RETURN AND VOLATILITY SPILLOVERS AMONG FIXED INCOME SECURITIES IN THAI BOND MARKET

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งานวิจัยฉบับนี้ศึกษาประเด็นของผลกระทบจากการส่งผ่านของพันธบัตรประเภทต่างๆในตลาดตราสารหนี้ไทย แบบจำลอง GARCH หลายตัวแปร ถูกนำมาใช้ในการประมาณค่าผลกระทบของพันธบัตรที่แตกต่างกัน 3 ประเภทคือ ระยะเวลาครบกำหนดของพันธบัตร การจัดอันดับความน่าเชื่อถือ รวมถึงสภาพคล่องของพันธบัตร การแบ่งประเภทของพันธบัตรถูกกำหนดโดย ความเสี่ยงในระดับที่แตกต่างกัน และความสนใจของนักลงทุนในกลุ่มที่แตกต่างกัน หรือวัตถุประสงค์ในการลงทุนที่แตกต่างกัน ข้อมูลตัวอย่างประกอบด้วยอัตราผลตอบแทนรายวันและรายสัปดาห์ในช่วงเวลาตั้งแต่ปี พ.ศ.2546-2556 ผลการทดสอบพบว่ามีการส่งผ่านอัตราผลตอบแทนและความผันผวนเกิดขึ้นในพันธบัตรแต่ละประเภทที่แตกต่างกัน ประเภทของพันธบัตรที่มีระยะเวลาครบกำหนดที่แตกต่างกันพบว่า พันธบัตรรัฐบาลที่มีอายุระดับสั้นมีการส่งผ่านอัตราผลตอบแทนไปยังพันธบัตรที่มีอายุระดับกลางและระดับยาว และหุ้นกู้เอกชนที่มีอายุระดับกลางมีการส่งผ่านอัตราผลตอบแทนไปยังหุ้นกู้เอกชนทุกระดับ สำหรับการจัดอันดับความน่าเชื่อถือพบว่า ระดับความน่าเชื่อถือของพันธบัตรรัฐบาลมีการส่งผ่านอัตราผลตอบแทนไปยังระดับความน่าเชื่อถือระดับต่ำของหุ้นกู้เอกชน และพันธบัตรรัฐบาลที่มีสภาพคล่องสูงมีการส่งผ่านอัตราผลตอบแทนไปยังพันธบัตรรัฐบาลที่มีสภาพคล่องต่ำ ในขณะเดียวกัน ความสัมพันธ์ในแต่ละระดับที่แตกต่างกันส่วนใหญ่พบว่ามีการส่งผ่านความผันผวนเกิดขึ้น สุดท้ายนี้งานวิจัยฉบับนี้จักเป็นประโยชน์อย่างยิ่งสำหรับนักลงทุน, ผู้มีส่วนเกี่ยวข้องและหน่วยงานกำกับทางการเงินในการควบคุมนโยบายทางการเงินของประเทศ

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KEYWORDS: RETURN SPILLOVERS / VOLATILITY SPILLOVERS / FIXED INCOME SECURITIES / BOND MARKETS / MULTIVARIATE GARCH MODEL

MALEE FUANGFOOKIJPYSAN: RETURN AND VOLATILITY SPILLOVERS AMONG FIXED INCOME SECURITIES IN THAI BOND MARKET. ADVISOR: RUTTACHAI SEELAJAROEN, Ph.D., 95 pp.

This paper examines the spillover effects among fixed income securities with different characteristics in Thai bond market. Multivariate GARCH (1,1) models are estimated for three different sub-classes of bond; time to maturity, credit rating as well as liquidity. The sub-classes are chosen such that they reflect different levels of risk and attract different groups of investors or different purposes of investment to capture the possible spillover effects in return and volatility. The sample consists of daily and weekly returns of bonds existing between 2003 – 2013. The results suggest that spillovers effects among different sub-classes of bonds exist in terms of return and volatility in the majority of Thai bonds. For time to maturity, short time to maturity has return spillover to both medium and long time to maturity of government bond and medium time to maturity has return spillover to all short, medium and long time to maturity of corporate bond. For credit rating, government credit rating has return spillover to low credit rating of corporate bond. And for liquidity, high liquidity has return spillover to low liquidity of government bond. However, most of all relations exist volatility spillovers among different sub-classes of bond. Lastly, the results are contributes to investors, market participants and regulators for monetary policy implementation.

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CHAPTER 1

Introduction

1.1 Background and motivation

Studies of the relationship among returns on different asset classes, for instance stocks and bonds, have been widely investigated after Markowitz (1952) introduced the idea of portfolio diversification[1]. Markowitz's idea was later extended to international diversifications by Adler and Solnik (1974). However, over the last decade, another aspect of asset relation, namely, return and volatility spillovers, has been widely examined in the literatures, partly due to an increase in financial market integration and international financial crises. Spillover is defined as a shock that occurs to return or volatility on one asset and causes return or volatility of another asset class to change. Most researchers measure spillover effects by using lead-lag relation between asset classes. The understanding of spillover effect is beneficial not only to regulators, who are responsible for stabilizing financial markets, but also investors who can use the knowledge to optimize asset allocation[2]. For example, if spillovers do exist, regulators or investors can use price movement of one asset class to predict price movement of another asset class.

There are numbers of researches examining the spillover effects, for example, Billio and Pelizzon (2003), Christiansen (2007), Christiansen (2010), Dean, Faff et al. (2010). Billio and Pelizzon (2003) studied volatility spillovers in European stock markets before and after EMU. He found that volatility spillover from both the world and German markets have increased after the EMU for most European stock markets. Ng (2000) studied spillovers between stocks in developed markets and emerging markets. She divided factors driving the spillover into global, regional and country-specific factors. She found that there are volatility spillovers from regional factor which is Japan country and global factor which is the US country to pacific-rim stock markets.

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[1] This paper illustrates that an average investor is better off, in terms of risk-return trade-off, investing in a well-diversified portfolio compared to investing in an individual asset. He showed that the diversification benefit is largely driven by imperfect correlation among asset returns.

[2] See Hassan, S. A. and F. Malik (2007). "Multivariate GARCH modeling of sector volatility transmission.".

Why are there spillover effects? One possible reason can be observed when there is a shock or unexpected news affecting value of the asset class before transmitting to another asset. Normally these spillover effects usually come from news that can impact many assets simultaneously, these news could refer to the common factor which directly influences to all assets at the same period of time. However, there are many reasons why value of certain asset class might respond to news before the others, these activities creating spillover effects. In other words, certain news might have a direct effect of the certain value of asset, but portfolio rebalanced by investors might cause value of another asset class to change as well. For example, when there is a negative news directly impacting to the stock market, the particular economic news might cause value of the stock to go down, but once investors rebalance their portfolios from stocks to bonds, value of bonds will be impacted by the same news but with the lag time. These activities also create spillover effects. In case of liquidity factors, because the liquid assets would normally have low cost of trading, when there are shocks or news occurs, investors would particularly adjust these liquid or low cost of trading assets first. Therefore, the illiquid assets or assets that have a high cost of trading will then be adjusted later because investors would wait until their assets in portfolio reach to expected return, then they would become worth trading. This statement means liquidity factor has an impact to each specific asset that responds to the news differently. This implies that when a shock occurs, it is possible that there are lead-lag reactions, if we can ensure that there are negative effects from lag reaction, this condition can be called contagion effects.

Regarding to spillover testing, most of the studies of spillover effects tend to focus on spillovers across broad asset classes or across national financial markets; such as stock markets, bond markets and foreign exchange markets. However, there are less researches attending to spillovers among sub-classes within the same asset class[3]. This kind of literatures, which are related to sub-classes, mostly focuses on the equity markets[4] such as sub-classes divided by

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[3] See Campbell, J. Y., M. Lettau, B. G. Malkiel and Y. Xu (2001) and Wang, Z. (2010).

[4] However, the topic about the industry-specific has been studies for a while mostly associate with international diversification of portfolio. With the motivation of arguments that some researches find that diversification across industries would provide more risk than diversification across countries. Nevertheless, recently gathered evidence

industry; financial, property manufacturing sectors and construction. In case there is a specific news impacting on a particular industry, for example interest policy news, this news would impact directly on financial industry, but also spillover later to other industries such as industries that rely on the financial industry. The question is "Would spillover exists if that news is industry specific?" If spillover exists, this could reflect that there are linkages between industries. For instance, Wang (2010) studied spillover effects between industry-specific volatility in Chinese stock market. Hassan and Malik (2007) studied spillovers across sectors in stock markets.

Investors whose portfolios are not well-diversified normally invest in particular types of assets such as assets in specific industries. It is important to know whether spillover effect between each industry exists in their portfolio or not. Previous studies pay little attention to different type of bonds in the market because they lack of data and bonds are traded in OTC market; however, this paper aims to fulfill this gap by emphasizing among different types of bond markets. Regarding to ThaiBMA summary report, in Thailand, bond market has also been increasing in the amount outstanding for last decades because Thai firms use more debt financing in form of bonds. Besides, there has been the high growth of bond financing over 6 times during last 10 years. When companies need to raise money, issuing bonds is one way to perform financing. Most firms can borrow from financial institutes such as banks, but direct borrowings from banks are more limited and higher cost than selling bond in the market through bond issuances. From this reason, many companies in Thailand issue more bonds; therefore, it is interesting to study bond market in Thailand (ThaiBMA: 76 Bond issues in 2003 compared to 432 Bond issues in 2013)

Hence, the gap in the literature is spillover among sub-classes of bond markets. And there are only few papers that study the relation between characteristics in bond market, for instance, Sy (2002) studied the relationship of bond spreads and bond ratings of the data for both cross sectional and time series data and found the statistically significant difference between actual bond spreads and rating based spreads. Gebhardt, Hvidkjaer et al. (2005) studied the cross

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depicts that local industry-specific source of risk becoming more important in 1990s might come from integration of business economics as proposed by Cavaglia, S., C. Brightman and M. Aked (2000).

sectional data of bond returns by controlling the characteristic in the dimension of duration, ratings and yield to maturity. This author found that yield to maturity among other characteristics is significantly related with mean in bond returns. Kim and Wu (2008) studied the channel transmission among different types of bond credit ratings. This article found that credit ratings have related to financial department developments including international capital flows. Fujiwara, Körber et al. (2013) studied asymmetry in government bond returns among different types of year to maturity. In particular, very limited researched were previously done on sub asset classes of bond markets and this paper aims to fulfill this gap of the literatures.

Why this paper interests in sub-classes of bond market? Because the purposes of holding sub-class bonds are different. In other words, some investors hold bonds for financial stability purpose, while some investors hold stock for return purpose. For example, risk-averse investors rebalance their portfolios by selling stocks and buying bonds, these activities could create spillover transmissions. Some investors hold short term bond, some investors hold long term bond, but finally, cost of capital for long term bond will later be cost of capital of short term bond, these activities also create spillover among sub - classes of bond market. The spillover effects among sub - classes of bond market are then interesting to observe.

To study the spillover effects among sub - classes of bond markets, this paper indicates the bond characteristic that is highly advantageous and has impact to market participants; time to maturity, credit rating and liquidity.

The first issue is time to maturity. Spillover effects among level of time to maturity are important to market participants, particularly for national banks and regulators. Yield curve expectation theory suggests that short term interest rate is the fundamental base for the interest policy measurement while long term interest rate is valued by adding the premiums. Hence, there are supposed to be the evidence that when news or shock occur, there possibly adjust prior to short time to maturity. Therefore, short-term interest rates would drive long-term interest rates. However, it is possible that long-term interest rates drive short-term rates as well. For example, when expecting that interest rate will reduce, investors may try to lock-in long-term investment causing long-term rate to reduce prior to short-term rate reduction. Therefore, the direction of cause and effect is unclear. Hence, to study the spillover effects among bond term rate (Short term bond has spillover to medium term bond or short term bond has spillover to long term bond) and whether these bond cascades to other term rate of bond are interesting to observe for government and regulators to predict and forecast their monetary policy. Another reason for time to maturity issue is because of the investors' behavior of portfolio strategy. Normally when investors want to adjust their portfolios, including to buy or to sell their assets, they would adjust assets which can then be influenced first and followed by the other assets. These activities also create spillover effects among level of time to maturity.

The second issue is credit rating, spillover effects among levels of credit rating are important to government departments and companies. After John Moody initially used a small rating book in 1909, credit rating becomes an important role in capital markets. With the development of Basel Core regulation of financial credit rating, the market has become multi-billion dollar industry[5]. There is also evidence that bond ratings are important factors of the pricing of bond assets and contribute to market participants. In particular, market participants commonly apply the credit rating to implement their portfolio strategies and enhance their profit opportunity from the rating base.[6]According to the interest calculation, government interest rate as already known as risk free rate is the basic background for other kind of interest measurement. In the meaning that when a bank lends to their clients such as corporate and personals, the bank would proposed by using the government based interest to calculate other stages of interest rates. This reflects to common belief that government bond yield adjusts first, then yields on other bonds follow so the companies would want to know that government bonds would impact corporate bonds or not. Because the cost of debt of the company is not the same as government bond, private companies that want to operate bond financing have to add the spread up from risk-free rate of government bond. The spreads or premiums are expected to differentiate in credit rating preference of that company. Meaning that, the change in government bond yield possibly has an

[5] See Güttler, A. and M. Wahrenburg (2007).
[6] See Sy, A. N. R. (2002).

impact to different classes of corporate bond market. Therefore, it is interesting to study the spillovers effect from government bond to credit rating levels of corporate bonds.

However, there could be the reverse reaction, such a way that corporate bond has spillover effects to government bond. This case is particularly for risk-averse investors. When there is a shock, investors that have a high risk aversion would normally get rid of risky asset class first. This action would reflect to corporate bond adjustment first and then transmitted to government bond in later period. Spillovers effect from credit rating levels of corporate bond to government bond are also interesting to observe.

The last issue is liquidity; spillover effects among high and low liquidity are important to bond investors. Many bond investors construct their portfolio by focusing on liquidity. Liquidity is a degree of asset that can be bought or sold in the financial market regardless to the asset's price. Liquidity is categorized by high level of trading asset activity. Liquid assets represents to assets that can be easily bought or sold in markets. Liquidity is a rather subjective concept, many measurements have been applied to figure out which bond is liquid. For bonds, where most transactions are traded over–the-counter market (OTC market), direct liquidity are usually based on the trading transaction data[7]. This paper employs the frequency of trading transaction data for bond liquidity.

Regarding to spillovers on liquidity case, investors hold many different assets or each of investors hold different portfolios. When shocks or news occur, investors' reactions would be to adjust their portfolios with one asset first (high liquidity) by doing trading activity such as selling or buying and the rest (low liquidity) of their portfolios will be adjusted in a later period reflecting slower reaction. These lead lag trading activities of investors would also create spillover effects. Therefore, this paper examines these spillover effects among level of liquidity.

This paper aims to investigate the spillover effects in different characteristic of bond in terms of return and volatility. Why study both return and volatility? Because there are the evidences

[7] Even though there is an argument from Houweling, P., A. Mentink and T. Vorst (2005). that the transaction data are difficult to obtain. So some papers apply indirect measures such as relative bond characteristic as a proxy instead.

that spillover across markets might not occur only through returns, but also through volatility[8]. It is supposed that if the two markets are more relevant, when the shocks occur in one market, it will effects both return and volatility another markets[9]. From the context above, this paper concludes the research questions as follows.

1.2 Research Questions

The aim of this paper is to investigate whether there are return and volatility spillover effects in different characteristic of bond assets in Thailand.

Specifically, this study attempts to answer these research questions.

Question 1 Are there return spillover effects among different classes of fixed income securities in Thai bond market?

Question 2 Are there volatility spillover effects among different classes of fixed income securities in Thai bond market?

1.3 Objectives & Contributions

As financial markets progress, the phenomenon of financial linkage will become more relevant and useful for investors. Investors can make utilize useful information for the decision in bond portfolio diversification. Investors can diversify bond portfolio allocation on sub-classes of bond with little difference in terms of risk preferences. For example, Investor would diversify their portfolios by level of time to maturity, level of credit ratings as well as level of liquidity. When there is a shock occurs, these investors would eager to know what will be happen to their portfolios. They might do the rebalancing and adjusting their particular assets and then rebalancing and adjusting other assets. These lead lag activities could create spillover effects among their portfolios. Therefore it is interesting for investors to understand the lead-lag

[8] See Singh et al. (2010), Baele (2000), Bekaert and Harvey (1997), Christiansen (2003), Ng (2000)

[9] See Singh et al. (2010).

reactions of assets in their portfolios. Moreover whether this paper could find the evidence of lead lag relations among sub-classes of bonds, investors could adopt the leading criterion as an effective forecast indicator for their benefits of rebalancing portfolio investment.

Bank of Thailand uses monetary policy to control the supply of money in the market by controlling the interest rate for the intention of encouraging economic growth and financial stability. Because when investors adjust and rebalance their portfolios on each characteristic, these trading activities reflect spillover effects on their portfolios. To control the capital regulatory requirement, Bank of Thailand would interest to know the origins of spillover effects among sub-classes of bond markets.

In addition, this paper makes a contribution to this literature on measuring bond index. This paper intends to contribute to the constructions of properly index measures as a proxy based on each bond characteristic. For level of time to maturity, this paper constructs short, medium and long time to maturity of gross price index series, for credit rating, this paper constructs low and high level of credit rating of corporate bond, and government credit rating level of gross price index series and lastly for liquidity, this paper constructs the low and high liquidity of government gross price index series. This paper also apply the weighed outstanding of each bond to contribute gross price bond index series for the index calculations.

1.4 Research Hypotheses

In this section, this paper aim to investigate relationships among fixed income securities in terms of return and volatility spillover effects in Thai bond market. This paper summarizes the hypothesis as the followings.

Hypothesis 1: There are return and volatility spillover effects among fixed income securities that have different time to maturity

Hypothesis 2: There are return and volatility spillover effects from government bonds to high investment grade corporate and low investment grade corporate bonds.

Hypothesis 3: There are return and volatility spillover effects from high liquidity government bonds to low liquidity government bonds.

1.5 Organization of the Paper

The rest of this proposal is organized as follows. Chapter 2 reviews the previous literature. Chapter 3 provides data and research methodology. Chapter 4 provides empirical results. Conclusions are provided in Chapter 5.

CHAPTER 2

Literature Review

Liberalization and investors sentiments were the main composition of spillover effects between markets. The spillover effect between international markets has been examined in two aspects are spillover in return and spillover in volatility. However, market participants much more concerned with volatility spillovers rather than return spillover. There are various reasons for investors or market participants to be interested in volatility spillover because they can use this information to build efficient portfolio. Hence this chapter will review prior researches about the spillover effects.

2.1 Spillover effects; definition and importance

For over two decades, many countries were affected by bad situations from economic recession, instability in political happening as well as financial crises. As a result, many markets around the world entered to recession period. Shock effects from one asset class spillover to other asset classes and that asset class could be affected negatively. This phenomenon, which often spread through various types of investment to other various markets, are commonly called spillover effects.

Since the world has become more globalization and the financial in each country are more liberalization, the transmission of shocks and spillover effects are increasing over time. However, market participants always concern with return and volatility spillovers in the perspective of international investors for asset allocation decision and portfolio rebalancing and regulators for restricting international capital flow policy.

Return is a statistical measure for gain and loss of a particular of asset on the investments. Generally, there is a high risk and high return trade-off from the investment. Volatility is a measure of the distribution of returns. In another meaning, volatility indicates the magnitude of risk or uncertainty regarding to the scale of changes in an underlying asset. High volatility implies that the underlying asset can be spread in the range of risk value. This high volatility signals a higher risk for investors holding that assets. Specifically, a high volatility means that the price can change dramatically in either direction over the given period of time. In contrast, low volatility means that the value of asset does not extremely change over the period of time.

The volatility spillover effect occurs when the lagged volatility in one market spillovers on volatility in other markets. To understand the volatility spillover effect across markets is useful and valuable for investors and market participants to rebalance their investment portfolios and hedging strategies in asset allocation decisions.

2.2 Spillover effects in foreign exchange and swap market

By the way there are a number of prior researches studies the transmission mechanism of spillover effects in various markets, for example, in foreign exchange markets, stock markets, bond markets and swap markets. However the volatility spillover analysis was initially investigated by Engle (1990). They found the volatility spillover evidence in the Yen/USD exchange rate. The results show that the Tokyo news has the greater impact on volatility spillover of Yen/Dollar exchange rate. In (2007) examines volatility spillovers in international swap markets, which are three main of international countries, namely, the UK, the US and Japan. The empirical results show that term structure variables which are the proxy of the different between 10 year bond rate and 90 days of bill rates are significantly impacts to the changes in the spread of swap markets in these three currencies. She also found that the US country has a major effect on the swap market in Japan country and the UK country, however, these result are not exist in the reverse direction. And she also finds the evidence of spillovers effects between Japan country and the UK country in swap market. And lastly, the degree of volatility persistence is fairly strong in most cases

2.3 Spillover effects in international stock market

Many research studies the spillover effects in stock markets for instance, Hamao, Masulis et al. (1990) found that there are volatility spillovers from the US to Japan market, from the UK to Japan market and from the US to the UK market, but no other directions are found during the sample period of April, 1985 to March, 1988.

Ng (2000) examined the changing nature as well as the magnitude of volatility spillovers. She concerns about sources of spillover effect by forming a volatility spillover model by focusing on three types of shocks, which are, the local, regional and world shocks. She considers spillover effects from regional and world shocks which are Japan and the US markets respectively. In another sense, she studied the spillover effects of six equity markets that were affected from Japan and the US. Theses six equity markets consist of Thailand, Korea, Malaysia, Taiwan, Hong Kong and Singapore. And the results show that the key factor of market volatility is come from both regional and world factors. And the result also that world factor has greater impact than regional factor.

Miyakoshi (2003) has investigated the amount of return and volatility spillover from Japan and the US to Asian stock markets deal with US shock as an exogenous variable. He mentioned that first, the influence of Japan not affect the Asian stock market return but the US. Second, compare to US the Japanese market is more influenced to the volatility of Asian markets. Third, Asian markets have an adverse influence to the Japanese market.[10]

2.4 Spillover effects in international bond market

Spillover effects in bond market were analyzed by Christiansen (2007) constructed a GARCH volatility spillover model which applied from the US to and Euro zone bond markets into bond market of each country in Europe. This paper applies weekly return data on Wednesdays total return government bond index for Europe, the US, six EU countries and three non-EMU countries which cover the period from 1988-2002. The EMU-countries consists of Italy, Germany, Spain France, Belgium and the Netherlands, while non-EMU countries consist of the UK, Sweden and Denmark. The results show that there exists strong statistical evidence of volatility spillover effects from both the US and Europe into particular European bond markets. With different

[10]Miyakoshi, T. (2003). "Spillovers of stock return volatility to Asian equity markets from Japan and the US." for more detail

results of volatility spillover effects, the US volatility spillover effects are rather weak compared to the European spillover effects. In addition, after the integration of the euro, bond market of EMU countries have more integrated and have nearly for being perfectly integrated in recent years. The central element of integration seems to be a merging in interest rate.

Recent study from Skintzi and Refenes (2006) investigated return and volatility spillover mechanism from the US bond market and Euro zone bond market to twelve countries of European bond markets to investigate the dynamic linkages employing an EGARCH model that is not restrict for a time-varying correlation. The data are weekly bond index series are proxies over the period from 1991-2002 They found that there exists the significant return and volatility spillover from both the Euro zone area bond markets and the US bond market to each country in European markets within and outside the Euro area. Own market effects are important in the volatility process in most European bond markets. These markets found an asymmetric impact in volatility. Likewise, their results also indicate that the world market factor of US has a significant influence in the each European bond market volatility process, while the US market returns influence the Euro zone bond market returns in a few numbers of samples. This means that the US market volatility is a key factor that can explain almost each country of European bond market volatility. Furthermore, for almost European bond markets the volatility spillover and the cross correlations have been increasing after the integration of the Euro zone.

The spillover effects in bond markets from prior researches are mainly focus on country level while there are very few of literatures study the spillover effects deeper on the characteristics of bond market. Furthermore, lots of bond investors would invest in a particular class of assets. Therefore, to study on each characteristic which represents to each specific risk is important to these investors whose portfolios are not well diversified. This paper would fulfill this room by investigating on the type of bond markets.

2.5 Relationship across sub-asset classes in stock market

In stock markets, investors who do not invest in the whole market portfolio or index portfolio, they invest in the specific industry such as; industry, financial, property and construction. Normally, each industry has different level of risks. Therefore, to study the industry specific risk is important to these investors because their portfolios are not well diversified. However, literatures relative to property of industry specific risk are still less number.

Some characteristic that researchers have examined for instance, the illustrations that there is a relationship between lagged information transmission and different capitalization size of portfolio in stock market as documented by Kanas and Kouretas (2005) the result suggests that in the long run, lead-lag effect is driven by size of capitalization. Hoti (2005) models the country spillover effects in country risk rating. Wang, Meric et al. (2009) also study the relationship across characteristic level of assets.[11] They investigated whether a crash in stock market affects each financial characteristic of stock markets. The shock transmissions among industries are examined in term of volatility linkages as proposed by Wang (2010). Masron, Zulkafli et al. (2012) studies the spillover effects within manufacturing sectors in Malaysia. Krause and Tse (2013) investigate the return and volatility spillovers to different industry in ETFs.

2.6 Relationship across sub-asset classes in bond market

From literature review, there are limited papers that study the relation between characteristic in bond market. The paper from Sy (2002) investigated the relationships between bond spreads and ratings for 17 emerging market countries. She found the evidence of difference between real bond spreads and rating based spreads. The author also illustrates that credit rating can be used as a signal for technical bond analysis.

Gebhardt, Hvidkjaer et al. (2005) study the cross sectional of bond return by controlling the characteristic in the dimension of duration, ratings and yield to maturity. This paper finds that

[11] Kanas, A. and G. P. Kouretas (2005).

duration and rating provide information about default risk and systematic risk. And yield to maturity is significantly related to average bond returns when controlling the default.

Kim and Wu (2008) study the channel transmission among different type of sovereign credit rating in emerging market and find that credit rating has a direct impact to international capital flows and financial sectors. They find that firstly, long term foreign currency credit ratings are the most main factor for capital flows. Secondly, long term local currency ratings encourage the local market growth, but not encourage international capital flow. They show the evidences of effects on different characteristic in emerging bond market.

Fujiwara, Körber et al. (2013) studied the asymmetry in government bond return among different type of year to maturity. This paper finds that an increasing in the maturity of the bond is an asymmetry correlation between countries. And also shows that specific factor is important in short time to maturity, while common factors play an important role in explaining asymmetries in long time to maturity.

Therefore, from the prior review, these literatures are relative to spillover transmission in several types of bond. And there has not been studying the spillovers effects across characteristics in specific countries. Even the researches regarding to spillover in specific country, have no similar characteristic in details. To fulfill these questions this paper aims to contribute the interesting issues to further testing.

2.7 Methodology for Spillover effects

The model that has been used to test spillover effects or to find the lead lag relations with causality pattern is Vector Auto regression (VAR) such as the research proposed by Yang (2005), and Ciner (2007) they studied the linkages between government bond market of industrialized countries and found that no long-run relationship exists during the sample period[12] However, using VAR model has a limitation that we cannot measure the volatility spillovers which

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[12] Yang, J. (2005) studied the spillover effects among five industrialized during 1986 – 2000, while Ciner, C. (2007) studied the government bond market of the UK, the US, Germany and Japan during 1988 – 2005.

is the requirement from this paper. Moreover, volatility is an important criterion to test spillover effects in this paper.

The ARCH model proposed by Engle (1982)[13], after that Bollerslev (1986) developed a method to measure volatility of financial time series data which is Generalized Autoregressive Conditional heteroskedasticity or GARCH(1,1) model. Bekaert and Harvey (1997) investigate the volatility spillovers by using two origins of shocks; local factor and world factor. And Ng (2000) developed GARCH(1,1) model using three origins of shocks; local, regional and world factors as exogenous factors. Later on, Miyakoshi (2003) examined the magnitude of return and volatility spillover from Japan and the US to Asian equity markets by using the Bivariate GARCH model and use US shock as an exogenous variable. Most of these studies employ univariate GARCH(1,1) in their testing, the limitation of this model is that it can test only one direction but it cannot test forward and backward at the same time. Therefore, this paper employs Multivariate GARCH models which are generally used to measure spillover effects among different assets. Hassan and Malik (2007) apply multivariate GARCH model to measure return and volatility simultaneously by using daily returns among different sector indices in the US country.

This paper uses multivariate GARCH models to examine return and volatility spillovers of gross price daily bond return. There are three widely used model types for the multivariate GARCH models used in the researches are the Constant correlation, BEKK and VECH. This paper employs BEKK model type of the multivariate GARCH model which allows the time-varying correlation among variable over time and also guarantee non-negative estimated variance and covariance matrix. Specifically, this paper uses a multivariate GARCH model which allows us to investigate the return and volatility spillovers simultaneously among different characteristics of bond.

[13] See more in the methodology, Engle, R. F. (1982). "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation."

CHAPTER 3

Data and Methodology

3.1 Hypothesis Development

This section provides details of the research questions and hypotheses tested in this study. This paper examines the return and volatility spillover across sub-classes of fixed income securities to answer the questions that "Are there return and volatility spillover effects among different classes of fixed income securities in Thai bond market?" This paper classifies bonds into sub-classes according to various dimensions, namely, time to maturity, credit rating and liquidity.

Time to maturity Hypothesis

The issue of spillover effects on time to maturity factors has happened because each level of time to maturity is different in purpose of investor holdings. Some investors hold bonds for short time to maturity, some for medium time to maturity and some for long time to maturity. Such as investors invest short time to maturity for liquidity purpose, and some investors invest in long time to maturity for investment purpose. However, with the cost of capital for long time to maturity will eventually be cost of capital as short time to maturity. Or when there is a shock occurs, investors would rebalance their portfolios, they might have to sell and/or buy their assets on their portfolios. And these investors might rebalance their most simply short time to maturity first, rather than long time to maturity because of higher price impact and higher durations. Consequently, these activities not only create spillover effects, but also the lead lag relationships among level of time to maturity as well.

Research documented by Park (1999) that finds the evidence about the prediction of future excess return from the market efficiency and rational theories. He found that term premium and changes in short term interest rate have related with time to maturity composition. The literature shows that even though all bonds have the same characteristics, they are not perfect substitutes if they contain different level of time to maturity. Consistent with the research from Milton (1977), Roley (1982), Wallace and Warner (1996), Baker, Greenwood et al. (2003), and

Gebhardt, Hvidkjaer et al. (2005) However, some research results which contrast with these research and found that maturity is not significantly impact bond returns.[14] The research analyses are not clear approach. However, when there is a shock occurs this paper hypothesizes short term interest rate expected to respond prior to the long term interest rate due to short term interest rate is the risk free rate base on government bond yield, while long term is a premium added compensate with risk preference.

Diamond (1991), and Rajan (1992) argue that shorter maturities limit the period of time that an opportunity for firm from being in default. Normally, short term debt of the firm has more opportunity to be issued than long term debt of the firm because borrowers in short term financing are more difficult to defraud creditors. From these reasons, it motivates us to set the first hypothesis that Return and volatility spillover exist among short term bonds, medium term bond and long term bonds.

Hypothesis 1: *There are return and volatility spillover effects among fixed income security that have different time to maturity.*

The lead lag reaction or spillover effects among different time to maturity are mainly important to the government department or central bank in order to implement the financial stabilization in monetary policy. Therefore the spillover transmission between short term bond, medium term bond and long term bond is an interesting topic for further study.

For regulators view, in case that foreign capital flow is normally transmitted to medium time to maturity, therefore the spillover transmission between medium time to maturity has spillover effects to short or long time to maturity is also an interesting issue for further study.

[14] See Park, C. W. (1999) for more details

Credit rating Hypothesis

Credit rating enhances directly to the creditworthiness of the issuer and their ability to pay back future debt obligations. From the research of Mizen and Tsoukas (2012) study the relative responses of the external finance premium for bonds and found that companies which have better financial credit can get external finance premiums in lower rate. With the reason that government bond is a risk free rate, while corporate bond is calculated by adding the risk premium from government bond rate. Therefore, corporate bond rate is normally higher than government bond rate. After that corporate bond rate would reflect in the cost of capital of the companies. The impact of different credit rating is expected to be absorbed in different period of time responsiveness with the expected direction that government bond has a prior spillovers to the corporate bond. Therefore, when there is a shock occurs, it is possible that government bond has spillover to corporate bond and this activity presents the lead lag relation among credit rating of bond.

Normally, when the company need to do the specific loans which are from outside financing, that company have to credibly commit their behaviors of payment contract to their investors. Each section of committed contracts or in particular subject are highly relevant to both company characteristics and the financial institutions that facilitate controlling and obligation of financial activities (Scott 1977).

This paper sets the second hypothesis that Return and volatility spillover exist from government bonds to different credit rating level of corporate bonds.

Hypothesis 2: *There are return and volatility spillover effects from government bonds to high investment grade corporate and low investment grade corporate bonds.*

The lead lag reaction or spillover effects are important issues, particularly for companies and investors. Because credit rating is related to credit risk premium and this premium reflects to cost of capital of the companies. Therefore, when the risk free rate has been changed, and when the credit rating level has been adjusted, companies would want to know that these activities would impact to their portfolio or not. As well as to investors, particularly for bond investors, when there is a shock occurs, these investors would interesting to know that their portfolio will be impacted regarding to these shocks or not. In addition, these kinds of investors would rather adjust their holding portfolio of bond prior to other assets. Therefore the spillover effects are the important issues in terms of rebalancing portfolios. Another character of investors that would interesting to know the spillover effects are the risk averse investors, investors would rather adjust and rebalancing their portfolios if there are spillover effects between corporate bond and government bond.

Liquidity Hypothesis

Lastly, liquidity is another determinant for investors to analyze the spillover impacts. From the document proposed by Friewald, Jankowitsch et al. (2012), they investigate how important of liquidity issue in corporate bond market of the US and they argue that liquidity is an important determinant to the price of bonds, moreover the effects have been increasing not only during the crisis period, but also during the rating grade bond period. However, with the reason that investors invest in bond asset in a different volume traded for matching their portfolios balancing, as a result of these trading activities, the high volume trade exhibits high liquidity, while the low volume trade exhibits low liquidity or illiquidity. Therefore, this paper employs the liquidity as a proxy for spillover transmissions. Hence, this paper hypothesizes that there are the spillover effects among high and low liquidity of bond class in the direction that high liquidity of asset expected to prior response from the impact of shock effects transmission. From this reason, we set the third hypothesis that Return and volatility spillover is from high liquidity government bonds to low liquidity government bonds.

Hypothesis 3: *There are return and volatility spillover effects from high liquidity government bonds to low liquidity government bonds.*

Spillover effects among level of liquidity are important topics for bond investors. Because when there is a shock occurs, the behavior of investors would react to each level of liquidity differently. Normally asset that has high liquidity would have lower cost of trading activities while asset that has low liquidity or illiquid would have higher cost of trading activities. Bond investors are prior adjusting their portfolio with low cost of trading first and then further adjust their higher cost of trading. Therefore the asset which has low cost of trading activities would react faster than high cost of trading. In other words, asset that has low cost of trading or high liquidity may respond to news spillovers in different period of time.

3.2 Data description

The datasets in this study are composed of daily bond database from Thailand's bond market between December 2003 to September 2013 is selected. The data consist of government and corporate bond. They are obtained from Thailand Bond Market Association (ThaiBMA). The dataset consists of daily transaction data of both government and corporate bonds and details of the bond series such as:

- Issue date
- Clean price
- Accrued interest
- Time to maturity (TTM)
- Trading volume
- Bond's value outstanding
- Credit Rating, for corporate bond.

3.3 Data Screening and Index Calculation

3.3.1 Data Screening

The data of bond which was supported by ThaiBMA are consisted with a lot of different details and some missing data. This paper would like to capture the most appropriate data for the calculation, then this paper screen some data for appropriation. The screening steps are as the followings.

1. This paper starts from clear N/A Outstanding out from the database.
2. This paper seeks to eliminate the data which have time to maturity less than one year in order to match the characteristic with the ThaiBMA principle.
3. Missing data of credit rating are fulfilled by the order continuously information.
4. Clean price which has no information which are able to reflect mistaken of bond data are also cleared out.
5. Bonds, which have the missing data of accrued interest as well as options-embedded bonds are rejected from the database of bond to avoid the effects of embedded option bonds, this paper excludes callable and putable bonds. This paper eliminates bonds with embedded options in order to avoid the potential effect of call or put risks.
6. This paper clears out bond which has the total of outstanding value less than one million (only 2 bonds). Because its outstanding value is less, we want to study in the overall market. It may cause the evidence to be a discrepancy. So we eliminate it for ensure.
7. Bond in which the data of credit rating are disappeared also cleared out from the database of bond information.
8. Bond in which average trading transaction less than 20% in each year also cleared out from the database of bond information because we only want to include bonds that are traded frequently enough to make our result have stronger evidence. However, this case only applies to government bond due to the data availability.

Table 1: Summary Statistic of government bond and corporate bond

	Government Bond	Corporate Bond
Number of bond	51	897
No.of transaction	59,705	484,303
Price in mean (Baht)	105.72776	101.506
AI in mean (Baht)	1.05428	0.803
Time to maturity in mean (years)	7.6568	3.694
Outstanding in mean (millions)	41,713.60	2,764.704

Table 2: Summary Statistic of government bond and corporate bond in each level of time to maturity

@ Issue date	Short	Medium	Long	More than 10	Total
Government Bond	2	16	9	24	51
Corporate Bond	403	383	63	48	897

Table 3: Summary Statistic in each credit rating level of bond

Credit Rating	Total of Bond
AAA	105
AA+	42
AA	34
AA-	57
A+	141
A	438
A-	203
BBB+	95
BBB	61
BBB-	10
BB+	2
Government	51

Table 4: Summary statistic of government bond in each level of time to maturity and liquidity

Liquidity/Time to maturity	Short	Medium	Long	More than 10	Total
Low liquidity	1	6	4	19	**30**
High liquidity	1	10	5	5	**21**
Total	**2**	**16**	**9**	**25**	**51**

Table 5: Summary statistic of corporate bond in each level of time to maturity and credit rating

Credit Rating/Time to maturity	Short	Medium	Long	More than 10	Total
Low credit	294	296	40	29	**659**
High credit	109	87	23	19	**238**
Total	**403**	**383**	**63**	**48**	**897**

3.3.2 Index Calculation

There are a large number of different Thai bond indexes, and they are all built a little bit differently, but most of them have regulatory driven. This means that an index provider defines a set of rules, and all of the bonds that meet those rules are included in the index. In this case, the index of bond is likely to be very objective and index makes investors are better understand and even predictable. Generally, the index committee will create rules and take control, but they did not say that the actual bonds are selected. This index is very different than other equity index like SET index, SET50 index etc., Therefore, this study will select bonds that meet criteria according to bond characteristics to basket for calculating gross price index. Bond indexes will be daily rebalancing at the end of each day. Moreover, this paper employs weighed outstanding value gross price bond index for the calculation.

According to ThaiBMA index calculation, ThaiBMA develops the European of Financial Analysts Societies or EFFAS which is the international principal for Bond Index calculation. However, government bond index is calculated from all registered government bond which has no default risk of interest and principal. Besides, the government bond also has the highest portion of total value outstanding of bond estimated 80% of total trading value of bond. The weighted Average executed yield is calculated to estimate the movement of the bond price. Whether there is a new bond coming, the bond index will be counted for the index calculation in the next day. Besides, if there is a delisted bond in which the end of the time to maturity, ThaiBMA apply the standard criteria to delist the bond on the 14 days before the end of time to maturity date. Importantly, this paper applies the standard of ThaiBMA organization to create the bond index in the period of the sample data.

3.3.3 Gross Price Index respect to time to maturity

This study, we were divided government and corporate bonds into three categories of time to maturities according to ThaiBMA by depending on their years to maturity: short time to maturity is 1 to 3 years, medium time to maturity is 3 to 7 years and long time to maturity is 7 to

10 years. Normally, the longer bond's time to maturity tend to be higher interest rate than shorter one and more influence bond price volatility. So, longer time from its expiration date, the greater price difference between its current price that is changed according market interest rates and its par value or principle.

3.3.4 Gross price index respect to level of credit rating

Bond ratings are representing to the cost of capital of the issuer and investment risk provide by independent rating institute. Bond ratings are available from FITCH and TRIS agencies, the two agencies produced equivalent qualification, but credit rating from FITCH are more available and we decided to use this agent as a source of data. If it is not available from FITCH, we use the credit rating data from TRIS instead. Only investment grades of fixed income securities are included in the index measurement in this paper, which AAA, AA, A, BBB. After that this paper splits these corporate bonds into two groups by grouping rating both AAA, AA+, AA and AA- as proxy of high investment grade and grouping A+, A, A-, BBB+, BBB and BBB- as proxy of low investment grade. The groups were divided in between AA- and A+ because the numbers of bonds are appropriate enough to run the hypothesis testing. Normally, Bond rating informs the public that the investor's risk to get a principle back and receive a coupon at expiration date from bond issuers.

3.3.5 Gross price index respect to liquidity

There is no conclusive on how to measure the asset liquidity while the widely method to measure liquidity is the bid–ask spread, nevertheless the spread for all bonds rarely available and accessible, particular for longer time period. Basically, a trading volume of bond would provide information respect to liquidity (Friewald, 2012). Thus, lower trading volume presents lower liquidity, while higher trading volume presents higher liquidity. Therefore, this study uses trading volume and trading transactions as a proxy of liquidity. This paper uses individual bond on each trading day given by ThaiBMA to calculate gross price bond index. Normally, we can expect larger size of bonds have more liquidity but for higher coupon rate should have less liquidity. Bonds with long time to maturity which more than ten years, is often inquired as less liquid, investors are rarely trade and usually invest on conservative strategy. On the other hand, it is basically consider recently issue bonds or on-the-run bonds have more liquidity. Therefore, we consider these natures of bonds to be important for trading volume because it can be changed over the time. This paper splits bonds into two of liquidity groups by using the average trading transactions in one year and separated them by percentile: high liquidity group is above or equal to the 50th percentile and low liquidity group at below than the 50th percentile. And this paper also rebalances groups of liquidity every year to take into the account on-the-run bonds and end of the year effect.

Formula for the Gross Price Index

$$GP_t = PR_t \ x \ (1 + AI_t)$$

$$PR_t = PR_{t-1} \ x \ \frac{\sum_{i=0}^{n} P_{i,t} \ x \ N_{i,t-1}}{\sum_{i=0}^{n} P_{i,t-1} \ x \ N_{i,t-1}}$$

$$AI_t = \frac{\sum_{i=0}^{n} A_{i,t} \ x \ N_{i,t-1}}{\sum_{i=0}^{n} P_{i,t} \ x \ N_{i,t-1}}$$

We set clean price bond index at base day $(\mathrm{PR_0})$ = 100

$\mathrm{PR_t}$ represents to clean price bond index at day t

$\mathrm{P_{i,t}}$ represents to clean price of bond i at day t

$\mathrm{P_{i,t-1}}$ represents to clean price of bond i at day t-1

$\mathrm{N_{i,t-1}}$ represents to amount outstanding value of bond i at day t-1

n represents to the number of bonds in basket

$\mathrm{AI_t}$ represents to accrued interest used for gross price bond index calculation at day t

$\mathrm{A_{i,t}}$ represents to accrued interest of bond i at day t

This paper contributes the weighed outstanding gross price bond index according to the characteristics of fixed income security which represents to each type of bond in a basket of portfolio. This paper contributes to the basket of portfolios represents to the each characteristics regarding to time to maturity, credit rating and liquidity consequently.

3.3.6 Daily bond gross price return

The daily bond return will be applied to the dependent variables of our regression. For daily bond return is calculated as the following equation.

$$R_{i,t} = \frac{GP_t - GP_{t-1}}{GP_{t-1}}$$

Where, $R_{i,t}$ represents bond return at time t. GP_t, GP_{t-1} represents to Gross Price bond index return at time t and lag time respectively.

However, we also test the sample data in weekly gross price index return, from Friday to Friday over the period of time. In order to avoid day of the week effects and non-synchronous trading issue. The disadvantage of weekly data is there could be less chance to capture return spillover effects, but it is possible to capture that volatility spillover effects.

3.3.7 Data Testing

In order to justify spillover model and data, all series of the data were tested for unit root test by using augmented Dicky-Fuller (ADF) in order to examine whether there is a stationary or non-stationary, drift and trend in the series of data. The results confirm that all series of daily gross price return has stationary, no drift and no trend in this sample data.

H_0: $\rho = 0$ (non-stationary)

Ha: $\rho < 0$ (stationary)

Table 6: Unit root test for stationary and non-stationary process for all series of data.

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Remark
G_Short	-0.731745	0.025356	-28.85899	0	Stationary
G_Medium	-0.736744	0.025276	-29.14765	0	Stationary
G_Long	-0.760866	0.037601	-20.23501	0	Stationary
C_Short	-0.828656	0.020023	-41.38566	0	Stationary
C_Medium	-0.772962	0.019796	-39.04696	0	Stationary
C_Long	-0.87689	0.020167	-43.48077	0	Stationary
C_Low	-0.801809	0.019921	-40.24998	0	Stationary
C_High	-0.778964	0.019821	-39.30088	0	Stationary
G_Total	-0.592502	0.032167	-18.4193	0	Stationary
G_Low	-0.685835	0.035609	-19.25991	0	Stationary
G_High	-0.728557	0.025308	-28.78782	0	Stationary

However, regarding to weekly gross price index return data testing for unit root test, the results also show that the data is stationary, no drift and no trend as described in Table 25 in Appendix

3.4 Methodology

For investigating the relation according to the return and volatility spillover effects transmission the original regression model has been constructed to find the relationship, however there are the researchers have developed more efficient model ARCH and GARCH for solving the problem and improving the calculation as well as the coefficient parameters.

Autoregressive process

$$R_t = \beta_0 + \sum_{i=1}^{q} \beta_i R_{t-i} + \varepsilon_t \qquad \varepsilon \sim N(0, \sigma^2)$$

Let ε denote the error terms (residuals). Under the assumption that variance of error terms is not time-varying. If the variances of error terms change over time, it will have heteroskedastic problems in regression.

Follow by the literature from Miyakoshi (2003), and Skintzi and Refenes (2006), they all use Autoregressive model AR(1) with one lag to examine the return spillover effects. We tested on the appropriate lag variable by using Akaike info criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ). Most of these methods show that there are able to use one lag variable in this condition return equation. The data was tested of one lag for autocorrelation by using correlogram and found that we accept the hypothesis that there is no anutocorrelation.

(Table 22: Test of AIC, SC and HQ is in the Appendix)

(Table 23: Test correlogram is in Appendix)

Engle (1982) proposed Auto Regressive Conditional Heteroskedastics (ARCH). The concept of ARCH is variance of error terms change over time by the variance of error terms depends on its variance in the past. ARCH equation is

$$h_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2$$, q is the length of ARCH lags

This paper tests the ARCH effects by using the applications of the ARCH Lagrange multiplier (LM) test. The results indicate that the existence of ARCH effects in each of our models. The Lagrange multiplier tests for each of our models are as follows;

Lagrange Multiplier for test number of lagged in ARCH model

H_0 = no serial correlation

H_a = serial correlation

Table 7: LM Test of daily return in each model

	Government Time to maturity		Corporate Time to maturity		Credit rating		Liquidity	
Lags	LM-Stat	Prob	LM-Stat	Prob	LM-Stat	Prob	LM-Stat	Prob
1	21.843	0.009	28.811	0.001	44.767	0.000	13.377	0.010
2	17.658	0.039	24.061	0.004	36.135	0.000	12.554	0.014
3	20.490	0.015	14.060	0.020	20.902	0.013	10.023	0.040
4	18.316	0.032	**7.513**	**0.584**	**9.351**	**0.406**	**7.557**	**0.109**
5	21.185	0.012	44.575	0.109	22.297	0.380	6.014	0.198
6	15.299	0.083	7.535	0.582	10.306	0.326	12.288	0.153
7	**12.627**	**0.180**	20.059	0.018	19.466	0.122	17.048	0.190
8	24.420	0.004	14.520	0.105	24.940	0.003	5.491	0.241

Regarding to LM test, the results depicts that existence of ARCH effects. In many literatures of financial data found that GARCH(1,1) seems to be able to capture ARCH (q) effects, hence this paper will use GARCH(1,1) as a based model

Generalized autoregressive conditional heteroskedasticity (GARCH) model proposed by Bollerslev (1986). On the idea that financial data such as stock price, indices etc. is likely to have a heteroskedasticity problem. This model is believed that the volatility depends on its volatility in the past. In that case, the GARCH (p, q) model where p is the order of the GARCH terms (H_t^2) and q is the order of the ARCH terms (ε_t^2) is given by

$$h_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}^2$$

This is consistent with normal practice in the literature; Ng (2000), Miyakoshi (2003), and Skintzi and Refenes (2006) also employ GARCH(1,1) to investigate the volatility spillovers. However, after running GARCH, we will test the appropriateness of GRACH (p,q) by using Akaike information criterion (AIC) to confirm the number of lag range of GARCH(1,1) in this model. The AIC for number of lag range are as follows;

(Table 24: AIC Table is in the Appendix)

We also test weekly data which are reported in the Appendix, for the Correlogram as described in Table 26 the results show that there are consistent with daily bond return that there are no autocorrelation. And Lagrange Multiplier to test numbers of lagged in ARCH model in Table 27 the results indicate that there presents the ARCH effects from this model.

In this paper, we employ a multivariate GARCH(1,1) models. In the prior research, there are various versions of multivariate GARCH model, for example, VECH, Constant Correlation and BEKK. However, BEKK is designed for estimating matrix of covariance will be all positive, which can guarantee all positive estimated variances. The BEKK model has been generally used in the researches on spillover effect such as Hassan and Malik (2007). Below, we talk about the characteristic of the BEKK multivariate GARCH model and parameterization for conditional return and conditional variance equations are given as:

Multivariate GARCH Model

Conditional return equation

$$\mathbf{R_t = C + \beta R_{t-1} + \varepsilon_t}$$

$$\mathrm{R_t} = \begin{bmatrix} \mathrm{R_{1,t}} \\ \mathrm{R_{2,t}} \\ \mathrm{R_{3,t}} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \begin{bmatrix} \mathrm{R_{1,t-1}} \\ \mathrm{R_{2,t-1}} \\ \mathrm{R_{3,t-1}} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix}$$

where R_t is a 3 x 1 vector of return at time t; $\mathbf{R_{t-1}}$ is a 3 x 1 vector of corresponding of lagged returns; $\boldsymbol{\varepsilon}_\mathbf{t}$ ~ N(0, $\mathrm{H_t}$) is a 3 x 1 vector of error term or residual term or return innovations; C is 3 x 1 constant terms vector ; β is 3 x 3 coefficient matrix parameters of the autoregressive terms, which allow for mean equation return spillovers among characteristic of the bond or we can transform to equations as:

$$R_{1,t} = c_1 + \beta_{11}R_{1,t-1} + \beta_{12}R_{2,t-1} + \beta_{13}R_{3,t-1} + \varepsilon_{1,t}$$
$$R_{2,t} = c_2 + \beta_{21}R_{1,t-1} + \beta_{22}R_{2,t-1} + \beta_{23}R_{3,t-1} + \varepsilon_{2,t}$$
$$R_{3,t} = c_3 + \beta_{31}R_{1,t-1} + \beta_{32}R_{2,t-1} + \beta_{33}R_{3,t-1} + \varepsilon_{3,t}$$

Conditional variance equation

Moreover, the multivariate GARCH(1,1) model allows for conditional variances depend on its past volatility and moreover, it allows conditional volatility depends on past of error terms. Therefore, the time varying covariance matrix of GARCH is specified as follows

$$\mathbf{H_t} = \mathbf{C_0}^{\mathrm{T}}\mathbf{C_0} + \boldsymbol{\alpha}^{\mathrm{T}}\boldsymbol{\varepsilon}_{\mathbf{t-1}}\boldsymbol{\varepsilon}_{\mathbf{t-1}}{}^{\mathrm{T}}\boldsymbol{\alpha} + \boldsymbol{\gamma}^{\mathrm{T}}\mathbf{H_{t-1}}$$

The individual variables for $\mathbf{H_t}$, $\mathbf{C_0}$, $\boldsymbol{\alpha}$ and $\boldsymbol{\gamma}$ matrices are given as follows:

$$\mathbf{H_t} = \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix}, \quad \mathbf{C_0} = \begin{bmatrix} c_{11,t} & 0 & 0 \\ c_{21,t} & c_{22,t} & 0 \\ c_{31,t} & c_{32,t} & c_{33,t} \end{bmatrix}$$

$$\boldsymbol{\alpha} = \begin{bmatrix} \alpha_{11,t} & \alpha_{12,t} & \alpha_{13,t} \\ \alpha_{21,t} & \alpha_{22,t} & \alpha_{23,t} \\ \alpha_{31,t} & \alpha_{32,t} & \alpha_{33,t} \end{bmatrix}, \quad \boldsymbol{\gamma} = \begin{bmatrix} \gamma_{11,t} & \gamma_{12,t} & \gamma_{13,t} \\ \gamma_{21,t} & \gamma_{22,t} & \gamma_{23,t} \\ \gamma_{31,t} & \gamma_{32,t} & \gamma_{33,t} \end{bmatrix}$$

Where, T is the operator for matrix transpose; where H is a 3x3 conditional variance matrix, C is a 3x3 lower triangular constant matrix contains six variables. α is a 3x3 past errors terms matrix parameters. The variables of matrix α represent to the spillover effects that occur by shocks or news or unexpected event. γ is also a 3x3 square matrix show effect of volatility persistent of past volatility affect current volatility.

The conditional volatility for each variance and covariance terms could be exploded for the multivariate GARCH(1,1) by ignoring the constant terms as:

$$
\begin{aligned}
\mathbf{h_{11,t}} = {} & \boldsymbol{\alpha_{11}^2 \varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{21}^2 \varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{31}^2 \varepsilon_{3,t-1}^2} + 2\alpha_{11}\alpha_{12}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + 2\alpha_{11}\alpha_{31}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{21}\alpha_{31}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \boldsymbol{\gamma_{11}^2 \mathbf{h}_{11,t-1}} \\
& + \gamma_{21}^2 h_{22,t-1} + \gamma_{31}^2 h_{33,t-1} + 2\gamma_{11}\gamma_{12}h_{12,t-1} + 2\gamma_{11}\gamma_{31}h_{13,t-1} \\
& + 2\gamma_{21}\gamma_{31}h_{23,t-1}
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{h_{22,t}} = {} & \boldsymbol{\alpha_{12}^2 \varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{22}^2 \varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{32}^2 \varepsilon_{3,t-1}^2} + 2\alpha_{12}\alpha_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + 2\alpha_{12}\alpha_{32}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{22}\alpha_{32}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \gamma_{12}^2 h_{11,t-1} \\
& + \boldsymbol{\gamma_{22}^2 \mathbf{h}_{22,t-1}} + \gamma_{32}^2 h_{33,t-1} + 2\gamma_{12}\gamma_{22}h_{12,t-1} + 2\gamma_{12}\gamma_{32}h_{13,t-1} \\
& + 2\gamma_{22}\gamma_{32}h_{23,t-1}
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{h_{33,t}} = {} & \boldsymbol{\alpha_{13}^2 \varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{23}^2 \varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{33}^2 \varepsilon_{3,t-1}^2} + 2\alpha_{13}\alpha_{23}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + 2\alpha_{13}\alpha_{33}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{23}\alpha_{33}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \gamma_{13}^2 h_{11,t-1} + \gamma_{23}^2 h_{22,t-1} \\
& + \boldsymbol{\gamma_{33}^2 \mathbf{h}_{33,t-1}} + 2\gamma_{13}\gamma_{12}h_{23,t-1} + 2\gamma_{13}\gamma_{33}h_{13,t-1} + 2\gamma_{23}\gamma_{33}h_{23,t-1}
\end{aligned}
$$

$$
\begin{aligned}
h_{12,t} = {} & \alpha_{11}\alpha_{12}\varepsilon_{1,t-1}^2 + \alpha_{12}\alpha_{22}\varepsilon_{2,t-1}^2 + \alpha_{23}\alpha_{13}\varepsilon_{3,t-1}^2 + (\alpha_{12}^2 + \alpha_{11}\alpha_{22})\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + (\alpha_{12}\alpha_{13} + \alpha_{11}\alpha_{23})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{13}\alpha_{22} + \alpha_{12}\alpha_{23})\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \gamma_{12}\gamma_{11}h_{11,t-1}^2 + \gamma_{12}\gamma_{22}h_{22,t-1}^2 + \gamma_{23}\gamma_{13}h_{33,t-1}^2 \\
& + (\gamma_{12}^2 + \gamma_{11}\gamma_{22})h_{12,t-1} + (\gamma_{12}\gamma_{13} + \gamma_{11}\gamma_{23})h_{13,t-1} \\
& + (\gamma_{13}\gamma_{22} + \gamma_{12}\gamma_{23})h_{23,t-1}
\end{aligned}
$$

$$
\begin{aligned}
h_{13,t} = {} & \alpha_{11}\alpha_{13}\varepsilon_{1,t-1}^2 + \alpha_{12}\alpha_{23}\varepsilon_{2,t-1}^2 + \alpha_{12}\alpha_{33}\varepsilon_{3,t-1}^2 + (\alpha_{13}\alpha_{12} + \alpha_{11}\alpha_{23})\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + (\alpha_{13}^2 + \alpha_{11}\alpha_{33})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{13}\alpha_{23} + \alpha_{12}\alpha_{33})\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \gamma_{11}\gamma_{13}h_{11,t-1}^2 + \gamma_{12}\gamma_{23}h_{22,t-1}^2 + \gamma_{12}\gamma_{33}h_{33,t-1}^2 \\
& + (\gamma_{13}\gamma_{12} + \gamma_{11}\gamma_{23})h_{12,t-1} + (\gamma_{13}^2 + \gamma_{11}\gamma_{33})h_{13,t-1} \\
& + (\gamma_{13}\gamma_{23} + \gamma_{12}\gamma_{33})h_{23,t-1}
\end{aligned}
$$

$$
\begin{aligned}
h_{23,t} = {} & \alpha_{12}\alpha_{13}\varepsilon_{1,t-1}^2 + \alpha_{22}\alpha_{23}\varepsilon_{2,t-1}^2 + \alpha_{23}\alpha_{33}\varepsilon_{3,t-1}^2 + (\alpha_{13}\alpha_{22} + \alpha_{12}\alpha_{23})\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\
& + (\alpha_{13}\alpha_{23} + \alpha_{11}\alpha_{33})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{23}^2 + \alpha_{22}\alpha_{33})\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \gamma_{12}\gamma_{13}h_{11,t-1}^2 + \gamma_{22}\gamma_{23}h_{22,t-1}^2 + \gamma_{23}\gamma_{33}h_{33,t-1}^2 \\
& + (\gamma_{13}\gamma_{22} + \gamma_{12}\gamma_{23})h_{12,t-1} + (\gamma_{13}\gamma_{23} + \gamma_{11}\gamma_{33})h_{13,t-1} \\
& + (\gamma_{23}^2 + \gamma_{22}\gamma_{33})h_{23,t-1}
\end{aligned}
$$

These equations show how unexpected event or news and volatility are transmitted across sectors and over time. To test volatility spillover, I will focus on coefficients of $\boldsymbol{\varepsilon}^{2}_{1,t-1}$, $\boldsymbol{\varepsilon}^{2}_{2,t-1}$ and $\boldsymbol{\varepsilon}^{2}_{3,t-1}$. These coefficients are represented to volatility spillover effects from its own effects and spillover from other asset classes. And we also focus on past volatility persistent which represented by coefficient $\mathbf{h_{11,t-1}}$, $\mathbf{h_{22,t-1}}$ or $\mathbf{h_{33,t-1}}$.

Under assumption, error terms, ε_t, are distributed as normal distribution. So, the log-likelihood function for the multivariate GARCH(1,1) model is:

$$L(\theta) = -\frac{Tn}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln|H_t| + \varepsilon_t'|H_t|^{-1}\varepsilon_t)$$

Where T represent to number of observations and θ is the estimated variables in the model and we use numerical calculation to maximize non-linear log likelihood function. For first conditional variance was obtained by calculating in the first observations using the method that proposed by Engle and Kroner (1995).

3.4.1 Testing Time to Maturity Hypothesis

This paper groups bond into three categories depending on their term to maturity: short term (1 to 3 years) defines to number 1, intermediate term or medium term (3 to 7 years) defines to number 2 and long term (7 to 10 years) defines to number 3 for both government and corporate bond by using multivariate GARCH(1,1) model as follows

Hypothesis 1: *There are return and volatility spillover effects among fixed income security that have different time to maturity.*

Conditional Return Equation

$$R_t = \begin{bmatrix} R_{short,t} \\ R_{medium,t} \\ R_{long,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \begin{bmatrix} R_{short,t-1} \\ R_{medium,t-1} \\ R_{long,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{short,t} \\ \varepsilon_{medium,t} \\ \varepsilon_{long,t} \end{bmatrix}$$

Where R_t, R_{t-1} and ε_t is an 3 x 1 vector of daily returns at time t, a vector of corresponding of lagged returns and a vector of innovation residuals in the arrangement of short term, medium term and long term for both government bond and corporate bond in Thailand.

H1.1: Short term bond has no return spillover effect to medium term bond

$$H_0: \beta_{21} = 0 \quad H_1: \beta_{21} \neq 0$$

H1.2: Short term bond has no return spillover effect to long term bond

$$H_0: \beta_{31} = 0 \quad H_1: \beta_{31} \neq 0$$

H1.3: Medium term bond has no return spillover effect to short term bond

$$H_0: \beta_{12} = 0 \quad H_1: \beta_{12} \neq 0$$

H1.4: Medium term bond has no return spillover effect to long term bond

$$H_0: \beta_{32} = 0 \quad H_1: \beta_{32} \neq 0$$

H1.5: Long term bond has no return spillover effect to short term bond

$$H_0: \beta_{13} = 0 \quad H_1: \beta_{13} \neq 0$$

H1.6: Long term bond has no return spillover effect to medium term bond

$$H_0: \beta_{23} = 0 \quad H_1: \beta_{23} \neq 0$$

Conditional Variance equation

$$\begin{aligned} H_t = & \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix}^T \\ & + \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix}^T \begin{bmatrix} \varepsilon_{short,t-1} \\ \varepsilon_{medium,t-1} \\ \varepsilon_{long,t-1} \end{bmatrix} \begin{bmatrix} \varepsilon_{short,t-1} \\ \varepsilon_{medium,t-1} \\ \varepsilon_{long,t-1} \end{bmatrix}^T \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \\ & + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix}^T H_{t-1} \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix} \end{aligned}$$

Where H_t and H_{t-1} are the 3 x 3 matrix represent to conditional variance and its own past conditional variance and ε_{t-1} is the cross product with past return innovations for short term, medium term and long term for both government bond and corporate bond in Thailand.

For short time to maturity bond

$$\mathbf{h_{11,t}} = \boldsymbol{\alpha_{11}^2\varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{21}^2\varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{31}^2\varepsilon_{3,t-1}^2} + 2\alpha_{11}\alpha_{12}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 2\alpha_{11}\alpha_{31}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{21}\alpha_{31}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \boldsymbol{\gamma_{11}^2}\mathbf{h_{11,t-1}} + \gamma_{21}^2 h_{22,t-1} + \gamma_{31}^2 h_{33,t-1} + 2\gamma_{11}\gamma_{12}h_{12,t-1} + 2\gamma_{11}\gamma_{31}h_{13,t-1} + 2\gamma_{21}\gamma_{31}h_{23,t-1}$$

H1.7: Short term bond has no volatility spillover effect from lagged short term bond

$$H_0: \alpha_{11}^2 = 0 \quad H_1: \alpha_{11}^2 \neq 0$$

H1.8: Short term bond has no volatility spillover effect from lagged medium term bond

$$H_0: \alpha_{21}^2 = 0 \quad H_1: \alpha_{21}^2 \neq 0$$

H1.9: Short term bond has no volatility spillover effect from lagged long term bond

$$H_0: \alpha_{31}^2 = 0 \quad H_1: \alpha_{31}^2 \neq 0$$

H1.10: Short term bond has no volatility spillover effect from past volatility persistent of short term

$$H_0: \gamma_{11}^2 = 0 \quad H_1: \gamma_{11}^2 \neq 0$$

For medium time to maturity bond

$$\mathbf{h_{22,t}} = \boldsymbol{\alpha_{12}^2\varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{22}^2\varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{32}^2\varepsilon_{3,t-1}^2} + 2\alpha_{12}\alpha_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 2\alpha_{12}\alpha_{32}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{22}\alpha_{32}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \gamma_{12}^2 h_{11,t-1} + \boldsymbol{\gamma_{22}^2}\mathbf{h_{22,t-1}} + \gamma_{32}^2 h_{33,t-1} + 2\gamma_{12}\gamma_{22}h_{12,t-1} + 2\gamma_{12}\gamma_{32}h_{13,t-1} + 2\gamma_{22}\gamma_{32}h_{23,t-1}$$

H1.11: Medium term bond has no volatility spillover effect from lagged short term bond

$$H_0: \alpha_{12}^2 = 0 \quad H_1: \alpha_{12}^2 \neq 0$$

H1.12: Medium term bond has no volatility spillover effect from lagged medium term bond

$$H_0: \alpha_{22}^2 = 0 \quad H_1: \alpha_{22}^2 \neq 0$$

H1.13: Medium term bond has no volatility spillover effect from lagged long term bond

$$H_0: \alpha_{32}^2 = 0 \quad H_1: \alpha_{32}^2 \neq 0$$

H1.14: Medium term bond has no volatility spillover effect from past volatility persistent of medium term

$$H_0: \gamma_{22}^2 = 0 \quad H_1: \gamma_{22}^2 \neq 0$$

For long time to maturity bond

$$\begin{aligned}\mathbf{h_{33,t}} = \boldsymbol{\alpha_{13}^2 \varepsilon_{1,t-1}^2} + \boldsymbol{\alpha_{23}^2 \varepsilon_{2,t-1}^2} + \boldsymbol{\alpha_{33}^2 \varepsilon_{3,t-1}^2} &+ 2\alpha_{13}\alpha_{23}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ &+ 2\alpha_{13}\alpha_{33}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2\alpha_{23}\alpha_{33}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \gamma_{13}^2 h_{11,t-1} + \gamma_{23}^2 h_{22,t-1} \\ &+ \boldsymbol{\gamma_{33}^2 h_{33,t-1}} + 2\gamma_{13}\gamma_{12}h_{23,t-1} + 2\gamma_{13}\gamma_{33}h_{13,t-1} + 2\gamma_{23}\gamma_{33}h_{23,t-1}\end{aligned}$$

H1.15: Long term bond has no volatility spillover effect from lagged short term bond

$$H_0: \alpha_{13}^2 = 0 \quad H_1: \alpha_{13}^2 \neq 0$$

H1.16: Long term bond has no volatility spillover effect from lagged medium term bond

$$H_0: \alpha_{23}^2 = 0 \quad H_1: \alpha_{23}^2 \neq 0$$

H1.17: Long term bond has no volatility spillover effect from lagged long term bond

$$H_0: \alpha_{33}^2 = 0 \quad H_1: \alpha_{33}^2 \neq 0$$

H1.18: Long term bond has no volatility spillover effect from past volatility persistent of long term

$$H_0: \gamma_{33}^2 = 0 \quad H_1: \gamma_{33}^2 \neq 0$$

3.4.2 Testing Credit Rating Hypothesis

This paper arranges the level into three criteria start from low credit rating level of investment grade of corporate bond which consists of A+, A, A-, BBB+, BBB and BBB-. Low credit rating level of corporate bond replaces in short time to maturity from the above equations. High investment grade of corporate bond consists of AAA, AA+, AA and AA-. High credit rating level of corporate bond replaces in medium time to maturity from the above equations. And the other level of credit rating represents by government bond as the main determinant variable of government credit rating level replaces in long time to maturity from the above equations.

Hypothesis 2: *There are return and volatility spillover effects from government bonds to high investment grade corporate and low investment grade corporate bonds.*

Conditional Return Equation

$$R_t = \begin{bmatrix} R_{low,t} \\ R_{high,t} \\ R_{gov,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \begin{bmatrix} R_{low,t-1} \\ R_{high,t-1} \\ R_{gov,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{low,t} \\ \varepsilon_{high,t} \\ \varepsilon_{gov,t} \end{bmatrix}$$

The conditional return equation regarding to credit rating content is applied the same function as the return equation respect to time to maturity. In the 3 x 1 vector of conditional return at time t, $R_{low,t}, R_{high,t}$ and $R_{gov,t}$ represent to the gross price index return for low investment grade corporate bond, high investment grade corporate bond and government credit level, respectively. This paper replaces $R_{short,t}, R_{medium,t}$ *and* $R_{long,t}$ in the conditional return equation with the following variables $R_{low,t}, R_{high,t}$ and $R_{gov,t}$ consequently and also replace to 3 x 1 vector of the lagged innovation term by the $R_{low,t-1}$, $R_{high,t-1}$ and $R_{gov,t-1}$ as well as 3 x 1 vector of the innovation residuals by the $\varepsilon_{low,t}$, $\varepsilon_{high,t}$ and $\varepsilon_{gov,t}$ respectively.

The hypothesis testing relative to return spillovers is applied among credit rating level for the calculation. In order to examine the return spillover effects, this paper prior focus on low investment grade corporate bond, high investment grade corporate bond and the government credit level of bond respectively.

Conditional Variance Equation

$$H_t = \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix}^T + \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix}^T \begin{bmatrix} \varepsilon_{low,t-1} \\ \varepsilon_{high,t-1} \\ \varepsilon_{gov,t-1} \end{bmatrix} \begin{bmatrix} \varepsilon_{low,t-1} \\ \varepsilon_{high,t-1} \\ \varepsilon_{gov,t-1} \end{bmatrix}^T \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix}^T H_{t-1} \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix}$$

The conditional variance equation regarding to credit rating content is applied the same function as the variance equation respect to time to maturity. This paper replaces the short term, medium term and long term by low investment grade corporate bond, high investment grade corporate bond and the government credit level of bond. The volatility spillover directions are calculated responding to the conditional variance equations.

3.4.3 Testing Liquidity Hypothesis

The trading volume is applied to be as a proxy of liquidity, this paper groups government bond into two categories depending on their liquidity: low liquidity and high liquidity. This paper considers the spillover effects by using bi-variate GARCH(1,1) model as follows

Hypothesis 3: *There are return and volatility spillover effects from high liquidity government bonds to low liquidity government bonds.*

Conditional Return Equation

$$R_t = \begin{bmatrix} R_{low,t} \\ R_{high,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \begin{bmatrix} R_{low,t-1} \\ R_{high,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{low,t} \\ \varepsilon_{high,t} \end{bmatrix}$$

In the same manner of the return equation of credit rating level, the variables $R_{low,t}$ and $R_{high,t}$ which represent to low liquidity and high liquidity are adjusted to the conditional return equation as mentioned. These practices are applied particularly to government bond in the sample data.

Conditional Variance equation

$$\begin{aligned} H_t = & \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}^T \\ & + \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix}^T \begin{bmatrix} \varepsilon_{low,t-1} \\ \varepsilon_{high,t-1} \end{bmatrix} \begin{bmatrix} \varepsilon_{low,t-1} \\ \varepsilon_{high,t-1} \end{bmatrix}^T \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} \\ & + \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix}^T H_{t-1} \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix} \end{aligned}$$

The conditional variance equation regarding to liquidity content is applied the same function as the variance equation respect to time to maturity as well as credit ratings. The matrix variables are adjusted to the level of liquidity. This paper measures prior to low liquidity and high liquidity respectively. The volatility spillover effects are calculated responding to the conditional variance equations.

CHAPTER 4

Empirical Results

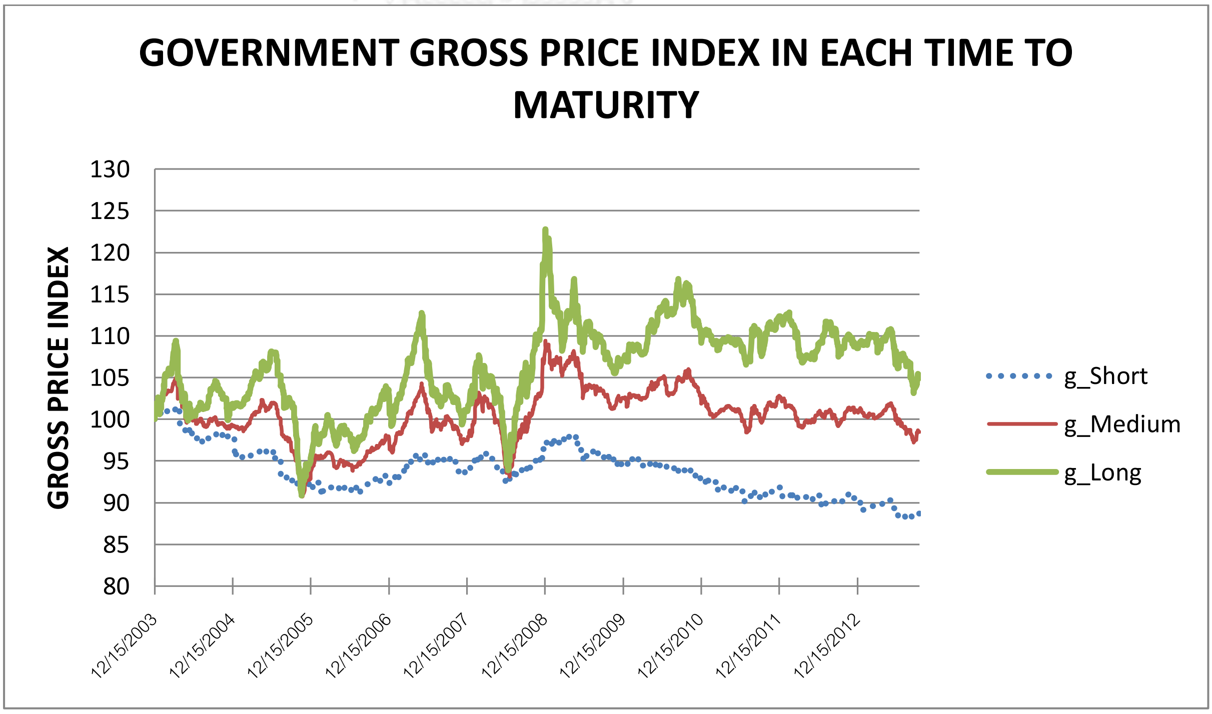
The objective of this study is to investigate the spillover effects between fixed income securities in terms of maturity, credit rating as well as liquidity measurement. The multivariate GARCH(1,1) model is applied in this analysis allows for both return and volatility spillovers.

4.1 Time to Maturity Spillovers Effects

Index calculation on each level of time to maturity for government and corporate bond

This paper contributes to the index calculation for the characteristic of bond regarding to time to maturity for both government and corporate bond from December 2003 to September 2013.

Figure 1: The graph represents the gross price index of government bond in each time to maturity during the period of December 2003 to September 2013



From the time varying of index in different level of time to maturity, this continuous line can be shown that long time to maturity appears to exhibit the highest volatile among all levels of time to maturity of government bond. The index point starts from 100 in December 2003 and the endpoint finish in September 2013. After that we calculate the government gross price index return series as shown in the graph.

Figure 2: The graph represents the government gross price index return of short time to maturity during the sample period of December 2003 to September 2013

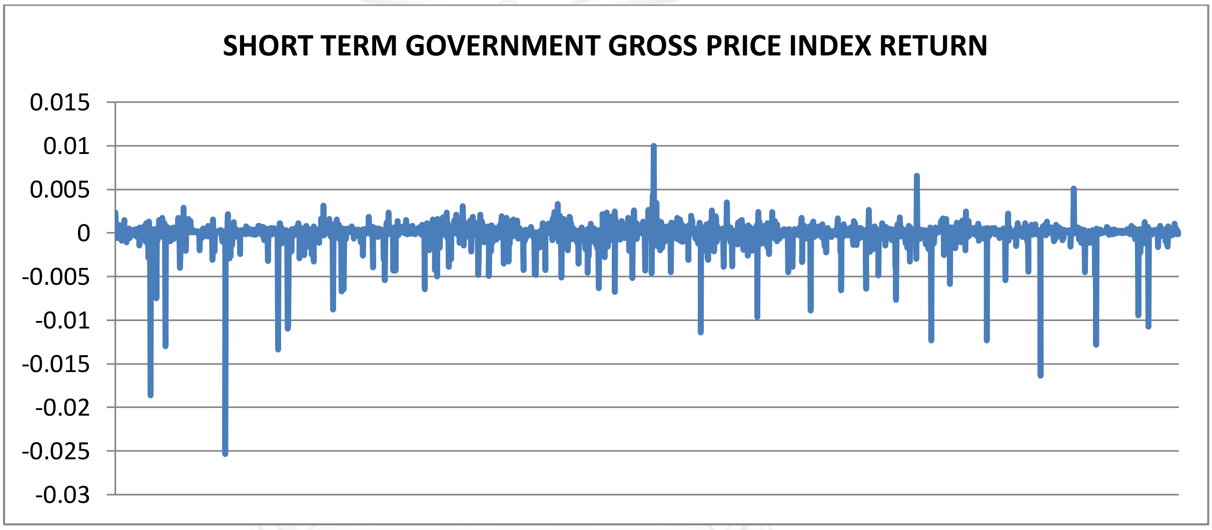


Figure 3: The graph represents the government gross price index return of medium time to maturity during the sample period of December 2003 to September 2013

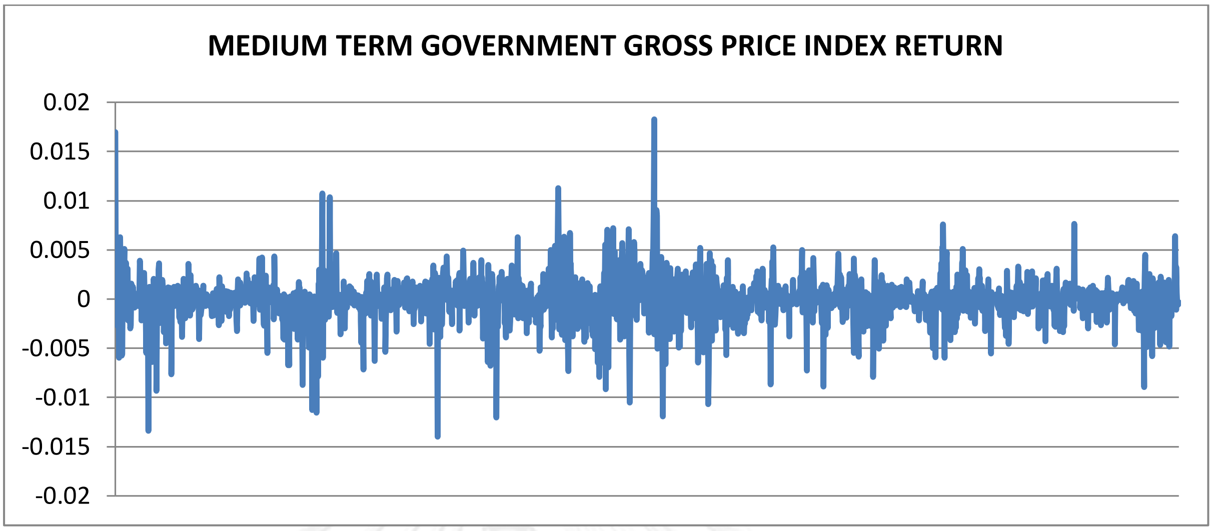
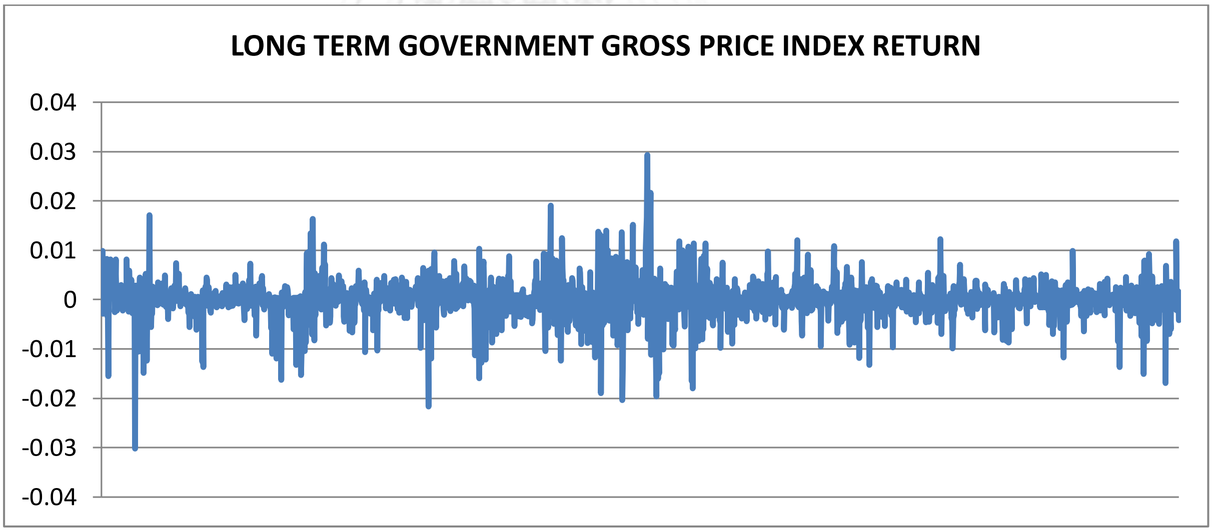
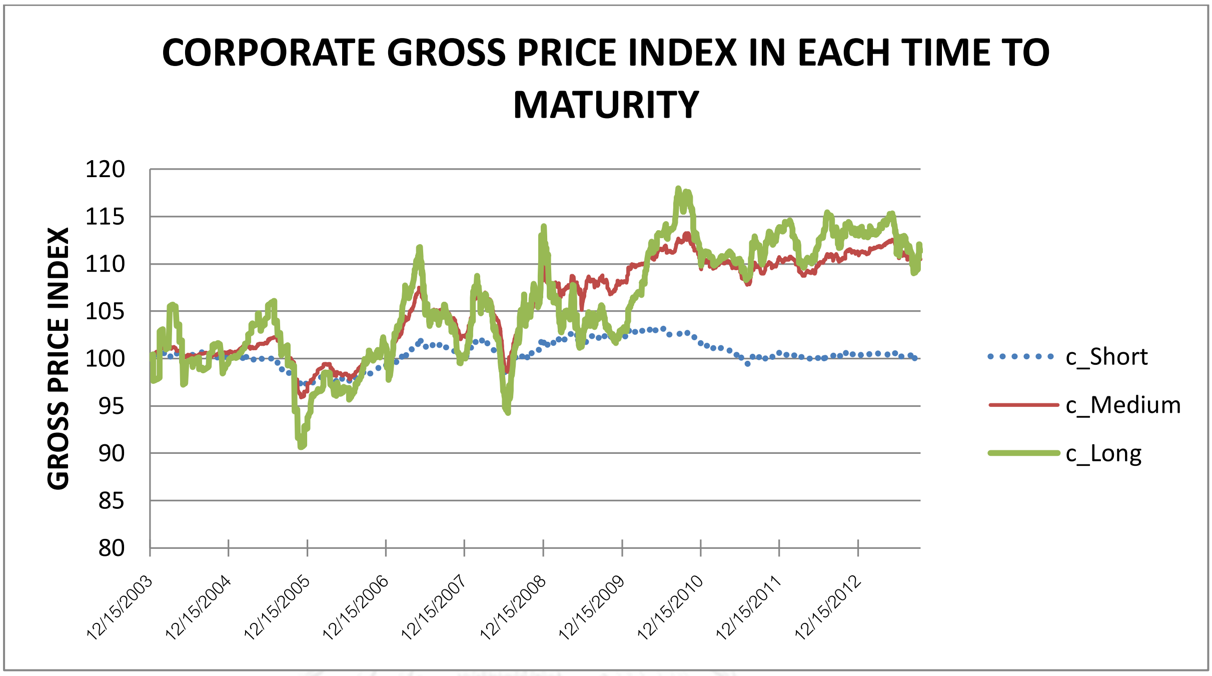


Figure 4: The graph represents the government gross price index return of long time to maturity during the sample period of December 2003 to September 2013



Regarding to Figure 2-4 which shows the government gross price index return in all levels of time to maturity, the data series exhibits the time varying variance during the sample period of December 2003 to September 2013. Therefore, this figure of time varying variance nature of gross price index return motivates us to employ GARCH model in this paper.

Figure 5: The graph represents the gross price index of corporate bond in each time to maturity during the period of December 2003 to September 2013



From the time varying of index in different level of time to maturity, this continuous line can be shown that long time to maturity appears to exhibit the highest volatile among all levels of time to maturity of corporate bond. The index point starts from 100 in December 2003 and the endpoint finish in September 2013. After that we calculate the corporate gross price index return series as shown in the graph.

Figure 6: The graph represents the corporate gross price index return of short time to maturity during the sample period of December 2003 to September 2013

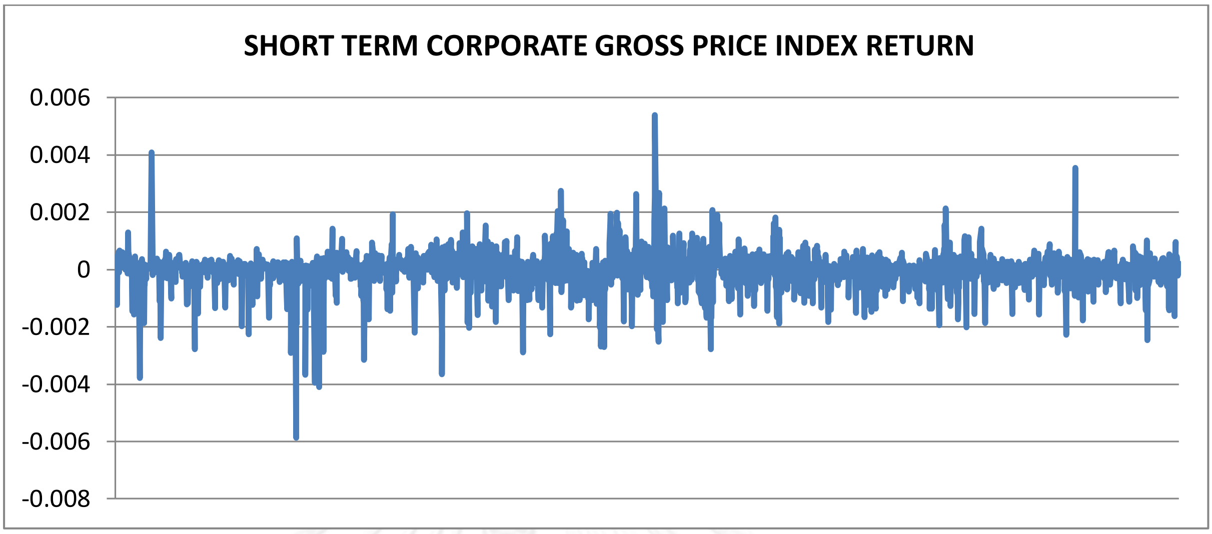


Figure 7: The graph represents the corporate gross price index return of medium time to maturity during the sample period of December 2003 to September 2013

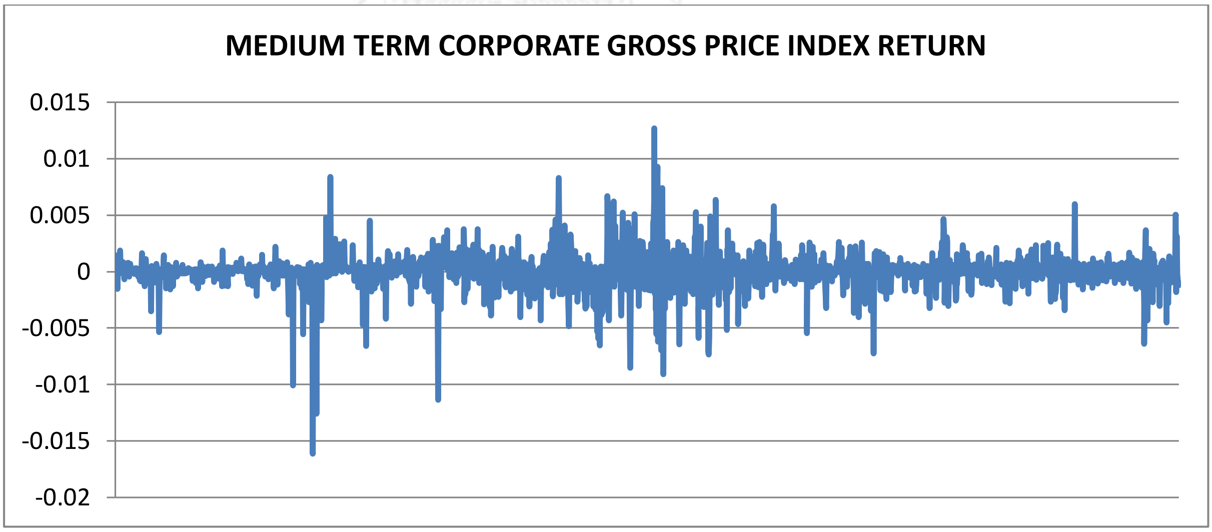
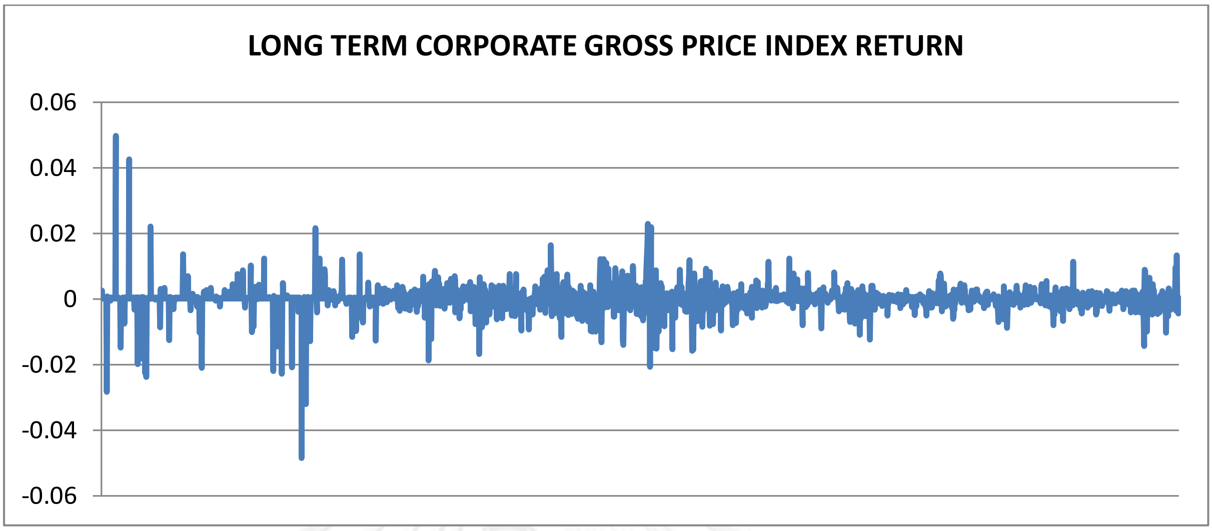


Figure 8: The graph represents the corporate gross price index return of long time to maturity during the sample period of December 2003 to September 2013



Regarding to Figure 6-8 which show the corporate gross price index return in all levels of time to maturity, the data series exhibits the time varying variance during the sample period of December 2003 to September 2013. Therefore, this figure of time varying variance nature of gross price index return motivates us to employ GARCH model in this paper.

Table 8 and 9 presents the summary statistic and correlation matrix among levels of maturity for government and corporate bond respectively.

Table 8: Summary statistics of daily gross bond return for government and corporate bond

	Government bond			Corporate bond		
	SHORT	MEDIUM	LONG	SHORT	MEDIUM	LONG
Mean	-0.0048%	-0.0004%	0.0027%	0.0001%	0.0042%	0.0052%
Median	0.0119%	0.0132%	0.0154%	0.0081%	0.0133%	0.0152%
Maximum	0.9965%	1.8259%	2.9278%	0.5396%	1.2706%	4.9844%
Minimum	-2.5323%	-1.4000%	-3.0155%	-0.5860%	-1.6123%	-4.8572%
Std. Dev.	0.1494%	0.2111%	0.3713%	0.0619%	0.1507%	0.3851%
Skewness	-6.152	-0.302	-0.455	-1.01	-0.99	-0.336
Kurtosis	71.733	12.986	11.644	15.607	19.991	40.499
Observations	2425	2425	2425	2425	2425	2425

Regarding to summary statistics of daily gross bond return for government bond, the numbers shown are consistent with the common perception that long term bond has the highest return and follow by medium and short term bond which can see from the mean and median accordingly. Meanwhile long term bond also has the highest risk which can see from the standard deviation. For corporate bonds, the numbers also exhibits the same manner of government bond.

Table 9: Correlation matrix of daily gross bond return for government and corporate bond

	Government bond			Corporate bond		
	SHORT	MEDIUM	LONG	SHORT	MEDIUM	LONG
SHORT	1.000	0.126	0.103	1.000	0.695	0.524
MEDIUM	0.126	1.000	0.671	0.695	1.000	0.729
LONG	0.103	0.671	1.000	0.524	0.729	1.000

Regarding to correlation relations, interestingly, short time to maturity has the low correlations with medium and long term. This reflects that each level of asset class does not have the same characteristic even though they are the same government bond. Therefore, each level of asset class could respond to factors differently.

However, for the weekly data, the results are consistent with daily return in terms of pattern of means and standard deviation and the correlation of weekly gross price return on government are lower than the correlation on corporate bond as described in Table 28 and Table 29 in Appendix.

4.1.1 Time to maturity spillovers in government bond market

This section investigates the return and spillover effects of each maturity of government and corporate bond market. The maximum likelihood estimates of the multivariate GARCH(1,1) model for characteristic of time to maturity in Thai government bond market are reported in table 10 and 11, respectively. Table 10 depicts that the estimated coefficients provide evidence of return spillovers among fixed income security as well as table 11 presents the volatility spillovers among term maturity of government bond.

Table 10: Results of multivariate GARCH(1,1) for return spillovers in different maturity on daily government bond market

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	-0.0001	0.0001	-1.1089	0.268
β_{11}	0.0428	0.0437	0.9799	0.327
β_{12}	0.0078	0.0339	0.2302	0.818
β_{13}	0.0103	0.0183	0.5618	0.574
c_2	-2.6E-05	0.0000	0.0721	0.943
$\boldsymbol{\beta_{21}}$	**0.3657*** **	**0.0096**	**38.1319**	**0.000**
$\boldsymbol{\beta_{22}}$	**0.0971*** **	**0.0232**	**4.1931**	**0.000**
$\boldsymbol{\beta_{23}}$	**0.0753*** **	**0.0109**	**6.8988**	**0.000**
c_3	0.0001	0.0001	0.9597	0.337
$\boldsymbol{\beta_{31}}$	**0.5693*** **	**0.0192**	**29.6501**	**0.000**
$\boldsymbol{\beta_{32}}$	**0.2741*** **	**0.0383**	**7.1643**	**0.000**
$\boldsymbol{\beta_{33}}$	**0.0553** **	**0.0254**	**2.1745**	**0.030**

Notes: Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

$$R_t = \begin{bmatrix} R_{short,t} \\ R_{medium,t} \\ R_{long,t} \end{bmatrix} = \begin{bmatrix} -0.0001 \\ -2.6E-05 \\ 0.0001 \end{bmatrix} + \begin{bmatrix} 0.0428 & 0.0078 & 0.0103 \\ \mathbf{0.3657}^{***} & \mathbf{0.0971}^{***} & \mathbf{0.0753}^{***} \\ \mathbf{0.5693}^{***} & \mathbf{0.2741}^{***} & \mathbf{0.0553}^{***} \end{bmatrix} \begin{bmatrix} R_{short,t-1} \\ R_{medium,t-1} \\ R_{long,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{short,t} \\ \varepsilon_{medium,t} \\ \varepsilon_{long,t} \end{bmatrix}$$

Based on the hypothesis that when there is a shock occurs, there are return spillover effects among different time to maturity of fixed income securities. The empirical results show that there are significant return spillover effects on different time to maturity in government bond which consistent with the hypothesis 1. The relationships of the spillover effects are one to many relations. The results show that each maturity of government bonds are depend on their own past values, as indicated by coefficients β_{22}, β_{33}. Particularly for medium and long maturity, this result is consistent with Skintzi and Refenes (2006) in the way that prices in most bond markets are dependent on their own past value.

The estimated coefficient β_{12} provides the evidence that there are no significant return spillovers effects from medium time to maturity of lagged term to short time to maturity however the result is not consistent adversely in the way that short time to maturity of lagged term has return spillover effect to medium time to maturity as indicated by coefficient β_{21}. From the result, this paper concludes that short time to maturity leads medium time to maturity. The result is consistent with the hypothesis. The results are consistent with Park (1999) who also claim that bonds with all the same characteristics except maturity are not perfect substitutes.

Long maturity of lagged time has no return spillover effect to short time to maturity, but the inverse direction shows that there is significant return spillover effect from short time to maturity of lagged time to long term maturity as measured by estimated coefficients β_{13} and β_{31}. This means that short time to maturity leads long time to maturity. The result is consistent with hypothesis. Investors may also be able to entrust the diversification benefit during the shock period regarding to portfolio of time to maturity in the baskets. Furthermore, the estimated coefficients β_{23} and β_{32} also depict that there are significant return spillover effects from long time to maturity of lagged term to medium time to maturity as well as medium time to maturity of lagged time has significant return spillover effects to long time to maturity at time t. The results could be the informative knowledge advantages for investors as the cause and effect factors for investment in government bond market respect to time to maturity. In addition, the estimated coefficients mostly provide the significant evidences at the 1% level of confidence.

Table 11: Results of multivariate GARCH(1,1) for volatility spillovers in different maturity on daily government bond market

Independent Variables	$h_{11,t}$		$h_{22,t}$		$h_{33,t}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0002	0.4485	0.0007***	0.0000	0.0008***	0.0085
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0007	0.0223	0.0028***	0.0000	0.0033***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0007	0.1578	0.0031***	0.0000	0.0036***	0.0000
$\varepsilon^2_{2,t-1}$	0.0007***	0.0000	0.0029***	0.0000	0.0034***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0015***	0.0000	0.0063***	0.0000	0.0075***	0.0000
$\varepsilon^2_{3,t-1}$	0.0008***	0.0085	0.0034***	0.0000	0.0041***	0.0000
$h_{11,t-1}$	0.0220	0.9086	0.1355	0.5890	0.1350	0.6384
$h_{12,t-1}$	0.1092	0.8034	0.6725***	0.0000	0.6699***	0.0000
$h_{13,t-1}$	0.1090	0.8163	0.6712***	0.0000	0.6685***	0.0000
$h_{22,t-1}$	0.1355	0.5890	0.8343***	0.0000	0.8310***	0.0000
$h_{23,t-1}$	0.2705	0.6144	1.6653***	0.0000	1.6588***	0.0000
$h_{33,t-1}$	0.1350	0.6384	0.8310***	0.0000	0.8277***	0.0000

Notes: h_{11} denotes the conditional variance for short time to maturity gross price index return series, h_{22} is the conditional variance for medium time to maturity gross price index return series, and h_{33} is the conditional variance for long time to maturity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Turning to the second moment of spillover effects, the estimation results of the multivariate GARCH model with Diagonal BEKK parameterization for each variance equation are reported in Table 11. The error term "ε" in each model represents the effect of volatility spillovers as unexpected shocks in each model on different types.

$\varepsilon^2_{1,t-1}$, $\varepsilon^2_{2,t-1}$ and $\varepsilon^2_{3,t-1}$ represent the deviation from the mean due to some unanticipated event in a particular type. The symbol $h_{11,t-1}$ represents the past volatility persistent for the first type of time to maturity at lagged time.

The empirical results show that for short time to maturity, there are significant volatility spillover effects from medium and long of lagged term to short time to maturity

For medium time to maturity in the second column, all short, medium and long time to maturity of lagged term have significant volatility spillover to medium time to maturity. As well as short time to maturity has spillover from own past volatility persistent.

Examining the long time to maturity in the third column, the results show all short, medium and long time to maturity of lagged time have volatility spillover effect to long time to maturity. Lastly, long time to maturity has spillover effect directly from own past volatility persistent.

We reject the null hypothesis of no spillovers effects across level of time to maturity. The result is consistent with the hypothesis. The reason that the volatility spillover occurs among level of time to maturity imply the effectiveness of monetary policy which the government wants to influence the longer time to maturity characteristic of bond by prior intervene in short time to maturity. The results align with Park (1999) that time to maturity components are significant in bond characteristics.

In summary, the results of each time to maturity of government bond generally show the significant return spillovers effects among level of time to maturity; short, medium and long time to maturity. The results are consistent with the hypothesis development regarding to the monetary policy principal and role of government department in order to control interest rate policy.

Turning to weekly of government bond return on each time to maturity compared to daily of government bond return, the results show that there are no evidence of return spillover effects, but in there exists of significant volatility spillovers as well as past volatility, the results are reported in Table 30 and Table 31 in Appendix.

4.1.2 Time to maturity spillovers in corporate bond market

This section investigates the return and volatility spillovers effects among each level of time to maturity of corporate bond. The summary statistics of are shown in Table 8 and Table 9 presents the correlation matrix of daily return of short, medium and long time to maturity.

The maximum likelihood estimates of the multivariate GARCH(1,1) model for characteristic of time to maturity in Thai corporate bond market are reported in Table 12 and 13, respectively. Table 12 depicts that the estimated coefficients provide evidence of return spillovers among short, medium and long time to maturity of corporate bond as well as Table 13 presents the volatility spillovers among term maturity of corporate bond.

Table 12: Results of multivariate GARCH(1,1) for return spillovers in different maturity on daily corporate bond market

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	-3.2E-06	0.0000	-0.2308	0.8175
β_{11}	0.0366	0.0379	0.9667	0.3337
$\boldsymbol{\beta_{12}}$	**0.0866*** **	**0.0151**	**5.7532**	**0.0000**
β_{13}	-0.0035	0.0044	-0.8069	0.4197
$\boldsymbol{c_2}$	**3.3E-05***	**0.0000**	**1.7206**	**0.0853**
β_{21}	0.0275	0.0340	0.8098	0.4181
$\boldsymbol{\beta_{22}}$	**0.2235*** **	**0.0236**	**9.4698**	**0.0000**
β_{23}	-0.0023	0.0072	-0.3211	0.7481
c_3	3.4E-05	0.0001	0.6128	0.5400
β_{31}	-0.0760	0.1133	-0.6709	0.5023
$\boldsymbol{\beta_{32}}$	**0.3821*** **	**0.0719**	**5.3166**	**0.0000**
β_{33}	0.0205	0.0301	0.6826	0.4949

Notes: Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

$$\mathrm{R_t} = \begin{bmatrix} \mathrm{R_{short,t}} \\ \mathrm{R_{medium,t}} \\ \mathrm{R_{long,t}} \end{bmatrix} = \begin{bmatrix} -3.2E-06 \\ \boldsymbol{3.3E-05}^{*} \\ 3.4E-05 \end{bmatrix} + \begin{bmatrix} 0.0366 & \boldsymbol{0.0866}^{***} & -0.0035 \\ 0.0275 & \boldsymbol{0.2235}^{***} & -0.0023 \\ -0.0760 & \boldsymbol{0.3821}^{***} & 0.0205 \end{bmatrix} \begin{bmatrix} \mathrm{R_{short,t-1}} \\ \mathrm{R_{medium,t-1}} \\ \mathrm{R_{long,t-1}} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\mathrm{short,t}} \\ \varepsilon_{\mathrm{medium,t}} \\ \varepsilon_{\mathrm{long,t}} \end{bmatrix}$$

Regarding to the hypothesis development that there are return spillover effects among level of maturity on corporate bond market in Thailand, the empirical results show that only medium to maturity in corporate bond has return correlated with their own past values as measured by the estimated coefficients β_{22}. Contradiction with short and long time to maturity that there are no return spillovers from their own past value as measured by the coefficients β_{11} and β_{33}. The estimated coefficients β_{21} and β_{12} depict that short time to maturity of lagged time has no return spillovers to medium time to maturity, while there is significant evidence of return spillover from medium time to maturity of lagged time to short time to maturity at time t. From these results imply that when there are shocks occurs the medium time to maturity leads short time to maturity respect to return spillovers. Moving on to the pair relations between short and long time to maturity as measured by the estimated coefficients β_{31} and β_{13}. The empirical results show that there are no evidence of return spillover effects between short and long time to maturity. In other words, there are no return spillovers from short time to maturity of lagged time to long time to maturity at time t as well as there are no return spillovers from long time to maturity of lagged time to short time to maturity. Last pair of relations, the empirical results show that medium time to maturity of lagged time has significant return spillovers to long time to maturity; reverse way does not exist in the way that there are no evidences of long time to maturity of lagged time to medium time to maturity as measured by the estimated coefficient β_{32} and β_{23}.

In summary the results contribute to the basket of portfolio in the perspective of the diversification benefits of corporate bond when there is a shock occurs. The summarizing of the result presents that medium time to maturity has return leads both short and long time to maturity characteristic of bond market.

Table 13: Results of multivariate GARCH(1,1) for volatility spillovers in different maturity on daily corporate bond market

Independent Variables	$h_{11,t}$		$h_{22,t}$		$h_{33,t}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0268***	0.0000	0.0139***	0.0000	0.0057***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0385***	0.0000	0.0199***	0.0000	0.0082***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0247***	0.0000	0.0127***	0.0000	0.0052***	0.0000
$\varepsilon^2_{2,t-1}$	0.0139***	0.0000	0.0072***	0.0000	0.0029***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0177***	0.0000	0.0092***	0.0000	0.0037***	0.0000
$\varepsilon^2_{3,t-1}$	0.0057***	0.0000	0.0029***	0.0000	0.0012***	0.0000
$h_{11,t-1}$	0.1592***	0.0000	0.3686***	0.0000	0.3849***	0.0000
$h_{12,t-1}$	0.4845***	0.0000	1.1215***	0.0000	1.1711***	0.0000
$h_{13,t-1}$	0.4951***	0.0000	1.1460***	0.0000	1.1967***	0.0000
$h_{22,t-1}$	0.3686***	0.0000	0.8531***	0.0000	0.8908***	0.0000
$h_{23,t-1}$	0.7533***	0.0000	1.7435***	0.0000	1.8206***	0.0000
$h_{33,t-1}$	0.3849***	0.0000	0.8908***	0.0000	0.9302***	0.0000

Notes: h_{11} denotes the conditional variance for short time to maturity gross price index return series, h_{22} is the conditional variance for medium time to maturity gross price index return series, and h_{33} is the conditional variance for long time to maturity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Test of the hypothesis regarding to volatility spillovers among level of time to maturity of corporate bond suggest that for short time to maturity, there are significant volatility spillover from short, medium and long time to maturity of lagged time to short time to maturity. And short time to maturity also has significant volatility spillover from own past volatility persistent.

For medium time to maturity, all linkages of short, medium and long time to maturity of lagged time have significant directly spillover to medium time to maturity. As well as medium time to maturity also has spillover from own past volatility persistent. The results are in the same manner according to short time to maturity characteristic of corporate bond.

Lastly, long time to maturity is significant directly affected by volatility spillover from short, medium and long time to maturity of lagged time including its own past volatility persistent.

In summary, the relationships among level time to maturity of corporate bond in terms of return spillovers show significant evidence, particularly, the spillovers effects mainly come from medium time to maturity. Regarding to volatility spillovers, the results show that there exist the volatility spillover among level of time to maturity of corporate bond. The results are consistent with the hypothesis and consistent with Skintzi and Refenes (2006) who claim that bond markets has significant volatility spillover effects from their own past values.

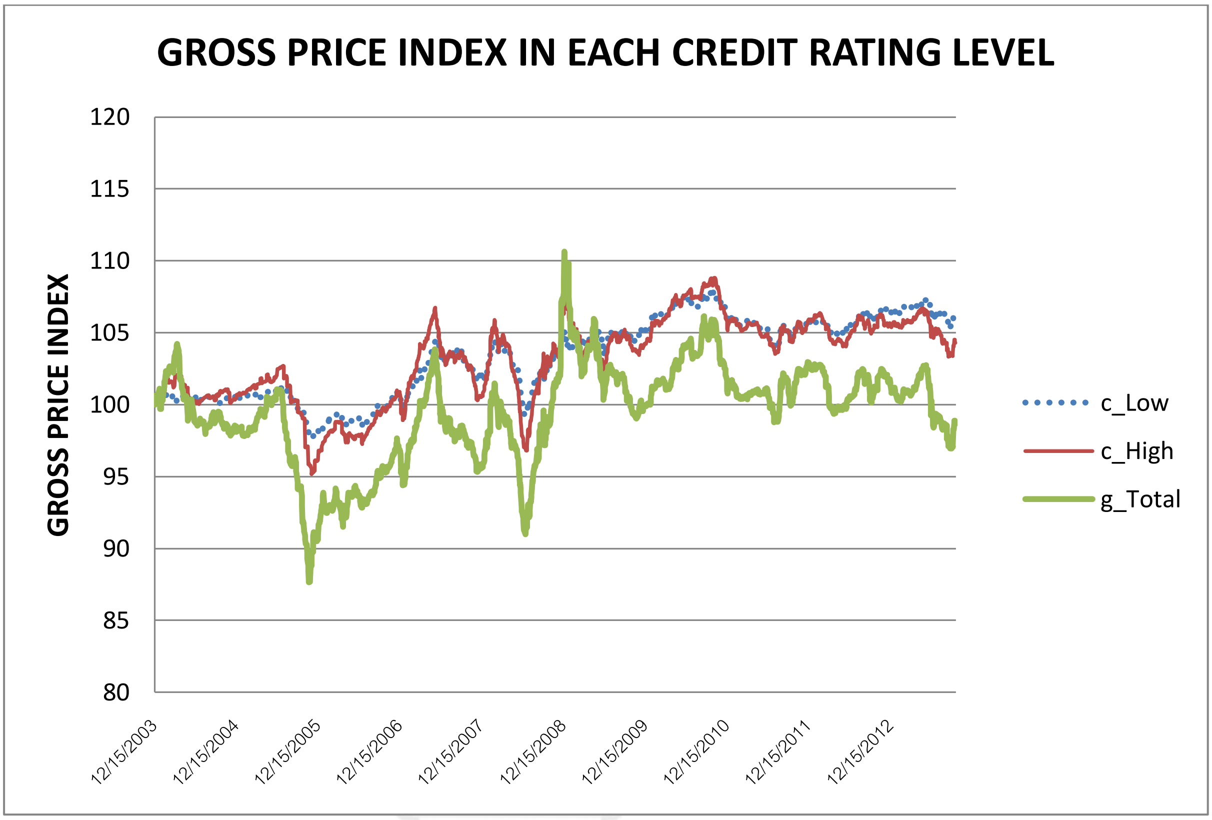
Turning to weekly of corporate bond return on each time to maturity, the results show that there are less evidence of significant return spillover effects that there are significant return spillovers from short time to maturity of lagged time to long time to maturity and from medium time to maturity of lagged time to long time to maturity. Consistent with volatility spillovers that there are less exists of significant volatility spillovers particularly that there are no evidence of short time to maturity has volatility spillovers to all levels of time to maturity, the results are reported in Table 32 and Table 33 in Appendix.

4.2 Credit Rating Spillover Effects

Index calculation on each level of credit rating for government and corporate bond

This paper also makes a contribution for the index calculation of another characteristic of bond regarding to credit rating level during the time period of December 2003 to September 2013. To align with the previous characteristic, this paper arranges the start period in the same manner.

Figure 9: The graph represents the gross price index of government and corporate bond in each credit rating level during the period of December 2003 to September 2013



From the time varying of index in different level of time to maturity, this continuous line can be shown that government credit rating level appears to exhibit the highest volatile among all levels of credit rating for government and corporate bond. The index point starts from 100 in December 2003 and the endpoint finish in September 2013.

Figure 10: The graph represents the low credit rating level of corporate gross price index return during the sample period of December 2003 to September 2013

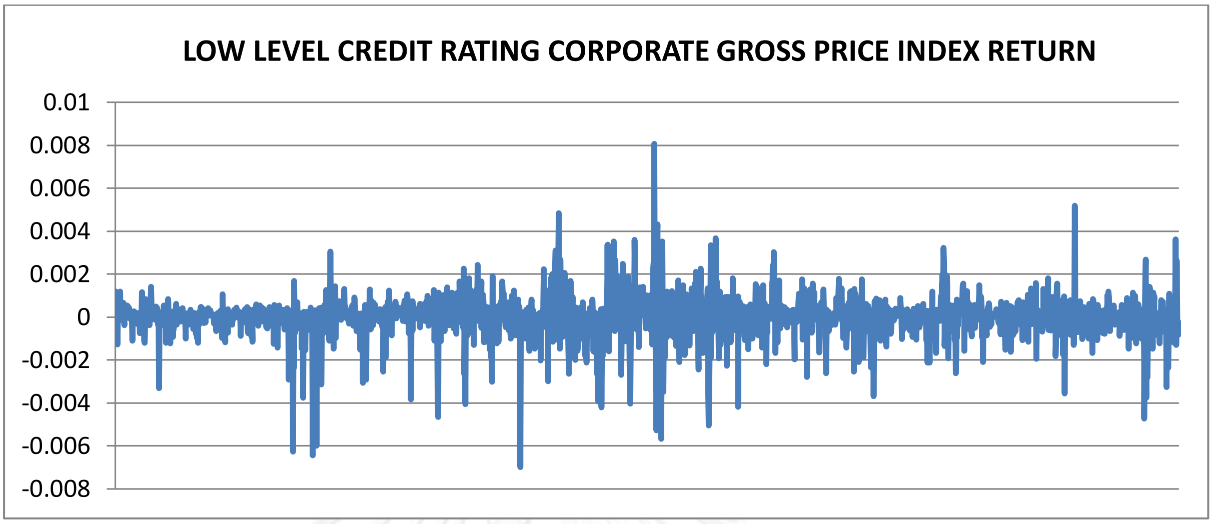


Figure 11: The graph represents the high credit rating level of corporate gross price index return during the sample period of December 2003 to September 2013

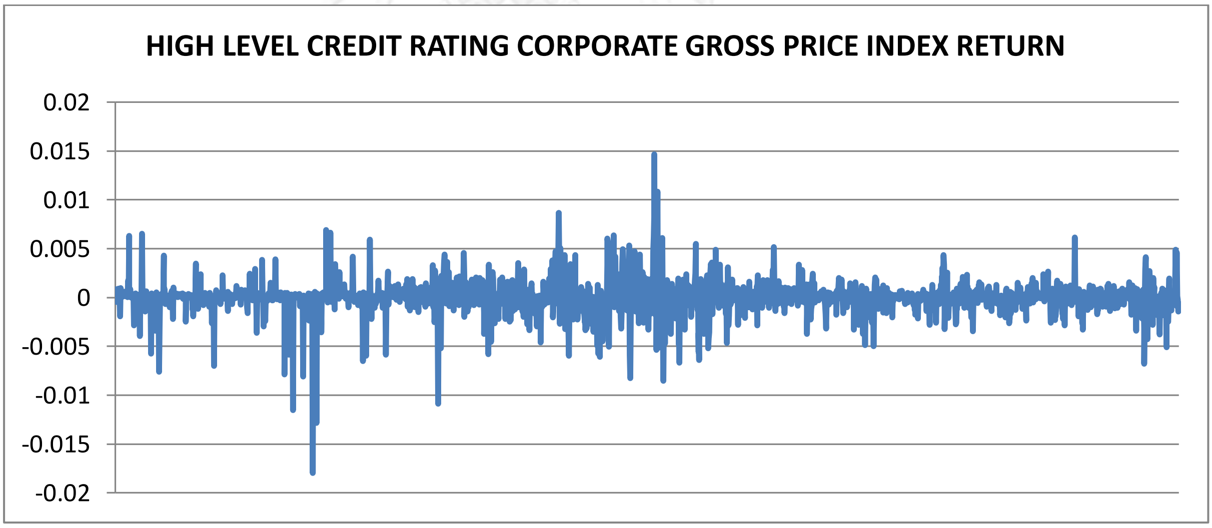
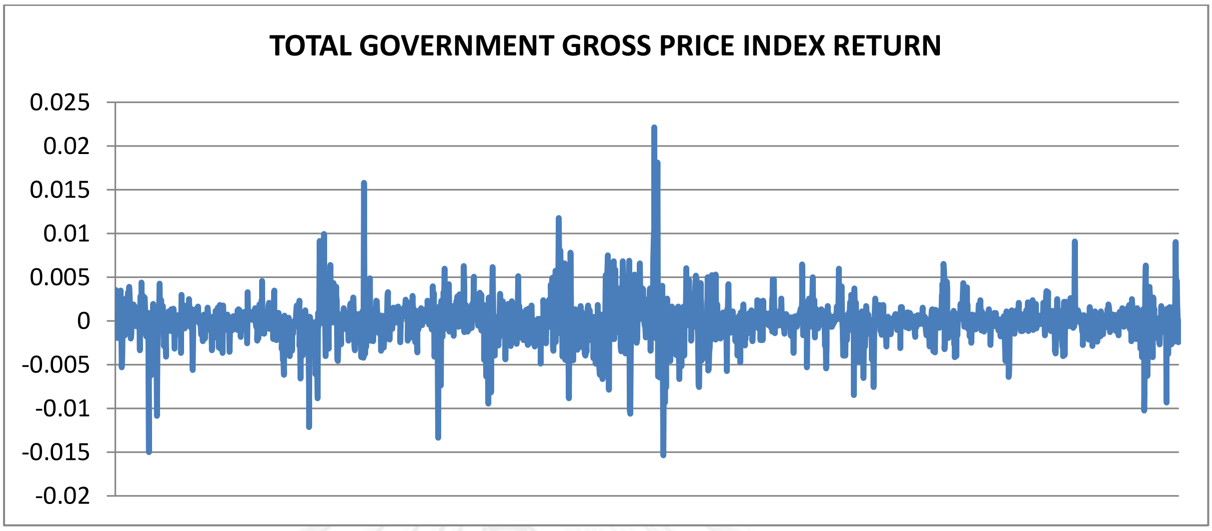


Figure 12: The graph represents the credit rating level of government gross price index return during the sample period of December 2003 to September 2013



Regarding to credit rating characteristic of bond, the data are divided into three variables of index calculation; low credit rating level, high credit rating level and government credit rating level. Table 14 and 15 presents the summary statistic and correlation matrix of daily gross bond return among credit rating level of government and corporate bond.

Table 14: Summary statistic of daily gross bond return for government and corporate bond

	LOW CREDIT	HIGH CREDIT	GOVERNMENT
Mean	0.0024%	0.0019%	-0.0003%
Median	0.0109%	0.0118%	0.0116%
Maximum	0.8067%	1.4640%	2.2159%
Minimum	-0.6981%	-1.7949%	-1.5401%
Std. Dev.	0.0918%	0.1595%	0.2249%
Skewness	-0.915	-0.910	0.170
Kurtosis	14.770	21.265	14.905
Observations	2425	2425	2425

The numbers get from the data are quite consistent with common practice that return from corporate bond is higher than government bond as well as low credit rating level has higher return than high credit rating level of corporate bond as described in mean in the table. The numbers also align with risk preferences that low credit rating lever is riskier than high credit rating and government credit rating level as shown in the standard deviation, respectively.

Table 15: Correlation matrix of daily gross bond return for government and corporate bond

	LOW CREDIT	HIGH CREDIT	GOVERNMENT
LOW CREDIT	1.000	0.751	0.590
HIGH CREDIT	0.751	1.000	0.665
GOVERNMENT	0.590	0.665	1.000

Regarding to the correlation matrix among credit rating level of corporate and government bond, the correlation between low credit rating and high credit rating of corporate bond is considered highly correlated, while the correlations between corporate bonds and government bond are considered moderately correlated.

For the weekly data of credit rating level, the results are also consistent with daily data of credit rating level in the pattern of mean, median as well as standard deviation. The correlation matrix also has the same pattern of the daily correlation as reported in Table 34 and Table 35 in Appendix.

4.2.1 Return and Volatility Spillovers among government and corporate bond market

This section examines the spillover effects for each level of credit rating for both government and corporate bond. The maximum likelihood estimates of the multivariate GARCH(1,1) model for characteristic of credit rating level for both government and corporate bond market are reported in table 16 and 17 respectively. Table 16 presents the estimated coefficients provide the evidence of return spillover effects as well as table 17 presents the volatility spillovers effects for credit rating level.

Table 16: Results of multivariate GARCH(1,1) for return spillovers among level of credit rating for daily government and daily corporate bond market.

	Coefficient	Std. Error	z-Statistic	Prob.
$\boldsymbol{c_1}$	**2.14E-05***	**0.0000**	**1.9145**	**0.0556**
$\boldsymbol{\beta_{11}}$	**0.1003*****	**0.0213**	**4.7047**	**0.0000**
$\boldsymbol{\beta_{12}}$	**0.0252***	**0.0133**	**1.8924**	**0.0584**
$\boldsymbol{\beta_{13}}$	**0.0450*****	**0.0071**	**6.3611**	**0.0000**
c_2	1.46E-05	0.0000	0.7059	0.4802
$\boldsymbol{\beta_{21}}$	**0.1049*****	**0.0372**	**2.8212**	**0.0048**
$\boldsymbol{\beta_{22}}$	**0.0742*****	**0.0240**	**3.0904**	**0.0020**
$\boldsymbol{\beta_{23}}$	**0.1083*****	**0.0119**	**9.1056**	**0.0000**
c_3	-5.7E-06	0.0000	-0.2384	0.8116
β_{31}	0.0597	0.0479	1.2457	0.2129
$\boldsymbol{\beta_{32}}$	**0.1155*****	**0.0315**	**3.6680**	**0.0002**
$\boldsymbol{\beta_{33}}$	**0.2781*****	**0.0197**	**14.0831**	**0.0000**

Notes: Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

$$\mathrm{R_t} = \begin{bmatrix} \mathrm{R_{low,t}} \\ \mathrm{R_{high,t}} \\ \mathrm{R_{gov,t}} \end{bmatrix} = \begin{bmatrix} \mathbf{2.1}\boldsymbol{E}-\mathbf{05}^{*} \\ 1.4E-05 \\ -5.7E-06 \end{bmatrix} + \begin{bmatrix} \mathbf{0.1003}^{***} & \mathbf{0.0252}^{*} & \mathbf{0.0450}^{***} \\ \mathbf{0.1049}^{***} & \mathbf{0.0742}^{***} & \mathbf{0.1083}^{***} \\ 0.0597 & \mathbf{0.1155}^{***} & \mathbf{0.2781}^{***} \end{bmatrix} \begin{bmatrix} \mathrm{R_{low,t-1}} \\ \mathrm{R_{high,t-1}} \\ \mathrm{R_{gov,t-1}} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\mathrm{low,t}} \\ \varepsilon_{\mathrm{high,t}} \\ \varepsilon_{\mathrm{gov,t}} \end{bmatrix}$$

Regarding to the hypothesis estimation that there are return spillovers effects among different credit level of fixed income securities. The empirical results show that there are significant return spillover effects for low credit rating, high credit rating as well as government rating depend on their own past values, as indicated by estimated coefficients β_{11}, β_{22} and β_{33} and significant at 1%.

The causality patterns are described as follows; the low credit rating level of lagged time has significant spillover effects to high credit rating level in 1% significance level. In contrast, high credit rating level of lagged time also has significant return spillover effects to low credit rating level in 10% level of significance. This pair between low credit rating level and high credit rating level is significant spillover effects, however the direction of causality pattern are unable to be identified. The related empirical results show that there are significant return spillover effects from government credit rating level of lagged time to low credit rating level at time t with 1% level, in contrast that there are significant no evidence of return spillover effects from low credit rating level of lagged time to government credit rating level. This causality pattern is able to show that government credit rating level leads spillover to low credit rating level. In other words, this empirical pair of results shows that low risk preferences are lead high risk preferences regarding to risk characteristics. The empirical results show that there are significant spillover effects evidence between high credit rating level and government credit rating level, however the direction of causality pattern are also unable to be identified.

In summary for credit rating level, this paper conclude the lead lag relationship in the direction that there are government credit rating level has lead low credit rating level. This result is consistent with the hypothesis in the way that government rating level is prior response to corporate rating level. In other words, government bond has prior response to corporate bond.

Table 17: Results of multivariate GARCH(1,1) for volatility spillovers among level of credit rating for daily government and daily corporate bond market.

Independent Variables	$h_{11,t}$		$h_{22,t}$		$h_{33,t}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0088***	0.0000	0.0042***	0.0000	0.0207***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0122***	0.0000	0.0059***	0.0000	0.0288***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0269***	0.0000	0.0130***	0.0000	0.0637***	0.0000
$\varepsilon^2_{2,t-1}$	0.0042***	0.0000	0.0020***	0.0000	0.0100***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0187***	0.0000	0.0090***	0.0000	0.0442***	0.0000
$\varepsilon^2_{3,t-1}$	0.0207***	0.0000	0.0100***	0.0000	0.0490***	0.0000
$h_{11,t-1}$	0.7826***	0.0000	0.8367***	0.0000	0.6658***	0.0000
$h_{12,t-1}$	1.6183***	0.0000	1.7302***	0.0000	1.3769***	0.0000
$h_{13,t-1}$	1.4437***	0.0000	1.5435***	0.0000	1.2283***	0.0000
$h_{22,t-1}$	0.8367***	0.0000	0.8945***	0.0000	0.7118***	0.0000
$h_{23,t-1}$	1.4928***	0.0000	1.5959***	0.0000	1.2700***	0.0000
$h_{33,t-1}$	0.6658***	0.0000	0.7118***	0.0000	0.5665***	0.0000

Notes: h_{11} denotes the conditional variance for low credit rating gross price index return series, h_{22} is the conditional variance for high credit rating gross price index return series, and h_{33} is the conditional variance for government credit rating gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Test of the hypothesis regarding to volatility spillovers among credit rating level of government and corporate bond suggest that for low credit rating level, the result shows that low and high credit rating level and government bond of lagged time have significant volatility spillover to low credit rating of corporate bond. And low credit rating level also has directly significant volatility spillover from its own past volatility persistent.

For high credit rating level, the result shows that low and high credit rating level and government bond of lagged time have significant volatility spillover to high credit rating level of corporate bond. And high credit rating level also has directly significant volatility spillover from its own past volatility persistent.

For government bond, the results show that low and high credit rating level and government of lagged time have significant volatility spillover to government bond. Lastly, government bond also has directly significant volatility spillover from its own past volatility persistent.

In summary, there are significant spillover effects of news and volatility spillover effects among government and corporate bond in each level of credit rating. The result consistent with hypothesis in the way that when the policy makers implement the government bond, this government bond has evidence of spillover effects to the corporate bond.

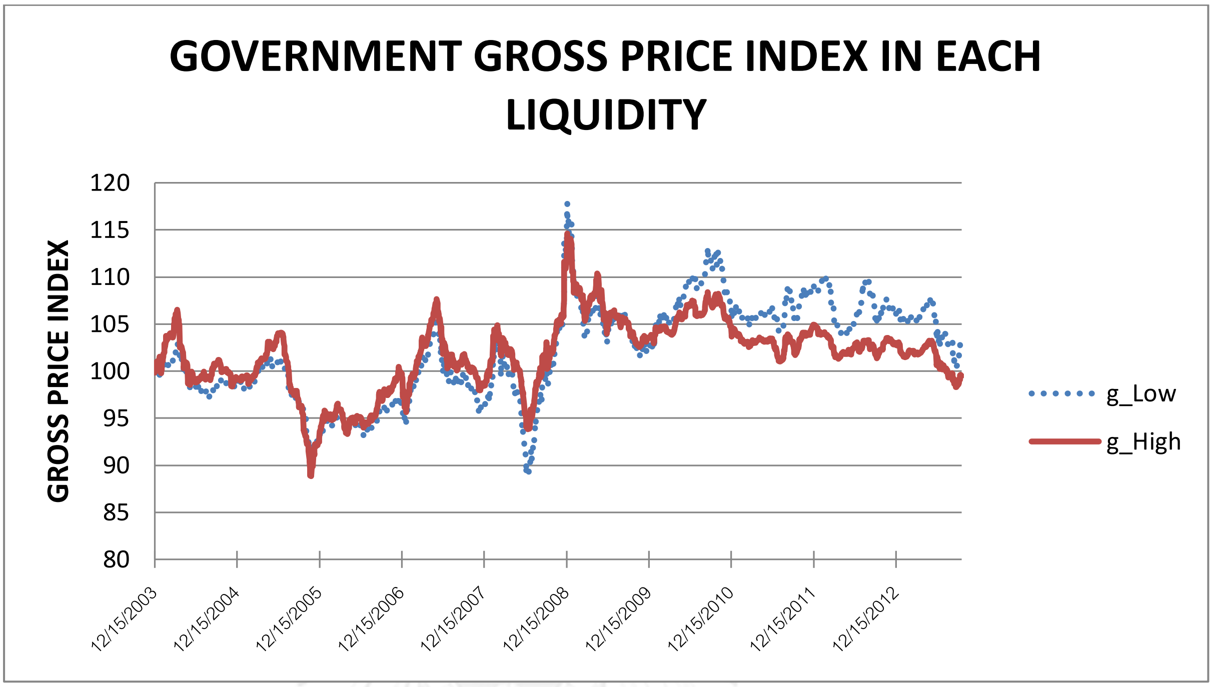
However, the testing of weekly bond returns among level of credit rating, the results are the same pattern with spillovers among level of time to maturity. Even though there are less evidence of significant return spillover effects, there still exists in volatility spillovers. The results show that there are significant return spillovers from government credit rating to high credit rating of corporate bond. The empirical results are reported in Table 36 and Table 37 in Appendix.

4.3 Liquidity Spillover Effects

Index Calculation on level of liquidity of government bond

Regarding to the gross price index that contribute to the research, this paper creates the line graph of gross price index during the period of January 2002 to September 2013. This paper separates each line as a gross price index on the liquidity characteristic of government bond; high liquidity and low liquidity.

Figure 13: The graph represents the gross price index of government bond in level of liquidity during the period of January 2002 to September 2013



From the graph, this can be shown that the gross price of high liquidity exhibits higher volatile than gross price index of low liquidity. The index point starts from 100 in December 2003 and the endpoint finish in September 2013.

Figure 14: The graph represents low level of liquidity of government gross price index return during the sample period of December 2003 to September 2013

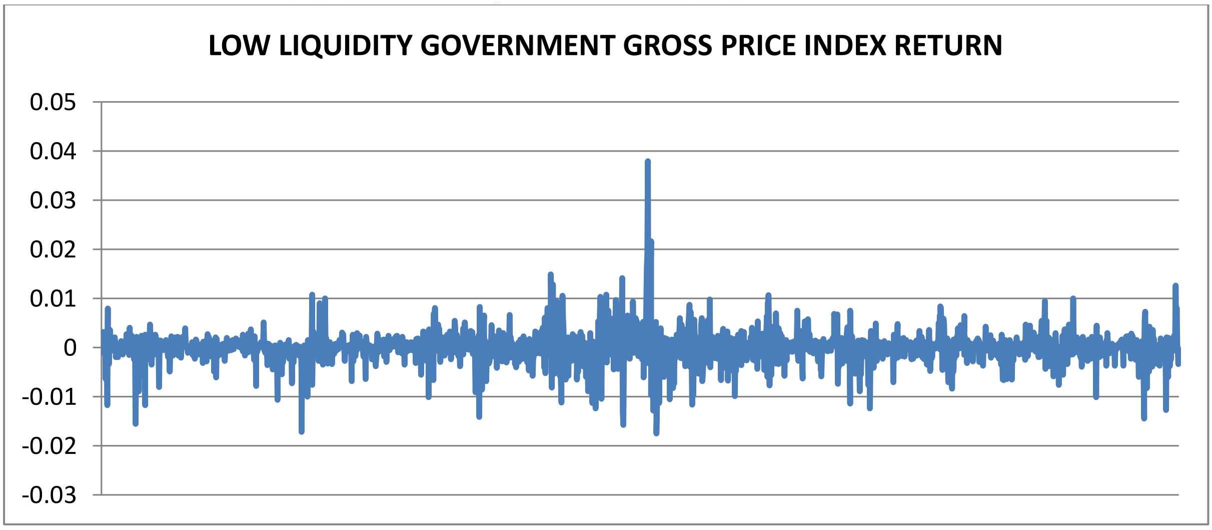
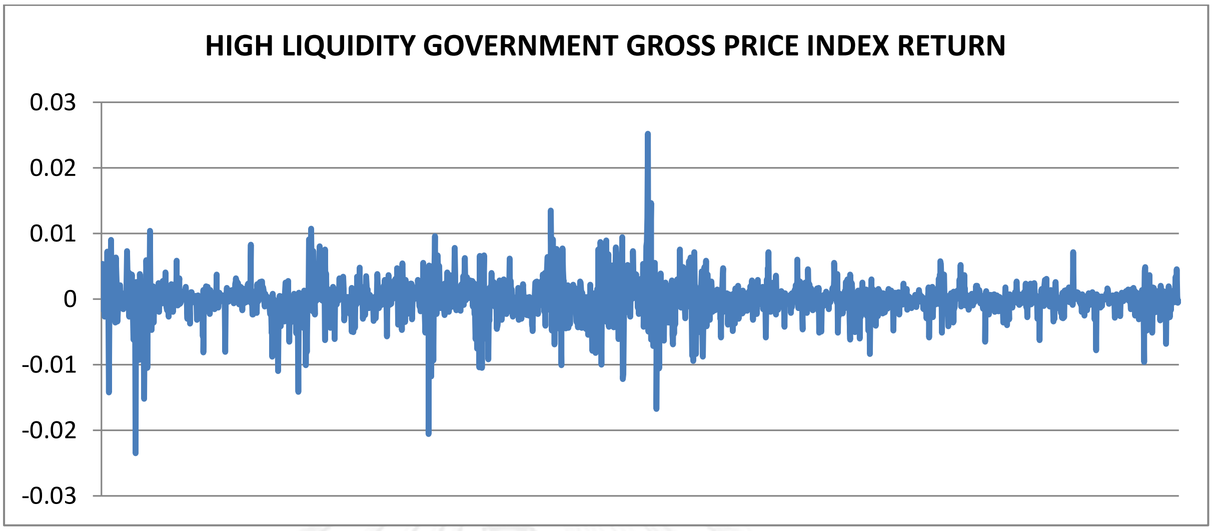


Figure 15: The graph represents high level of liquidity of government gross price index return during the sample period of December 2003 to September 2013



Regarding to Figure 14-15 above, the graphs show the government gross price index return in all levels of liquidity, the data series exhibits the time varying variance during the sample period of December 2003 to September 2013. Hence, this figure of time varying variance nature of gross price index return motivates us to employ GARCH model in this paper.

Table 18 and 19 presents the summary statistic and correlation matrix among levels of liquidity for government bond.

Table 18: Summary statistic of gross price bond return among levels of liquidity for government bond.

	LOW LIQUIDITY	HIGH LIQUIDITY
Mean	0.0016%	0.0001%
Median	0.0132%	0.0115%
Maximum	3.7984%	2.5198%
Minimum	-1.7445%	-2.3535%
Std. Dev.	0.3013%	0.2630%
Skewness	0.612	-0.534
Kurtosis	19.896	15.355
Observations	2425	2425

The numbers from the summary statistic shows that low liquidity has higher return than high liquidity of government bond as shown in mean and median. The returns are consistent with risk preference that higher risk has higher return as shown in the standard deviation.

Table 19: Correlation matrix of gross price bond return among levels of liquidity for government bond.

	LOW LIQUIDITY	HIGH LIQUIDITY
LOW LIQUIDITY	1.000	0.743
HIGH LIQUIDITY	0.743	1.000

The correlation between low liquidity and high liquidity can be considered highly correlated as shown in the table.

For the weekly gross price index return data among liquidity level, the results are also consistent with daily data in the pattern that low liquidity has value more than high liquidity as presented in mean, median as well as standard deviation. The correlation matrix of weekly gross price index return bond among low and high liquidity are higher than the correlation of daily gross price index return bond. These numbers are reported in Table 38 and Table 39 in Appendix.

4.3.1 Return and Volatility Spillovers in government bond market

This section investigates the spillover effects of low liquidity and high liquidity of government bond. The maximum likelihood estimates of the multivariate GARCH(1,1) model for characteristic of liquidity in Thai government bond market are reported in table 20 and 21. Table 20 depicts that the estimated coefficients provide evidence of return spillovers as well as table 21 presents the volatility spillovers among liquidity of government bond.

Table 20: Results of multivariate GARCH(1,1) for return spillovers among level of liquidity for government bond market.

	Coefficient	Std. Error	z-Statistic	Prob.
$\boldsymbol{c_1}$	-3.6E-05*	0.0000	-1.7563	0.0790
$\boldsymbol{\beta_{11}}$	**-0.5148*****	**0.0244**	**-21.1319**	**0.0000**
$\boldsymbol{\beta_{12}}$	**0.3403*****	**0.0133**	**25.5806**	**0.0000**
c_2	0.0001	0.0001	0.9160	0.3597
β_{21}	-4.6E-05	0.0028	-0.0164	0.9869
$\boldsymbol{\beta_{22}}$	**0.1549*****	**0.0188**	**8.2423**	**0.0000**

Notes: Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

$$\mathrm{R_t} = \begin{bmatrix} \mathrm{R_{low,t}} \\ \mathrm{R_{high,t}} \end{bmatrix} = \begin{bmatrix} \mathbf{0.00003}^{***} \\ 0.00005 \end{bmatrix} + \begin{bmatrix} \mathbf{0.5148}^{***} & \mathbf{0.340}^{***} \\ 0.00004 & \mathbf{0.154}^{***} \end{bmatrix} \begin{bmatrix} \mathrm{R_{low,t-1}} \\ \mathrm{R_{high,t-1}} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\mathrm{low,t}} \\ \varepsilon_{\mathrm{high,t}} \end{bmatrix}$$

Regarding to the hypothesis development that there are return spillover effects among levels of liquidity in government bond in Thailand, the empirical results show that low liquidity and high liquidity have significant return spillover effects with their own past values as measured by the estimated coefficients $\beta_{11} and\ \beta_{22}$. Moreover the empirical results also show that there are significant return spillover effects from high liquidity of lagged time to low liquidity at time t with at 1% level. In contrast, there are no significant return spillover effects from low liquidity of lagged time to high liquidity at time t. These results mean that the high liquidity has lead low liquidity, this result has consistent with the hypothesis estimation.

Summarizing that high liquidity leads low liquidity in terms of lead lag relationship. This result is consistent with Huth and Abergel (2014) they confirm that in French stock markets, the most liquid asset tend to lead illiquid, because illiquidity asset would take more period of time to adjust the price from the information, and they construct a liquidity measures by using short duration and bid-ask spread.

Table 21: Results of multivariate GARCH(1,1) for volatility spillovers among level of liquidity for government bond market.

Independent Variables	$h_{11,t}$		$h_{22,t}$	
	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0054***	0.0000	0.0055***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0109***	0.0000	0.0113***	0.0000
$\varepsilon^2_{2,t-1}$	0.0055***	0.0000	0.0058***	0.0000
$h_{11,t-1}$	0.8077***	0.0000	0.8109***	0.0000
$h_{12,t-1}$	1.6186***	0.0000	1.6250***	0.0000
$h_{22,t-1}$	0.8141***	0.0000	0.8141***	0.0000

Notes: h_{11} denotes the conditional variance for low liquidity gross price index return series, and h_{22} is the conditional variance for high liquidity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significant at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Test of the hypothesis regarding to volatility spillovers among liquidity levels of government bond, suggest for low liquidity level, the result show that low and high liquidity of lagged time have significant volatility spillover to low liquidity of government bond. And low liquidity also has directly significant volatility spillover from its own past volatility persistent.

For high level of liquidity, the results show that there are significant volatility spillover effects from both low and high levels of liquidity of lagged time to high level of liquidity. Lastly, high liquidity also has directly significant volatility spillover from its own past volatility persistent.

The results are consistent with the hypothesis in the way that there are return and volatility spillovers among level of liquidity. The outcome shows that investors would rebalance their portfolios in high liquidity prior to low liquidity in their portfolio investments.

Turning to weekly of government bond return on each level of liquidity, particularly on return spillover effects, the results show that there are no evidences of return spillovers among levels of liquidity. However, the volatility spillovers of weekly data are still exists of in the same pattern of daily data, the results are reported in Table 40 and Table 41 in Appendix.

CHAPTER 5

Conclusion

This paper studied the spillover transmission on characteristic of fixed income securities in Thai bond market. The analysis comprises tests of spillover effects in terms of return and volatility spillovers transmissions among sub - classes of bond markets. The sub-class of bond markets namely, time to maturity, credit rating as well as liquidity. We divide time to maturity into 3 levels: short time to maturity, medium time to maturity as well as long time to maturity. Secondly, credit ratings are low credit rating and high credit rating of corporate bond including government credit rating level. Lastly, liquidity, we divide into level of low and high liquidity of government bonds. The sample period of the data starts from December 2003 to September 2013 for the spillover testing. We employ multivariate GARCH(1,1) to measure spillover effects in terms of return and volatility spillovers. We mainly focus on daily return data, however; weekly return data are also tested in this paper.

The results of this study show that there are significant evidences of daily return and volatility spillovers effects among level of time to maturity of government bond particularly the effects by own past values. And there are volatility spillovers effects among time to maturity characteristics. Furthermore, in particular of government bond, this paper provides the evidence that short time to maturity is a leader among all levels of time to maturity. However, for corporate bond, this paper provides the evidence in contradict from government bond in the way that medium time to maturity leads short time to maturity and also leads long time to maturity. However, weekly data of government bond return show that there are no evidence of return spillover effects, but exists the significant in volatility spillovers.

For credit rating of government and corporate bond, this paper can conclude from the empirical results that government credit rating leads low credit rating. This outcome might come from the risk preferences as low risk securities have an ability to influence high risk securities under the same condition. However, there is also significant evidences respect to volatility spillover effects among low credit rating, high credit rating and government credit rating. In addition to weekly data spillovers, the empirical results show less evidences of return spillovers, but exists only government credit rating spillovers to high credit rating of corporate bond. Besides, weekly data also has the same manner of daily data in terms of volatility spillovers.

Lastly, in the perspective of liquidity, this paper summarizing that high liquidity leads low liquidity in terms of return spillovers. Besides, there are significant evidences volatility spillovers among both low and high liquidity. In addition to weekly data, the empirical results are not able to capture any return spillovers, but there exists significant volatility spillovers in the same pattern of daily bond data.

Summarizing that, daily data of bond presents more evidence in terms of return and volatility spillover effects than weekly data of bond.

This paper contributes to the financial department relevant to portfolio managers and regulators to continue to analyze the impact spillovers among characteristic of bond market in Thailand. This study provides important information to regulators about the role of time to maturity, credit ratings and liquidity characteristic in financial measurement in perspective of return and volatility spillovers among others as well as to investors in order to rebalancing their portfolios as a cost of capital for financial investments.

The investigation of the spillovers effects among characteristics of fixed income securities for example, type of coupon rate, Macaulay duration and option embedded bonds etc. or the impacts among countries could leave in providing the spillover effects for future research.

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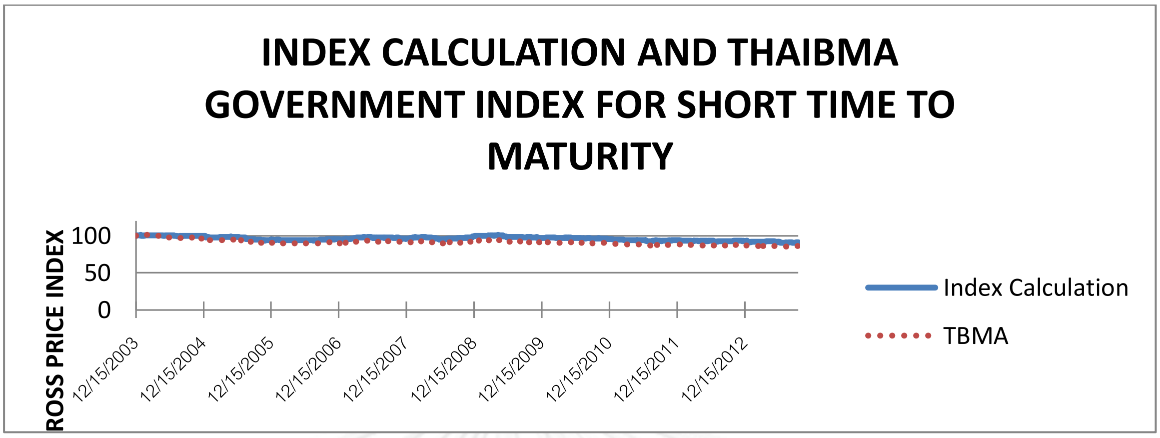
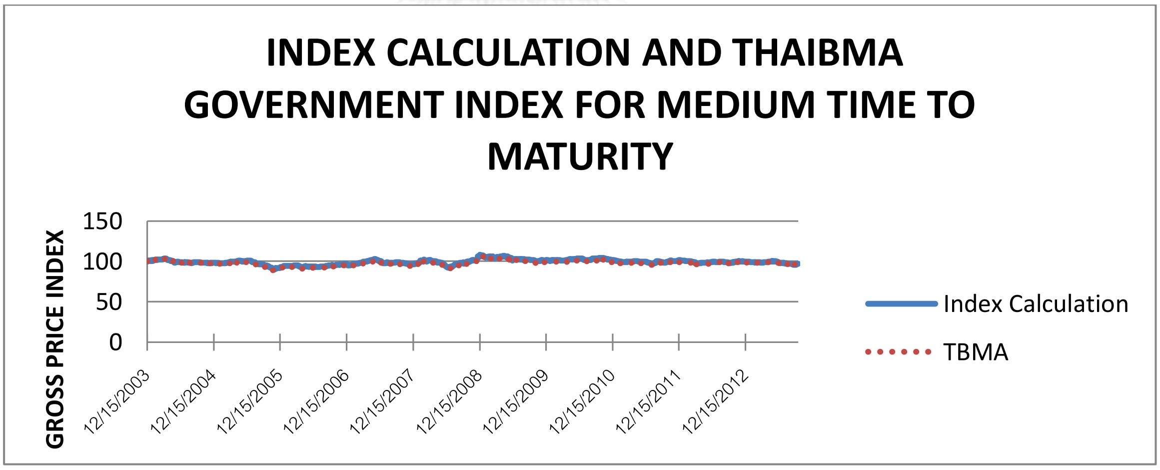
APPENDIX

Figure 16: Index Calculation and ThaiBMA index for short time to maturity



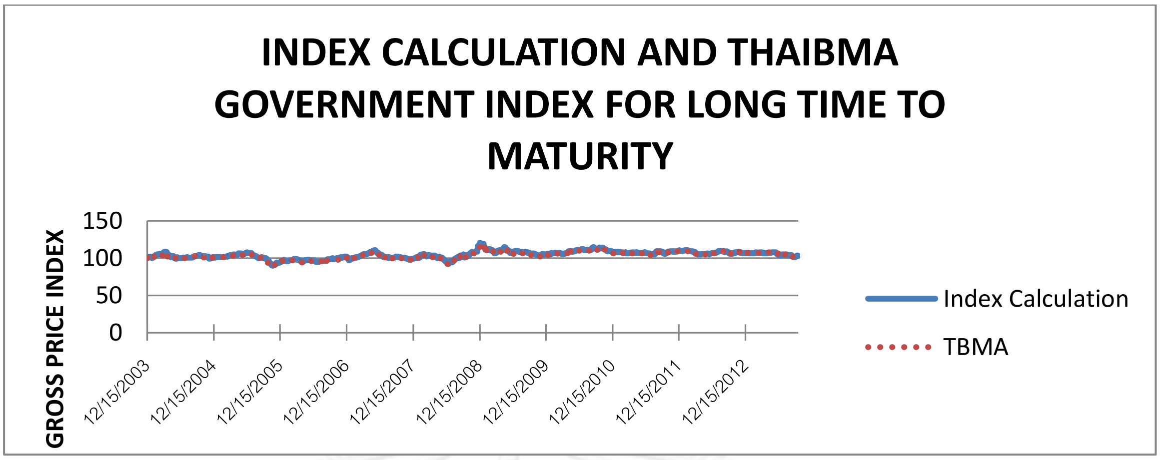
Correlation Matrix	*Index Calculation*	*TBMA*
Index Calculation	1	
TBMA	0.913571749	1

Figure 17: Index Calculation and ThaiBMA index for medium time to maturity



Correlation Matrix	*Index Calculation*	*TBMA*
Index Calculation	1	
TBMA	0.972093514	1

Figure 18: Index Calculation and ThaiBMA index for long time to maturity



Correlation Matrix	*Index Calculation*	*TBMA*
Index Calculation	1	
TBMA	0.991236088	1

Test AIC, SC,HQ

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

Table 22: Test of AIC, SC and HQ

Panel A

	Government Bond			Corporate bond		
Lag	AIC	SC	HQ	AIC	SC	HQ
1	-28.812	**-28.790**	**-28.804**	-31.848	**-31.826**	**-31.840**
2	-28.813	-28.770	-28.797	-31.852	-31.809	-31.837
3	-28.811	-28.746	-28.787	-31.850	-31.785	-31.827
4	-28.813	-28.727	-28.782	-31.845	-31.759	-31.814
5	**-28.815**	-28.707	-28.775	**-31.855**	-31.748	-31.816
6	-28.812	-28.683	-28.765	-31.851	-31.722	-31.804
7	-28.814	-28.663	-28.759	-31.853	-31.702	-31.798
8	-28.815	-28.643	-28.752	-31.850	-31.678	-31.788

Panel B

	Credit Rating			Liquidity		
Lag	AIC	SC	HQ	AIC	SC	HQ
1	-32.129	**-32.108**	**-32.123**	-18.703	**-18.693**	**-18.699**
2	**-32.139**	-32.096	-32.121	-18.706	-18.686	-18.699
3	-32.138	-32.074	-32.115	-18.706	-18.678	-18.696
4	-32.135	-32.049	-32.104	-18.705	-18.667	-18.691
5	-32.139	-32.031	-32.100	-18.706	-18.658	-18.688
6	-32.137	-32.007	-32.090	-18.708	-18.651	-18.687
7	-32.137	-31.986	-32.082	**-18.712**	-18.645	-18.687
8	-32.139	-31.966	-32.076	-18.710	-18.633	-18.682

Test Correlogram for daily return bond market

H_0 : no autocorrealtion correlation

H_a : has autocorrelation correlation

Table 23: Test correlogram

Panel A

	Government Bond			Corporate bond		
	Short	Medium	Long	Short	Medium	Long
Lag	Prob	Prob	Prob	Prob	Prob	Prob
1	0.970	0.941	0.944	0.876	0.974	0.982
2	0.990	0.897	0.961	0.811	0.871	0.974
3	0.901	0.750	0.992	0.347	0.309	0.619
4	0.870	0.865	0.976	0.372	0.342	0.626
5	0.908	0.884	0.978	0.156	0.455	0.661
6	0.908	0.555	0.947	0.225	0.581	0.776
7	0.935	0.595	0.789	0.108	0.271	0.508
8	0.943	0.344	0.857	0.160	0.166	0.440
9	0.969	0.438	0.716	0.185	0.130	0.002
10	0.976	0.493	0.735	0.071	0.090	0.003

Panel B

	Credit Rating			Liquidity	
	Low raing	High rating	All government	Low	High
Lag	Prob	Prob	Prob	Prob	Prob
1	0.931	0.953	0.946	0.899	0.977
2	0.881	0.817	0.950	0.868	1.000
3	0.418	0.855	0.858	0.800	0.959
4	0.130	0.901	0.636	0.212	0.974
5	0.203	0.953	0.468	0.311	0.989
6	0.271	0.961	0.376	0.423	0.166
7	0.038	0.250	0.212	0.225	0.102
8	0.016	0.120	0.196	0.108	0.022
9	0.022	0.010	0.029	0.001	0.033
10	0.036	0.001	0.043	0.002	0.036

Akaike info criterion for tested model

Table 24: The table of AIC value in each number of lagged ARCH and GARCH terms for government bond in time to maturity characteristics

Panel A

		ARCH			
	lag	0	1	2	3
GARCH	0	N/A	-22.027	-28.919	-28.937
	1	-28.813	**-29.096**	-29.093	-29.086
	2	-28.803	-29.091	-29.086	-29.082

Panel B : The table of AIC value in each number of lagged ARCH and GARCH terms for corporate bond in time to maturity characteristics

		ARCH			
	Lag	0	1	2	3
GARCH	0	N/A	-30.942	-31.065	-31.962
	1	-31.911	-32.433	**-32.436**	-32.435
	2	-31.835	-32.409	-32.404	-32.399

Panel C : The table of AIC value in each number of lagged ARCH and GARCH terms for government and corporate bond in different credit rating characteristics

		ARCH			
	Lag	0	1	2	3
GARCH	0	N/A	-31.521	-31.835	-31.964
	1	-32.123	**-32.338**	-32.335	-32.333
	2	-32.120	-32.335	-32.333	-32.332

Panel D : The table of AIC value in each number of lagged ARCH and GARCH terms for government bond in different liquidity characteristics

		ARCH			
	Lag	0	1	2	3
GARCH	0	N/A	-18.953	-19.003	-19.062
	1	-18.742	**-19.301**	-19.281	-19.268
	2	-18.755	-19.180	-19.269	-19.265

Test Unit root test for weekly return bond market

H_0: $\rho = 0$ (non-stationary)

Ha: $\rho < 0$ (stationary)

Table 25: Unit root test for stationary and non-stationary process for weekly of all serie data

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Remark
G_SHORT	-0.98122	0.044981	-21.8142	0	Stationary
G_MID	-0.65485	0.056002	-11.6933	0	Stationary
G_LONG	-0.702	0.058526	-11.9948	0	Stationary
C_SHORT	-0.78667	0.043958	-17.896	0	Stationary
C_MID	-0.66446	0.056688	-11.7214	0	Stationary
C_LONG	-0.76593	0.059411	-12.8921	0	Stationary
C_LOW	-0.80841	0.044142	-18.314	0	Stationary
C_HIGH	-0.65515	0.056435	-11.609	0	Stationary
G_TOTAL	-0.66775	0.055065	-12.1266	0	Stationary
G_LOW	-0.64932	0.056348	-11.5235	0	Stationary
G_HIGH	-0.68229	0.056587	-12.0574	0	Stationary

Test Correlogram for weekly return bond market

H_0 : no autocorrealtion correlation

H_a : has autocorrelation correlation

Table 26: Test correlogram

Panel A

	Government Bond			Corporate bond		
	Short	Medium	Long	Short	Medium	Long
Lag	Prob	Prob	Prob	Prob	Prob	Prob
1	0.895	0.951	0.712	0.957	0.983	0.912
2	0.966	0.976	0.726	0.965	1.000	0.908
3	0.925	0.959	0.338	0.980	0.959	0.921
4	0.188	0.972	0.074	0.834	0.911	0.054
5	0.065	0.985	0.120	0.908	0.959	0.090
6	0.108	0.988	0.142	0.946	0.959	0.139
7	0.165	0.993	0.175	0.888	0.941	0.183
8	0.233	0.997	0.247	0.936	0.969	0.234
9	0.281	0.999	0.314	0.521	0.832	0.291
10	0.264	1.000	0.363	0.592	0.807	0.296

Panel B

	Credit Rating			Liquidity	
	Low raing	High rating	All government	Low	High
Lag	Prob	Prob	Prob	Prob	Prob
1	0.962	0.973	0.824	0.914	0.983
2	0.999	0.968	0.889	0.957	0.990
3	0.971	0.988	0.963	0.970	0.970
4	0.711	0.586	0.677	0.880	0.760
5	0.830	0.608	0.706	0.946	0.825
6	0.771	0.431	0.720	0.945	0.822
7	0.707	0.424	0.522	0.858	0.799
8	0.781	0.485	0.506	0.881	0.849
9	0.688	0.398	0.527	0.744	0.655
10	0.668	0.452	0.495	0.738	0.732

Lagrange Multiplier for test number of lagged in ARCH model

H_0 = no serial correlation

H_a = serial correlation

Table 27: LM Test

	Government Time to maturity		Corporate Time to maturity		Credit rating		Liquidity	
Lags	LM-Stat	Prob	LM-Stat	Prob	LM-Stat	Prob	LM-Stat	Prob
1	27.362	0.001	36.997	0.000	42.563	0.000	14.883	0.005
2	38.466	0.000	23.967	0.004	34.870	0.000	20.394	0.000
3	18.525	0.030	22.563	0.007	**14.070**	**0.120**	**2.222**	**0.695**
4	20.160	0.017	33.284	0.000	15.665	0.074	4.128	0.389
5	**9.288**	**0.411**	**6.039**	**0.736**	13.687	0.134	8.628	0.071
6	10.611	0.303	4.005	0.911	27.665	0.001	8.459	0.076
7	4.861	0.846	14.369	0.110	11.852	0.222	4.133	0.388
8	4.721	0.858	17.662	0.039	22.579	0.007	0.613	0.962

Table 28: Summary statistics of weekly gross bond return for government and corporate bond

	Government bond			Corporate bond		
	SHORT	MEDIUM	LONG	SHORT	MEDIUM	LONG
Mean	-0.0242%	-0.0051%	0.0118%	0.0002%	0.0205%	0.0254%
Median	0.0371%	0.0326%	0.0471%	0.0047%	0.0362%	0.0993%
Maximum	1.7081%	3.4311%	6.3240%	1.0460%	2.7622%	6.0889%
Minimum	-2.4700%	-2.0988%	-3.6346%	-0.7932%	-1.8887%	-4.7890%
Std. Dev.	0.0036	0.0055	0.0095	0.0017	0.0040	0.0094
Skewness	-2.3292	0.2905	0.2884	-0.0522	0.0991	0.4813
Kurtosis	15.46	6.83	7.66	8.75	10.10	10.33
Observations	498	498	498	498	498	498

Table 29: Correlation matrix of weekly gross bond return for government and corporate bond

	Government bond			Corporate bond		
	SHORT	MEDIUM	LONG	SHORT	MEDIUM	LONG
SHORT	1.000	0.406	0.329	1.000	0.797	0.581
MEDIUM	0.406	1.000	0.822	0.797	1.000	0.782
LONG	0.329	0.822	1.000	0.581	0.782	1.000

Table 30: Results of multivariate GARCH(1,1) for return spillovers in different maturity on weekly government bond market

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	0.0000	0.0001	-0.4312	0.6663
β_{11}	0.0888	0.0829	1.0714	0.2840
β_{12}	0.0300	0.0422	0.7116	0.4767
β_{13}	0.0152	0.0129	1.1739	0.2404
c_2	0.0002	0.0002	1.2216	0.2218
β_{21}	0.2629	0.1699	1.5468	0.1219
β_{22}	0.0629	0.0897	0.7012	0.4831
β_{23}	0.0198	0.0250	0.7924	0.4281
c_3	0.0003	0.0004	0.8818	0.3779
β_{31}	-0.1108	0.3769	-0.2940	0.7688
β_{32}	0.1662	0.2134	0.7787	0.4362
β_{33}	0.0668	0.0678	0.9852	0.3245

Notes: Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 31: Results of multivariate GARCH(1,1) for volatility spillovers in different maturity on weekly government bond market

Independent Variables	$h_{11,t}$		$h_{22,t}$		$h_{33,t}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0005***	0.0000	0.0006***	0.0000	0.0004***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0006***	0.0000	0.0008***	0.0000	0.0007***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0005***	0.0000	0.0009***	0.0000	0.0009***	0.0000
$\varepsilon^2_{2,t-1}$	0.0006***	0.0000	0.0011***	0.0000	0.0012***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0005***	0.0000	0.0012***	0.0000	0.0016***	0.0000
$\varepsilon^2_{3,t-1}$	0.0004***	0.0000	0.0012***	0.0000	0.0020***	0.0000
$h_{11,t-1}$	0.9214***	0.0000	0.8939***	0.0000	0.8725***	0.0000
$h_{12,t-1}$	0.9075***	0.0000	0.8808***	0.0000	0.8588***	0.0000
$h_{13,t-1}$	0.8966***	0.0000	0.8693***	0.0000	0.8500***	0.0000
$h_{22,t-1}$	0.8939***	0.0000	0.8679***	0.0000	0.8454***	0.0000
$h_{23,t-1}$	0.8831***	0.0000	0.8566***	0.0000	0.8367***	0.0000
$h_{33,t-1}$	0.8725***	0.0000	0.8454***	0.0000	0.8280***	0.0000

Notes: h_{11} denotes the conditional variance for short time to maturity gross price index return series, h_{22} is the conditional variance for medium time to maturity gross price index return series, and h_{33} is the conditional variance for long time to maturity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 32: Results of multivariate GARCH(1,1) for return spillovers in different maturity on weekly corporate bond market

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	-0.0002	0.0002	-0.8508	0.3957
β_{11}	-0.0194	0.0834	-0.2324	0.8162
β_{12}	0.0801	0.0658	1.2168	0.2237
β_{13}	-0.0178	0.0365	-0.4868	0.6264
c_2	0.0001	0.0002	0.5256	0.5999
β_{21}	0.2433	0.3763	1.5468	0.1219
β_{22}	0.2480	0.3030	1.2216	0.2218
β_{23}	-0.0441	0.0391	-1.1264	0.2600
c_3	0.0002	0.0003	0.6744	0.5011
$\boldsymbol{\beta_{31}}$	**0.1798***	**0.1019**	**1.7652**	**0.0775**
$\boldsymbol{\beta_{32}}$	**0.4454*****	**0.1157**	**3.8496**	**0.0001**
β_{33}	-0.0475	0.0755	-0.6290	0.5293

Notes: Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 33: Results of multivariate GARCH(1,1) for volatility spillovers in different maturity on weekly corporate bond market

Independent Variables	$h_{11,t}$		$h_{22,t}$		$h_{33,t}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0000	0.9892	0.0001	0.9264	0.0001	0.9450
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0000	0.9718	0.0009	0.2314	0.0007	0.2630
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0000	0.9757	0.0008	0.1951	0.0007	0.2898
$\varepsilon^2_{2,t-1}$	0.0001	0.9264	0.0110***	0.0000	0.0080***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0001	0.9364	0.0094***	0.0000	0.0085***	0.0000
$\varepsilon^2_{3,t-1}$	0.0001	0.9450	0.0080***	0.0000	0.0091***	0.0000
$h_{11,t-1}$	0.8039***	0.0000	0.7009***	0.0052	0.7349***	0.0011
$h_{12,t-1}$	0.7506***	0.0000	0.6544***	0.0000	0.6862***	0.0000
$h_{13,t-1}$	0.7686***	0.0000	0.6701***	0.0000	0.7026***	0.0000
$h_{22,t-1}$	0.7009***	0.0052	0.6110***	0.0000	0.6407***	0.0000
$h_{23,t-1}$	0.7177***	0.0025	0.6257***	0.0000	0.6561***	0.0000
$h_{33,t-1}$	0.7349***	0.0011	0.6407***	0.0000	0.6718***	0.0000

Notes: h_{11} denotes the conditional variance for short time to maturity gross price index return series, h_{22} is the conditional variance for medium time to maturity gross price index return series, and h_{33} is the conditional variance for long time to maturity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 34: Summary statistic of weekly gross bond return for government and corporate bond

	LOW CREDIT	HIGH CREDIT	GOVERNMENT
Mean	0.0116%	0.0092%	-0.0016%
Median	0.0172%	0.0419%	0.0158%
Maximum	1.6218%	3.3372%	4.9826%
Minimum	-1.2127%	-1.9751%	-2.1866%
Std. Dev.	0.0024	0.0042	0.0064
Skewness	-0.0466	0.5304	0.7120
Kurtosis	9.24	12.27	10.57
Observations	498	498	498

Table 35: Correlation matrix of weekly gross bond return for government and corporate bond

	LOW CREDIT	HIGH CREDIT	GOVERNMENT
LOW CREDIT	1.000	0.801	0.674
HIGH CREDIT	0.801	1.000	0.768
GOVERNMENT	0.674	0.768	1.000

Table 36: Results of multivariate GARCH(1,1) for return spillovers among level of credit rating for weekly government and weekly corporate bond market.

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	0.0001	0.0001	0.5763	0.5644
β_{11}	0.0599	0.0692	0.8649	0.3871
β_{12}	0.0038	0.0471	0.0813	0.9352
β_{13}	0.0718	0.0222	3.2328	0.0012
c_2	0.0000	0.0001	0.1166	0.9072
β_{21}	-0.1338	0.1032	-1.2961	0.1949
β_{22}	0.0678	0.0849	0.7985	0.4246
$\boldsymbol{\beta_{23}}$	**0.1710*** **	**0.0384**	**4.4497**	**0.0000**
c_3	0.0000	0.0002	-0.0531	0.9576
β_{31}	-0.0675	0.1681	-0.4017	0.6879
β_{32}	-0.0710	0.1289	-0.5509	0.5817
$\boldsymbol{\beta_{33}}$	**0.2954*** **	**0.0618**	**4.7785**	**0.0000**

Notes: Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 37: Results of multivariate GARCH(1,1) for volatility spillovers among level of credit rating for weekly government and weekly corporate bond market.

Independent Variables	$\mathbf{h_{11,t}}$		$\mathbf{h_{22,t}}$		$\mathbf{h_{33,t}}$	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
$\varepsilon^2_{1,t-1}$	0.0015***	0.0000	0.0027***	0.0000	0.0034***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{2,t-1}$	0.0020***	0.0000	0.0038***	0.0000	0.0048***	0.0000
$\varepsilon_{1,t-1}\varepsilon_{3,t-1}$	0.0023***	0.0000	0.0043***	0.0000	0.0057***	0.0000
$\varepsilon^2_{2,t-1}$	0.0027***	0.0000	0.0054***	0.0000	0.0067***	0.0000
$\varepsilon_{2,t-1}\varepsilon_{3,t-1}$	0.0030***	0.0000	0.0060***	0.0000	0.0080***	0.0000
$\varepsilon^2_{3,t-1}$	0.0034***	0.0000	0.0067***	0.0000	0.0094***	0.0000
$\mathbf{h_{11,t-1}}$	0.8865***	0.0000	0.8525***	0.0000	0.8302***	0.0000
$\mathbf{h_{12,t-1}}$	0.8694***	0.0000	0.8386***	0.0000	0.8154***	0.0000
$\mathbf{h_{13,t-1}}$	0.8579***	0.0000	0.8263***	0.0000	0.8040***	0.0000
$\mathbf{h_{22,t-1}}$	0.8525***	0.0000	0.8249***	0.0000	0.8008***	0.0000
$\mathbf{h_{23,t-1}}$	0.8413***	0.0000	0.8128***	0.0000	0.7896***	0.0000
$\mathbf{h_{33,t-1}}$	0.8302***	0.0000	0.8008***	0.0000	0.7786***	0.0000

Notes: h_{11} denotes the conditional variance for low liquidity gross price index return series, and h_{22} is the conditional variance for high liquidity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 38: Summary statistic of gross price bond return among level of liquidity for weekly government bond.

	LOW LIQUIDITY	HIGH LIQUIDITY
Mean	0.0087%	-0.0002%
Median	0.0471%	-0.0046%
Maximum	8.4198%	5.5681%
Minimum	-3.3702%	-2.8873%
Std. Dev.	0.0082	0.0071
Skewness	1.9658	0.6447
Kurtosis	25.96	11.46
Observations	498	498

Table 39: Correlation matrix of gross price bond return among level of liquidity for weekly government bond.

	LOW LIQUIDITY	HIGH LIQUIDITY
LOW LIQUIDITY	1.000	0.872
HIGH LIQUIDITY	0.872	1.000

Table 40: Results of multivariate GARCH(1,1) for return spillovers among level of liquidity for weekly government bond market.

	Coefficient	Std. Error	z-Statistic	Prob.
c_1	-0.0001	0.0003	-0.3341	0.7383
β_{11}	0.0734	0.0718	1.0226	0.3065
β_{12}	0.1161	0.0721	1.6097	0.1075
c_2	-0.0002	0.0002	-0.9193	0.3580
β_{21}	0.0674	0.0583	1.1550	0.2481
β_{22}	0.0550	0.0699	0.7868	0.4314

Notes: Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

Table 41: Results of multivariate GARCH(1,1) for volatility spillovers among level of liquidity for government bond market.

Independent Variables	$\mathbf{h}_{11,t}$		$\mathbf{h}_{22,t}$	
	Coefficient	Prob.	Coefficient	Prob.
$\boldsymbol{\varepsilon}^2_{1,t-1}$	0.0054***	0.0000	0.0055***	0.0000
$\boldsymbol{\varepsilon}_{1,t-1}\boldsymbol{\varepsilon}_{2,t-1}$	0.0109***	0.0000	0.0113***	0.0000
$\boldsymbol{\varepsilon}^2_{2,t-1}$	0.0055***	0.0000	0.0058***	0.0000
$\mathbf{h}_{11,t-1}$	0.8077***	0.0000	0.8109***	0.0000
$\mathbf{h}_{12,t-1}$	1.6186***	0.0000	1.6250***	0.0000
$\mathbf{h}_{22,t-1}$	0.8141***	0.0000	0.8141***	0.0000

Notes: h_{11} denotes the conditional variance for low liquidity gross price index return series, and h_{22} is the conditional variance for high liquidity gross price index return series. The corresponding p-values are given next to the estimated coefficients. Statistically significance at the 1%, 5% and 10% level are marked with ***, **, and * respectively.

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