimes their lagged information affects H shares in the short-run (usually at lag 1 or 2). On the other hand, H shares are not significantly affected by their own lagged items, but their lagged items significantly impact A shares. In contrast, from the perspective of Shanghai and Hong Kong stock markets, Shanghai returns are not significantly affected by its own lagged term, but its lagged term has a significant impact on Hong Kong stock returns.

Based on the Granger causality test, we can see that after November 2014, the information transmission between Shanghai and Hong Kong stock markets increases, and the Hong Kong stock market is no longer the "leader" of the Shanghai stock market. This empirical result supports the findings of Hui and Chan (2018). Moreover, it also suggests that the stock market in mainland China has experienced significant growth and progress after 2010 and has a stronger influence in the relationship with the Hong Kong stock market.

For cross-listed bank stocks, one-way Granger causality was found for only three stocks before the Connect, but significant one-way Granger causality was found for six shares and the AH share market after the Connect. For cross-listed bank stocks, H-shares have a leading role for A-shares, which is contrary to the overall Shanghai-Hong Kong market performance, but again proves the enhanced information transmission of cross-listed stocks after 2010.

The DCC-GARCH model proved a dynamic conditional correlation between all AH shares and the two stock markets, with correlation coefficients moving within a certain range throughout the study period.

2. The Shanghai-Hong Kong Stock Connect does not essentially promote market linkage and increases the correlation of cross-listed AH shares.

The Shanghai-Hong Kong Stock Connect is an essential element of China's capital market opening to the world, and its purpose is to strengthen the capital market linkage between Shanghai and Hong Kong and promote the two-way opening of the capital market. To study the actual effects of the Shanghai-Hong Kong Stock Connect implementation, we divided the data into two groups." Before November 2014" and "After November 2014".

The results of VAR and Granger causality tests tell us that the information transmission between the two stock markets and cross-listed stocks enhances after 2014, and the Granger causality becomes significant for more AH bank shares. However, when we examine the dynamic correlation coefficients in the DCC GARCH model, we cannot say that the Shanghai-Hong Kong Stock Connect provides a long-term impact on the AH cross-listed stocks and stock markets. We can see in the DCC GARCH model that the correlation coefficient increases in the short run after the Shanghai-Hong Kong Stock Connect but has little impact on strengthening the linkage between the Shanghai and Hong Kong stock markets and cross-listed shares in the medium and long run. Thus, "Shanghai-Hong Kong Stock Connect" only provides an investment channel for Shanghai and Hong Kong stock markets. However, it does not eliminate the Shanghai and Hong Kong stock market segmentation and does not enhance the two-way opening and linkage of the capital market in the medium and long term again.

3. AH bank shares are more stable than general AH shares.

In the background introduction, we mentioned that AH bank shares have several advantages: low AH share price premium, large market capitalization, and less speculative influence. Therefore, studying AH bank shares could help us truly understand the information transmission and correlation of cross-listed stocks and the Shanghai-Hong Kong Stock Connect impact on cross-listed stocks.

First, in Granger causality, the findings of AH bank shares and AH share markets are the same. For most AH bank shares and AH share markets, H shares are the Granger causality of A shares, and the information transmission is from H shares to A shares. And when we analyze the results of the DCC GARCH model, we find that the parameter β of most AH bank shares (except CITIC and CMB) are smaller than the parameter β of the AH share market, which indicates that the past market volatility of AH bank shares has a lower degree of influence on the present market volatility. Furthermore, the sum of α and β parameters of most AH bank shares is lower than AH share market, which indicates that AH bank shares can absorb the historical market information more quickly.

Chapter 6 Conclusion

This thesis systematically investigates the information transmission and dynamic correlation of cross-listed AH bank shares and their listed stock markets. We also take Shanghai-Hong Kong Stock Connect as a breakthrough point to study the development of market integration.

In terms of market correlation, we confirm a dynamic correlation between Shanghai and Hong Kong stock markets; while the AH share market has the highest correlation, but the AH bank stocks with lower premiums show a lower correlation. From the perspective of information transmission, the influence of the Shanghai stock market is increasing, and it gradually has a " leading role" in the information transmission of Shanghai and Hong Kong stock markets. However, for the AH share market and AH bank stocks, the information transmission continues to be mainly from H shares to A shares, with H shares as Granger causality for A shares. It is worth mentioning that many literatures discussing information transmission prove that information transmission usually flows from developed to developing markets. However, we find the opposite result in our empirical study, where the Shanghai stock market, as a developing market, starts to have a stronger influence on the Hong Kong stock market. However, the cross-listed A-shares do not have that performance.

The dynamic correlation coefficients obtained from the DCC GARCH model show that the Shanghai-Hong Kong Stock Connect positively impacts the dynamic correlation of Shanghai and Hong Kong markets only for a short period, but the impact is not long-lasting. The dynamic correlations of all cross-listed AH bank stocks are more dependent on the listed market conditions, and their correlations do not increase significantly in the long run after the Shanghai-Hong Kong Stock Connect.

Moreover, in this thesis, we find that the Granger causality of cross-listed bank shares is the opposite of the Granger causality of Shanghai and Hong Kong stock markets, which is an interesting topic for further research.

In general, the correlation between Shanghai and Hong Kong stock markets and AH cross-listed stocks persists over time. The Shanghai-Hong Kong Stock Connect, which serves as a channel to guide the integration of the two stock markets, provides investment channels for both Shanghai and Hong Kong stocks, but does not have a significant long-term impact on the market's correlation and the correlation of AH bank stocks is not enhanced. However, investors can use Granger causality to arrange their portfolios appropriately. In addition, the Chinese government may promote the integration of Shanghai and Hong Kong stock markets by improving the liberalization of capital markets from internal perspective.

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Appendix:

Appendix 1: The Summary of AH shares and market indexes and its return before and after the Connect

Appendix_Table_1.1 The summary of market index/share price Before the Connect

	ABC_A_B	ABC_H_B	BOC_A_B	BOC_H_B	BOCM_A_B	BOCM_H_B	CCB_A_B	CCB_H_B	CITIC_A_B	CITIC_H_B
nbr.val	1016	1016	1135	1135	1137	1137	1135	1135	1135	1135
min	2.29	2.115342	2.45	1.9317	3.63	3.606278	3.78	3.9026	3.41	2.634126
max	3.23	3.966906	4.2331	4.0071	8.53636	7.392229	6.21	6.89621	7.76291	5.737443
median	2.605	2.886356	2.95	2.8311	4.68	4.63362	4.61	4.811709	4.46	3.782954
mean	2.610276	2.941674	3.027329	2.892055	4.835562	5.038424	4.578044	4.940292	4.627962	3.773163
var	0.02224012	0.1331316	0.1549397	0.1823755	0.857136	0.9851105	0.21626	0.3567107	0.627678	0.3226563
std.dev	0.1491312	0.3648721	0.3936238	0.4270545	0.9258164	0.9925273	0.4650376	0.5972526	0.7922613	0.5680284
	CMB_A_B	**CMB_H_B**	**CMBC_A_B**	**CMBC_H_B**	**ICBC_A_B**	**ICBC_H_B**	**SSE_B**	**HSI_B**	**AH_A_B**	**AH_H_B**
nbr.val	1141	1141	1140	1140	1136	1136	1143	1143	717	717
min	9.39752	8.993829	3.43056	2.674341	3.23	3.132018	1950.012	17407.8	1346.5	1492.61
max	16.49	19.74063	8.13194	6.743829	5.3065	5.826956	3282.179	25317.95	1851.88	2108.46
median	11.7518	12.60221	4.34375	4.232008	4.10881	4.21137	2331.136	22035.42	1520.95	1784.13
mean	11.93063	13.37418	4.769003	4.359438	4.064389	4.351744	2418.955	21797.29	1548.51	1780.26
var	2.559587	5.918106	1.111461	0.3425683	0.1487813	0.3232497	111675.1	2781129	12250.47	16325.54
std.dev	1.599871	2.432716	1.054259	0.5852933	0.3857218	0.5685505	334.1783	1667.672	110.6818	127.7714
Correlation	**ABC_A_B**	**ABC_H_B**	**BOC_A_B**	**BOC_H_B**	**BOCM_A_B**	**BOCM_H_B**	**CCB_A_B**	**CCB_H_B**	**CITIC_A_B**	**CITIC_H_B**
	1	0.6785968	1	0.6830215	1	0.8216308	1	0.7003158	1	0.851561
	0.6785968	1	0.6830215	1	0.8216308	1	0.7003158	1	0.851561	1
	CMB_A_B	**CMB_H_B**	**CMBC_A_B**	**CMBC_H_B**	**ICBC_A_B**	**ICBC_H_B**	**SSE_B**	**HSI_B**	**AH_A_B**	**AH_H_B**
	1	0.8659042	1	0.8043342	1	0.6859206	1	0.0807388	1	0.496802
	0.8659042	1	0.8043342	1	0.6859206	1	0.0807388	1	0.496802	1

Appendix_Table_1.2 The summary of data After the Connect (After 17th November 2014)										
	ABC_A_A	ABC_H_A	BOC_A_A	BOC_H_A	BOCM_A_A	BOCM_H_A	CCB_A_A	CCB_H_A	CITIC_A_A	CITIC_H_A
nbr.val	980	980	980	980	980	980	980	980	980	980
min	2.54	2.151936	2.92	2.4293	4.37	3.69864	4.17	3.774915	4.91	3.563315
max	4.75	3.97194	5.6	4.4428	9.4	6.74021	9.81	7.392672	10.28	5.874855
median	3.45	3.053503	3.7	3.2046	6.095	5.05356	6.11	5.398794	6.35	4.333509
mean	3.464755	2.97312	3.820949	3.202829	6.125653	5.00512	6.185612	5.33431	6.519439	4.381302
var	0.1168621	0.1391567	0.2055876	0.1513622	0.3867255	0.2867631	1.002097	0.5879588	0.5954137	0.1471377
std.dev	0.3418511	0.3730371	0.4534176	0.3890529	0.6218726	0.5355027	1.001048	0.7667847	0.7716305	0.3835853
	CMB_A_A	CMB_H_A	CMBC_A_A	CMBC_H_A	ICBC_A_A	ICBC_H_A	SSE_A	HSI_A	AH_A_A	AH_H_A
nbr.val	980	980	980	980	977	977	978	978	980	980
min	5.36667	4.471526	3.68	3.227904	2451.167	18542.15	1568.09	1461.75	5.36667	4.471526
max	9.25	7.71807	7.75	6.030864	5166.35	33154.12	3213.82	2777.08	9.25	7.71807
median	7.29167	5.454222	4.87	4.530139	3159.15	24619.45	2358.345	2025.505	7.29167	5.454222
mean	7.225488	5.634953	5.057214	4.522268	3217.972	25155.6	2395.807	2042.124	7.225488	5.634953
var	0.5733217	0.4669651	0.5340634	0.4134114	193288.2	11088220	91051.96	84188.85	0.5733217	0.4669651
std.dev	0.7571801	0.6833484	0.7307964	0.6429707	439.6455	3329.897	301.7482	290.1532	0.7571801	0.6833484
Correlation	ABC_A_A	ABC_H_A	BOC_A_A	BOC_H_A	BOCM_A_A	BOCM_H_A	CCB_A_A	CCB_H_A	CITIC_A_A	CITIC_H_A
	1	0.7929627	1	0.7550221	1	0.6696661	1	0.9003867	1	0.6705885
	0.7929627	1	0.7550221	1	0.6696661	1	0.9003867	1	0.6705885	1
	CMB_A_A	CMB_H_A	CMBC_A_A	CMBC_H_A	ICBC_A_A	ICBC_H_A	SSE_A	HSI_A	AH_A_A	AH_H_A
	1	0.7431501	1	0.8809541	1	0.218566	1	0.9098203	1	0.7431501
	0.7431501	1	0.8809541	1	0.218566	1	0.9098203	1	0.7431501	1

Appendix_Table_1.3 The summary of Return Rate Before the Connect (Before17th November 2014)										
Before November 2014	**ABC_A_B**	**ABC_H_B**	**BOC_A_B**	**BOC_H_B**	**BOCM_A_B**	**BOCM_H_B**	**CCB_A_B**	**CCB_H_B**	**CITIC_A_B**	**CITIC_H_B**
nbr.val	1015	1015	1134	1134	1136	1136	1134	1134	1134	1134
min	-0.0656	-0.08956	-0.08668	-0.08319	-0.06576	-0.08356	-0.1002	-0.09646	-0.0955	-0.08966
max	0.096414	0.124872	0.096581	0.097004	0.09531	0.092481	0.05535	0.063064	0.095859	0.100399
median	0	-0.00025	0	0	0	-0.00057	0	0	0	-0.00017
mean	-7.4E-06	1.34E-06	-0.00026	-0.00014	-0.00052	-0.00033	-0.0003	-0.00018	-0.00036	-0.00022
var	0.000124	0.000367	0.000122	0.000254	0.000209	0.000327	0.000147	0.000263	0.000396	0.000408
std.dev	0.011154	0.019147	0.011061	0.015924	0.01444	0.018092	0.012107	0.016208	0.0199	0.02021
Before November 2014	**CMB_A_B**	**CMB_H_B**	**CMBC_A_B**	**CMBC_H_B**	**ICBC_A_B**	**ICBC_H_B**	**SSE_B**	**HSI_B**	**AH_A_B**	**AH_H_B**
nbr.val	1140	1140	1139	1139	1135	1135	1142	1142	716	716
min	-0.06893	-0.0964	-0.10477	-0.08486	-0.10583	-0.09045	-0.05445	-0.05827	-0.05554	-0.06221
max	0.09135	0.130385	0.094253	0.095222	0.06614	0.099702	0.04494	0.054778	0.048835	0.081829
median	-0.0007	-0.00058	0	-0.00063	0	-0.00046	3.45E-05	0.000201	-0.00033	-0.00094
mean	-0.00036	-0.00028	0.000181	0.00014	-0.00029	-0.00027	-0.00024	8.64E-05	-8.9E-05	8.37E-05
var	0.000276	0.000432	0.000319	0.000421	0.000135	0.000301	0.000141	0.000135	0.000123	0.000198
std.dev	0.016604	0.020794	0.017859	0.020512	0.011602	0.017362	0.011874	0.011606	0.011103	0.014086
Before November 2014	**ABC_A_B**	**ABC_H_B**	**BOC_A_B**	**BOC_H_B**	**BOCM_A_B**	**BOCM_H_B**	**CCB_A_B**	**CCB_H_B**	**CITIC_A_B**	**CITIC_H_B**
	1	0.408266	1	0.397363	1	0.459252	1	0.404057	1	0.512357
	0.408266	1	0.397363	1	0.459252	1	0.404057	1	0.512357	1
Correlation	**CMB_A_B**	**CMB_H_B**	**CMBC_A_B**	**CMBC_H_B**	**ICBC_A_B**	**ICBC_H_B**	**SSE_B**	**HSI_B**	**AH_A_B**	**AH_H_B**
	1	0.506308	1	0.548931	1	0.371409	1	0.566294	1	0.708309
	0.506308	1	0.548931	1	0.371409	1	0.566294	1	0.708309	1

Appendix_Table_1.4 The summary of Return Rate After the Connect (After 17th November 2014)										
After November 2014	**ABC_A_A**	**ABC_H_A**	**BOC_A_A**	**BOC_H_A**	**BOCM_A_A**	**BOCM_H_A**	**CCB_A_A**	**CCB_H_A**	**CITIC_A_A**	**CITIC_H_A**
nbr.val	979	979	979	979	979	979	979	979	979	979
min	-0.10423	-0.0745	-0.11629	-0.07943	-0.106	-0.08264	-0.10577	-0.08054	-0.10564	-0.07349
max	0.095051	0.062443	0.09531	0.08528	0.096247	0.077565	0.095661	0.079582	0.096129	0.088812
median	0	-0.00024	0	-0.00034	0	0.000118	0	0.000209	0	0.000101
mean	0.000328	6.18E-05	0.000182	-1.8E-05	0.000257	0.000141	0.000404	0.000224	9.83E-05	5.68E-06
var	0.000308	0.000223	0.000356	0.000243	0.000406	0.000252	0.000417	0.000245	0.000512	0.000239
std.dev	0.017563	0.014948	0.018872	0.015578	0.02014	0.01588	0.020413	0.015653	0.022618	0.015462
After November 2014	**CMB_A_A**	**CMB_H_A**	**CMBC_A_A**	**CMBC_H_A**	**ICBC_A_A**	**ICBC_H_A**	**SSE_A**	**HSI_A**	**AH_A_A**	**AH_H_A**
nbr.val	979	979	979	979	979	979	976	976	977	977
min	-0.1044	-0.10282	-0.10525	-0.11794	-0.10428	-0.07878	-0.08906	-0.06018	-0.09843	-0.07996
max	0.095542	0.222361	0.095437	0.074824	0.09531	0.087335	0.063691	0.069869	0.096549	0.09848
median	0.000523	0.0005	0	-0.00035	0	0.000122	0.000744	0.000667	0.000634	3E-05
mean	0.000865	0.000782	4.49E-05	-0.0001	0.000351	0.000188	7.74E-06	7.1E-05	0.000354	4.11E-05
var	0.000418	0.000461	0.000333	0.000302	0.000304	0.000248	0.000274	0.000137	0.000289	0.000251
std.dev	0.02044	0.021471	0.018244	0.017365	0.017446	0.015753	0.016557	0.011717	0.016991	0.015834
After November 2014	**ABC_A_A**	**ABC_H_A**	**BOC_A_A**	**BOC_H_A**	**BOCM_A_A**	**BOCM_H_A**	**CCB_A_A**	**CCB_H_A**	**CITIC_A_A**	**CITIC_H_A**
Correlation	1	0.410175	1	0.409679	1	0.474755	1	0.463556	1	0.481359
	0.410175	1	0.409679	1	0.474755	1	0.463556	1	0.481359	1
	CMB_A_A	**CMB_H_A**	**CMBC_A_A**	**CMBC_H_A**	**ICBC_A_A**	**ICBC_H_A**	**SSE_A**	**HSI_A**	**AH_A_A**	**AH_H_A**
	1	0.614298	1	0.478336	1	0.434606	1	0.556877	1	0.660299
	0.614298	1	0.478336	1	0.434606	1	0.556877	1	0.660299	1

Appendix 2: Results from ARMA DCC GARCH model

	Estimate	Std.Error	p-value		Estimate	Std._Error	p-value
[SSE].mu	0.000327	0.000206		[AH_A].mu	0.000382	0.000251	
[SSE].ar1	0.530003	0.102847	***	[AH_A].ar1	-0.972287	0.006876	***
[SSE].ar2	-0.856102	0.138693	***	[AH_A].ma1	0.984704	0.000536	***
[SSE].ma1	-0.519259	0.106159	***	[AH_A].ω	0.000001	0.000002	
[SSE].ma2	0.857762	0.129884	***	[AH_A].α1	0.063822	0.022691	**
[SSE].ma3	0.02992	0.020861		[AH_A].β1	0.930677	0.022321	***
[SSE].ω	0.000001	0.000001		[AH_H].mu	0.000241	0.000356	
[SSE].α1	0.053364	0.009352	***	[AH_H].ar1	-0.725714	0.098384	***
[SSE].β1	0.945636	0.009095	***	[AH_H].ma1	0.76715	0.090293	***
[SSE].shape	4.291962	0.402823	***	[AH_H].ω	0.000005	0.000003	
[HSI].mu	0.000546	0.000211	**	[AH_H].α1	0.047829	0.008544	***
[HSI].ω	0.000001	0.000001		[AH_H].β1	0.93181	0.015767	***
[HSI].α1	0.044067	0.00599	***	[Joint]dcca1	0.020958	0.007159	**
[HSI].β1	0.946149	0.007707	***	[Joint]dccb1	0.96387	0.01443	***
[HSI].shape	6.378502	0.81753	***				
[Joint]dcca1	0.006684	0.001975	***				
[Joint]dccb1	0.989104	0.002639	***				

	Estimate	Std._Error	p-value		Estimate	Std._Error	p-value
[ABC_A].mu	0.000073	0.000011	***	[CMBC_A].mu	-0.000318	0.000272	
[ABC_A].ar1	0.961467	0.011593	***	[CMBC_A].ω	0.000005	0.000005	
[ABC_A].ma1	-0.981389	0.000048	***	[CMBC_A].α1	0.118536	0.025125	***
[ABC_A].ω	0.000005	0.000003	*	[CMBC_A].β1	0.875086	0.028115	***
[ABC_A].α1	0.077489	0.018459	***	[CMBC_H].mu	-0.000048	0.000364	
[ABC_A].β1	0.896812	0.026671	***	[CMBC_H].ω	0.00001	0.000003	***
[ABC_H].mu	0.000037	0.000352		[CMBC_H].α1	0.100437	0.012212	***
[ABC_H].ar1	-0.86328	0.09141	***	[CMBC_H].β1	0.872748	0.012657	***
[ABC_H].ma1	0.898634	0.080108	***	[Joint]dcca1	0.011061	0.003469	**
[ABC_H].ω	0.000015	0.000002	***	[Joint]dccb1	0.981273	0.005447	***
[ABC_H].α1	0.082224	0.008129	***				
[ABC_H].β1	0.866145	0.010267	***				
[Joint]dcca1	0.019676	0.011185	*				
[Joint]dccb1	0.947767	0.032648	***				

	Estimate	Std._Error	p-value		Estimate	Std._Error	p-value
[BOCM_A].mu	-0.000437	0.000296		[CITIC_A].mu	-0.000368	0.000362	
[BOCM_A].ar1	-1.343943	0.020784	***	[CITIC_A].ar1	1.006272	0.146843	***
[BOCM_A].ar2	-0.960604	0.007823	***	[CITIC_A].ar2	-0.890402	0.160412	***
[BOCM_A].ma1	1.36121	0.012416	***	[CITIC_A].ma1	-0.986085	0.153477	***
[BOCM_A].ma2	0.983956	0.001015	***	[CITIC_A].ma2	0.898492	0.146058	***
[BOCM_A].ω	0.00001	0.000003	***	[CITIC_A].ω	0.000011	0.000003	***
[BOCM_A].α1	0.127853	0.022701	***	[CITIC_A].α1	0.076466	0.008341	***
[BOCM_A].β1	0.839318	0.018414	***	[CITIC_A].β1	0.897972	0.016954	***
[BOCM_H].mu	-0.000108	0.000324		[CITIC_H].mu	-0.000029	0	***
[BOCM_H].ar1	0.061821	0.007347	***	[CITIC_H].ar1	1.370144	0.003422	***
[BOCM_H].ar2	-0.985958	0.003317	***	[CITIC_H].ar2	-0.375877	0.000777	***
[BOCM_H].ma1	-0.073724	0.008191	***	[CITIC_H].ma1	-1.31177	0.000032	***
[BOCM_H].ma2	0.979942	0.000406	***	[CITIC_H].ma2	0.310019	0.000081	***
[BOCM_H].ω	0.000009	0.000002	***	[CITIC_H].ω	0.000003	0.000007	
[BOCM_H].α1	0.075424	0.009126	***	[CITIC_H].α1	0.062127	0.012299	***
[BOCM_H].β1	0.893758	0.008956	***	[CITIC_H].β1	0.931104	0.021264	***
[Joint]dcca1	0.014161	0.008396	*	[Joint]dcca1	0.008764	0.005143	*
[Joint]dccb1	0.94384	0.031629	***	[Joint]dccb1	0.956946	0.014106	***

	Estimate	Std._Error	p-value		Estimate	Std._Error	p-value
[BOC_A].mu	-0.000264	0.000202		[CCB_A].mu	-0.000135	0.000523	
[BOC_A].ar1	0.042722	1.121489		[CCB_A].ar1	0.704431	0.033804	***
[BOC_A].ar2	0.280734	0.413896		[CCB_A].ar2	-0.078137	0.021597	***
[BOC_A].ar3	-0.065737	0.997143		[CCB_A].ar3	-0.714122	0.025875	***
[BOC_A].ar4	0.545074	0.384069		[CCB_A].ar4	0.86827	0.009442	***
[BOC_A].ma1	-0.078352	1.124645		[CCB_A].ma1	-0.729385	0.000891	***
[BOC_A].ma2	-0.309357	0.356888		[CCB_A].ma2	0.069533	0.000729	***
[BOC_A].ma3	0.094492	1.041902		[CCB_A].ma3	0.726772	0.000247	***
[BOC_A].ma4	-0.571957	0.337299	*	[CCB_A].ma4	-0.904213	0.000272	***
[BOC_A].ω	0.000008	0.000002	***	[CCB_A].ω	0.000014	0.000008	*
[BOC_A].α1	0.116002	0.018734	***	[CCB_A].α1	0.140521	0.064311	**
[BOC_A].β1	0.843056	0.020256	***	[CCB_A].β1	0.804919	0.040308	***
[BOC_H].mu	0.000025	0.000322		[CCB_H].mu	-0.000295	0	***
[BOC_H].ar1	-0.122224	0.015072	***	[CCB_H].ar1	0.060965	0.000706	***
[BOC_H].ar2	0.918878	0.010047	***	[CCB_H].ar2	-0.025993	0.007187	***
[BOC_H].ar3	-0.447376	0.011201	***	[CCB_H].ar3	0.004591	0.008066	
[BOC_H].ar4	-0.778876	0.013983	***	[CCB_H].ar4	0.941942	0.000435	***
[BOC_H].ma1	0.128483	0.004416	***	[CCB_H].ma1	-0.059745	0.000014	***
[BOC_H].ma2	-0.92652	0.004256	***	[CCB_H].ma2	-0.004641	0.000882	***
[BOC_H].ma3	0.472463	0.002855	***	[CCB_H].ma3	-0.006244	0.00054	***
[BOC_H].ma4	0.76906	0.00003	***	[CCB_H].ma4	-0.94338	0.000119	***
[BOC_H].ω	0.000012	0.000001	***	[CCB_H].ω	0.000022	0.000009	**
[BOC_H].α1	0.072821	0.004668	***	[CCB_H].α1	0.078314	0.023998	**
[BOC_H].β1	0.876032	0.008088	***	[CCB_H].β1	0.834789	0.045105	***
[Joint]dcca1	0.022607	0.013725	*	[Joint]dcca1	0.016251	0.009174	*
[Joint]dccb1	0.815135	0.084503	***	[Joint]dccb1	0.938827	0.028666	***

	Estimate	Std._Error	p-value		Estimate	Std._Error	p-value
[ICBC_A].mu	-0.000007	0.000023		[CMB_A].mu	-0.000153	0.000052	**
[ICBC_A].ar1	-1.42237	0.001437	***	[CMB_A].ar1	-0.665196	0.000546	***
[ICBC_A].ar2	-0.391178	0.000201	***	[CMB_A].ar2	0.821765	0.000592	***
[ICBC_A].ar3	0.746362	0.000447	***	[CMB_A].ar3	-0.133124	0.000098	***
[ICBC_A].ar4	0.690741	0.000378	***	[CMB_A].ar4	-0.724645	0.000424	***
[ICBC_A].ar5	0.347132	0.000207	***	[CMB_A].ma1	0.723066	0.000563	***
[ICBC_A].ar6	0.284095	0.000036	***	[CMB_A].ma2	-0.766044	0.000457	***
[ICBC_A].ma1	1.341577	0.000169	***	[CMB_A].ma3	0.11533	0.000098	***
[ICBC_A].ma2	0.230135	0.000108	***	[CMB_A].ma4	0.700005	0.00018	***
[ICBC_A].ma3	-0.828043	0.000079	***	[CMB_A].ω	0.000004	0.000007	
[ICBC_A].ma4	-0.641465	0.000193	***	[CMB_A].α1	0.051996	0.035379	
[ICBC_A].ma5	-0.292918	0.000324	***	[CMB_A].β1	0.938473	0.041428	***
[ICBC_A].ma6	-0.30164	0.000278	***	[CMB_H].mu	0.000133	0.000082	
[ICBC_A].ω	0.000007	0.000005		[CMB_H].ar1	-0.50051	0.000167	***
[ICBC_A].α1	0.179397	0.040182	***	[CMB_H].ar2	-0.739553	0.000288	***
[ICBC_A].β1	0.803409	0.027931	***	[CMB_H].ar3	-0.290673	0.000154	***
[ICBC_H].mu	0.000018	0.000121		[CMB_H].ar4	0.309714	0.000133	***
[ICBC_H].ar1	-0.468161	0.009498	***	[CMB_H].ma1	0.530603	0.000216	***
[ICBC_H].ar2	-1.019512	0.00952	***	[CMB_H].ma2	0.742951	0.000349	***
[ICBC_H].ar3	0.30355	0.013732	***	[CMB_H].ma3	0.32441	0.000123	***
[ICBC_H].ar4	0.616675	0.012931	***	[CMB_H].ma4	-0.323623	0.000053	***
[ICBC_H].ar5	0.768335	0.008792	***	[CMB_H].ω	0.000004	0.00001	
[ICBC_H].ar6	0.694415	0.008535	***	[CMB_H].α1	0.029993	0.02095	
[ICBC_H].ma1	0.495083	0.001505	***	[CMB_H].β1	0.960321	0.005114	***
[ICBC_H].ma2	0.991237	0.001677	***	[Joint]dcca1	0.006166	0.003421	*
[ICBC_H].ma3	-0.274503	0.001569	***	[Joint]dccb1	0.984511	0.011392	***
[ICBC_H].ma4	-0.686181	0.001028	***				
[ICBC_H].ma5	-0.749996	0.001106	***				
[ICBC_H].ma6	-0.742835	0.00037	***				
[ICBC_H].ω	0.000015	0.000002	***				
[ICBC_H].α1	0.074478	0.007036	***				
[ICBC_H].β1	0.867801	0.011723	***				
[Joint]dcca1	0.011385	0.006929	*				
[Joint]dccb1	0.961494	0.010089	***				