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The relationship between South African stocks and bonds volatility and US stocks volatility

Mark Comline

A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Business Administration

Johannesburg, 2009

ABSTRACT

The volatility of a share or market is used as a proxy for risk in a number of financial calculations. Volatility measures the deviation from the average value, and is therefore an estimate of how much a share or market moves up and down. It is therefore measured as the standard deviation, or the square root of the variance of a time series. Understanding time-varying volatility of the South African stock and bond market, as well as that of the US stock market, is of interest to fund managers, and can have an effect on portfolio selection.

The background to the individual markets, volatility in general, and findings of volatility of other stock and bond markets are discussed. Volatility of one market is described as having an influence on another market, through what is termed volatility transmission. Therefore a time-varying covariance between the markets can be determined, which assists in the description of the relationship between the respective markets' volatility.

This research describes the relationship between the volatility of the South African stock and bond market and the US stock market, through determination of a time-varying variance-covariance matrix of the markets. This is performed through the framework of a GARCH(1,1) model with BEKK representation for the variance-covariance matrix (Engle and Kroner 1995). Further restrictions are placed on elements of the model to allow empirical determination of causality in variance in one direction at a time, for example from stock to bond market, and from bond to stock market. The relationship is therefore determined within a framework that allows for prediction of the variance and covariance conditional on previous existing information.

Results from this research indicate that the South African stock, bond and US stock markets are highly persistent on themselves. Results further indicate that volatility is transmitted in a unidirectional manner from the South African stock market to the South African bond market. The influence of volatility transmission is seen from the volatility persistence value, or the previous days' stock market volatility, causing a negative influence on the current day's bond market variance level. There is no significant influence of the South African bond market volatility on the volatility of the stock market.

There is no evidence of a volatility relationship between the South African bond market and the US stock market. The US stock market, however, is determined to have a bidirectional volatility transmission relationship with the South African stock market. The volatility is transmitted through shocks in one market influencing the volatility of the other market, as well as through changes in the persistence of one market influencing the volatility of the other market. The US stock market is identified as the dominant partner in the relationship, as the magnitude of the volatility transmission from the US stock market to the South African stock market is larger than the volatility linkage in the opposite direction.

DECLARATION

I, Mark Comline, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Mark Comline

Signed at ……

On the …….. day of …… 2009

DEDICATION

I dedicate this report to my wife, Jenny, who has loved, supported and tolerated me throughout my studies.

ACKNOWLEDGEMENTS

Acknowledgement must be extended to Prof Mthuli Ncube, who assisted in the selection of my topic and the understanding of relevant research; as well as to my wife, family and friends who offered intellectual and emotional support throughout the research report process.

Acknowledgement should further be extended to the sources of data for this research, Datastream and Sharenet.

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CHAPTER 1: INTRODUCTION

1.1 Purpose of the study

The purpose of this research is to determine the relationship between the volatility of the South African bond market, stock market and the US stock market.

1.2 Context of the study

South Africa has separate markets on which equity and bonds are publicly traded. The JSE Securities Exchange, previously Johannesburg Stock Exchange, was established in 1987 and is the country's only equity stock exchange. It is based in Johannesburg and had a market capitalisation of ZAR4447.2 billion at the end of January 2009 (JSE 2009).

Debt securities or bonds are traded on the Bond Exchange of South Africa, which is generally referred to as BESA. BESA is an independent financial exchange, constituted as a public company. Although the Exchange officially opened in 1996, it was developed from the former Bond Market Association that was established in 1987. By the end of 2007 BESA had a total market capitalisation of ZAR862 billion (Barnes 2009).

The context of the study as being in South Africa is relevant, as the financial maturity of the market would have an impact on the risks associated with the market. South Africa is classified as an upper-middle income economy by the World Bank, which is included in the developing economies classification (The World Bank Group 2009). South Africa would be considered an emerging market, and therefore volatility experienced through this market would generally be considered to be higher than that of a first world market.

US stocks or equity are traded on a number of different stock exchanges, such has the New York Stock Exchange and the NASDAQ. The combined market capitalisation of the US stock market was approximately US$ 11373 billion at the end of 2008 (World Federation of Exchanges 2009). Therefore, at the end of 2008, the combined US stock market capitalisation was approximately 24 times larger in

US dollar terms than that of the JSE Securities Exchange. The US stock market would be considered as a first world market, and would generally be considered as lower risk than emerging markets.

Markowitz (1952) detailed the mathematics behind building a portfolio based on the overall risk-reward characteristics of the portfolio, as opposed to the risk-reward characteristics of the individual shares. Volatility has since been widely investigated as a proxy for risk. Determination of the time-varying volatility relationship between markets, as well as instances where the volatility of one market has an influence on another market, has received research attention (Engle and Kroner 1995; Caporale, Pittis and Spagnolo 2002, 2006; Fang, Lim and Lin 2006; Fang 2007). The influence of the volatility of one market on another is commonly termed volatility spillover or volatility transmission from one market to the other. As this is relevant to this research, it is discussed later in this document.

1.3 Problem statement

1.3.1 *Main problem*

The main problem is to determine the nature and size of the relationship between South African stock and bond volatility and the US stock market volatility.

1.3.2 *Sub-problems*

The first sub-problem is to determine the nature and size of the relationship the South African stock market volatility has to the South African bond market volatility.

The second sub-problem is to determine the nature and size of the relationship the South African bond market volatility has to the South African stock market volatility.

The third sub-problem is to determine the nature and size of the relationship the US stock market volatility has to the South African bond market volatility.

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1.4 Significance of the study

Fleming, Kirby and Ostdiek (1998) and Fang, Lim and Lin (2006) have studied the relationship of the volatility of domestic stock and bond markets in particular countries. Their findings suggest that the behaviour is time-varying. In the case of the USA, the relationship has become stronger through particular structural breaks in the market, such as the USA 1987 stock market crash (Fleming et al. 1998).

This study fills the gap that has not been investigated regarding the relationship between the volatility of the South African stock market, bond market and the US stock market.

This study will provide guidance to fund managers who, through better understanding of the transmission of volatility between international and domestic stocks and bonds, should be able to achieve better diversification within their portfolio. Reilly, Wright and Chan (2000) have noted that while making asset allocation decisions, portfolio managers should know both the current and historical relationship between the bond market and stock market volatility. Sharpe (1973) confirms aspects of the capital asset pricing model theory in stating that a balanced portfolio in terms of risk and reward, with both stocks and bonds according to their riskiness, provides the best prospects for the future.

Kroner and Ng (1998) describe the importance of understanding the time-varying covariance between markets by illustrating two applications. The first is in the calculation of optimal portfolio weights for particular assets in a fully invested portfolio holding that is subject to a no-shorting constraint. The risk-minimising portfolio weights are calculated using equation 1. It is assumed that the expected returns are zero in order to avoid forecasting expected returns.

(1) $$\omega_{1t} = \frac{h_{22,t} - h_{12,t}}{h_{11,t} - 2h_{12,t} + h_{22,t}}$$

where $\omega_{1t}$is the weight associated with asset 1, in a portfolio

$h_{ii,t}$ is the conditional variance of a the return of the asset, given all information at t – 1

$h_{ij,t}$ is the conditional covariance of a the return of the asset *i* and asset *j*, given all information at t – 1.

The optimal portfolio holding of asset 1, assuming a mean-variance utility function, is

(2) $$\omega_{1t}^{*} = \begin{cases} 0 & if \quad \omega_{1t} < 0 \\ \omega_{1t} & if \;\; 0 \leq \omega_{1t} \leq 1 \\ 1 & if \quad \omega_{1t} > 1 \end{cases}$$

(3) $$\omega_{2t}^{*} = 1 - \omega_{1t}^{*}$$

A second application is in the estimation of a dynamic risk-minimising hedge ratio using multivariate GARCH models. Within this application, the minimisation of a portfolio that is ZAR1 long in portfolio 1 can be achieved by shorting ZARx in portfolio 2, where the risk-minimising hedge ratio x is

(4) $$x_t^{*} = -\frac{h_{12,t}}{h_{22,t}}$$

1.5 Delimitations of the study

This research report aims to determine the relationship between the volatility of the South African stock market, bond market and US stock market, and therefore has the following delimitations:

- The data will be analysed at aggregated index level, and as such will only be relative to the market factors. Individual stock or bond analysis is excluded from this research. Particular industries within the markets are therefore also excluded from this research.
- Bonds that are over the counter, or not publicly traded, are delimited from this research.

1.6 Definition of terms

Term	Meaning	Reference
AR(1) process	Autoregressive process order 1	(Taylor 2005:36)
ARCH models	Autoregressive conditional heteroskedastic models	(Engle 1982)
BESA	Bond Exchange of South Africa	
GARCH	Generalised version of the ARCH model	(Bollerslev 1986)
JSE Securities Exchange	JSE Securities Exchange, previously Johannesburg Stock Exchange	
Second central moment	The second central moment of a random variable is another name for variance	(Taylor 2005)
Stochastic processes	A sequence of random variables arranged in time order	(Taylor 2005)
Structural break	A structural change detected in a time series sample	

The following general notation is adopted in this document:

r_{it}	The rate of return of asset i from time $t-1$ to time t
μ_{it}	The expected return of asset i given all

	information at tine $t-1$
ϵ_{it}	The unexpected return of asset i ($\epsilon_{it} = R_{it} - \mu_{it}$)
$h_{ii,t}$	The conditional variance of R_{it} given all information at time $t-1$
$h_{ij,t}$	The conditional covariance between R_{it} and R_{jt} given all information at time $t-1$
H_t	The conditional covariance matrix ($H_t = [h_{ij,t}]$
$X\|Y$	indicates that random variable X is conditional on another variable Y
$X \sim N(u, \sigma)$	indicates that the distribution of X is normal, with mean u and variance σ.

1.7 Assumptions

Due to the changing nature of the volatility of both stocks and bonds, as well as the time-varying relationship between the volatility of stocks and bonds, a key assumption in this research report is that the historical relationship of recent years is not currently changing or undergoing a structural break due to recent macroeconomic events such as the credit crunch. Therefore the assumption is that the derived relationships between the volatility of the researched markets, based on historical information, remains valid.

The assumption is reasonable in the short term, as there is insufficient information post the sub-prime crisis of 2008 in order to determine it unreasonable. The relationship that is investigated is determined from the most recent 10 years' worth of daily information, and therefore can be seen to represent the relationship over a time period of similar length.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The stock and bond markets offer investors different types of investment opportunities. The literature review introduction initially describes some differences between stocks and bonds asset classes, as well as rationale behind their different behaviour. This offers a basis for the subsequent discussions describing the volatility of these markets, and any literature relevant to a volatility relationship which may exist.

Stock markets or equity markets offer the investor and opportunity to purchase a share of the ownership or equity of a company, and therefore a share in the profitability and growth of the company.

Alternatively, bonds in their simplest form can be compared to the lending of money by the investor to a company. The investor is assured of interest payments, in the form of coupons, as well as repayment of the initial investment at the termination of the bond. Within this context, reasons for stocks and bonds being priced differently within their respective markets, as well as correlation between the markets, are now discussed.

There are several reasons why corporate bonds may diverge from prices of corporate equities, as explained by Campbell and Taksler (2003):

- Optimism over future corporate profits will result in an increase in the stock price to a greater extent than that of the bond price, as the bond price will receive no more than the payments of principle and interest. In this instance, yield spreads of corporate bonds over treasuries would be expected to fall as the optimism over profits should reduce the expected probabilities of default.
- The composition of the companies that issue the corporate bonds may be different from that of the companies that dominate the equity indices.
- An increase in the liquidity of corporate bonds relative to Treasury bonds might have a downward effect on the corporate bond price, while the equity price may remain unaffected.

- Yields of newly issued corporate bonds may be lower than seasoned bond prices, due to changes in the special features of these bonds. This would therefore have no effect on the seasoned bond prices.
- Volatility is expected to have opposite effects on bond and stock prices. Increased volatility increases the probability of default, and therefore hurts bondholders, where it should have a positive effect for equity holders.

Darbar and Deb (2002) have investigated the arrival of information, such as the prime rate, on the US stock and bond correlation. The prime rate was found to not be a statistically significant determinant of the conditional correlation between the US stock and bond market prior to the 1987 crash. However, after the 1987 US crash the prime rate becomes a significant determinant of the stock bond conditional correlation. Dummy variables such as weekends and holidays were not statistically significant in the correlation equations of the above research.

The correlations of the US stock on US bonds around the 1987 market crash are included in Figure 1 in order to emphasise the changing nature of the stock relative to the bond market. The effect of a structural break such as the US 1987 market crash can be seen in the correlation relationship.

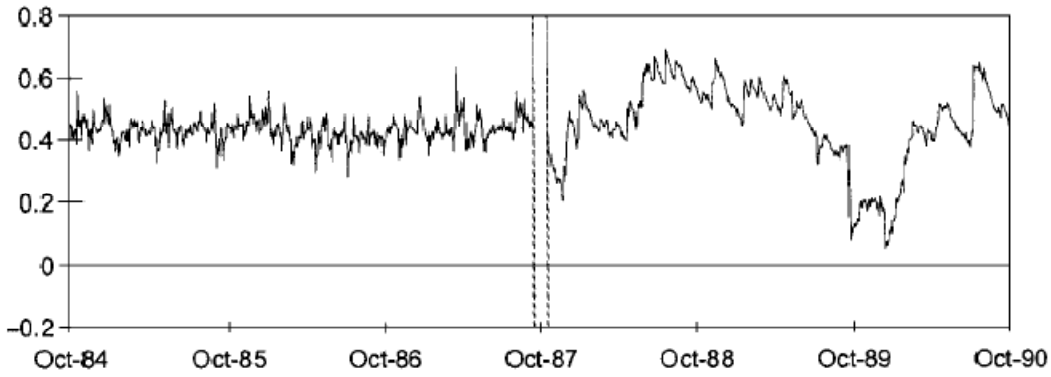


Figure 1: Cross-market correlations between US stock and bond markets (Darbar and Deb 2002)

The remainder of this research report is structured as follows: There is a general introduction to volatility, as well as a discussion of the causes of volatility in Section 2.2. Thereafter, Section 2.3, to 2.5 describes literature relevant to the relationship between the volatility of stock and bond markets, including research into volatility

transmission between markets. The hypothesis for this research report is also formulated at the conclusion of each section.

Chapter 3 describes research methodology used in similar research, as well as the methodology used in this research report. Chapter 4 deals primarily with the results of the investigation, with Chapter 5 reflecting a discussion of the results.

Chapter 6 represents the conclusion of the research report. This section is followed by detailed academic references and appendices relevant to this research report.

2.2 Market volatility

2.2.1 *Introduction to market volatility*

Volatility is important to investors as it is a measure of how much particular indices are varying over time. It is therefore a good estimate of risk, and is vital for portfolio managers who aim to provide a return from investing in a diversified portfolio that has a particular risk. The relative risk of stocks is therefore a vital consideration in the risk-return trade-off. Volatility estimates are also used in option pricing models such as the Black-Scholes model (Black and Scholes 1973).

Volatility has also been described as a separate effect to be considered when investing, which is of comparable magnitude to the classic size, value and momentum strategies (Blitz and Van Vliet 2007).

Taylor (2005) explains that there are many definitions of volatility depending on the particular context and definition used. In general, it is the measure of price variability over some period of time, and typically describes the standard deviation of returns. Taylor (2005) further explains that the context in which volatility is used include the following:

Realised volatility, or *historical volatility,* is the standard deviation of a set of actual previous returns. This volatility measure can be stated in time periods of annual units, or even trading periods measured in minutes.

Conditional volatility is the standard deviation of a future return that is conditional on known information such as previous returns. Time series models, such as the

autoregressive conditional heteroskedastic (ARCH) models developed by Engle (1982), are used to determine the variance expectation of the next period, based on prior information.

Stochastic volatility processes are motivated by noting that volatility is not constant and changes over time.

Implied volatility is a value of volatility calculated from an option price. It therefore equals the volatility parameter σ for which an option's market price equals its theoretical price according to a pricing formula. An example of a pricing formula is the Black-Scholes pricing formula (Black and Scholes 1973), used for European call options.

The different types of volatility often have different values for the same stock, as they calculate the value of volatility based on different assumptions.

In this research report, the realised or historical volatility is analysed in order to determine the volatility relationship, if any, between South African stocks, bonds and US stocks. The definition of the time period of the historical volatility in the research report will relate to daily volatility of the respective markets. As discussed in the research methodology section of this report, this is done by matching the information to a mathematical model. The mathematical model used is based on a time series GARCH model, which was originally developed by Bollerslev (1986) as the generalised version of the ARCH model. The GARCH model therefore uses conditional volatility. This volatility is assumed to be conditional on volatility of previous returns, and is matched to the historical volatility of the returns.

While most analysts accept that volatility changes over time, the causes of volatility remain largely unexplained (Taylor 2005). In order to illustrate potential causes that may influence a relationship between market volatilities, potential causes of volatility are discussed in section 2.2.2

2.2.2 *Causes of stock market volatility*

The causes of stock market volatility remain largely unexplained. The following section describes research that has attempted to explain the reasons for changes in volatility, or associations that volatility has with other variables.

It is generally accepted that volatility displays volatility clustering, or that general times of low volatility are followed by general times of high volatility (Taylor 2005). This characteristic is modelled by Engle in his description of volatility time series as displaying autoregressive conditional heteroskedasticity, or ARCH characteristics (Engle 1982).

Shiller (1981) concludes that stock market volatility in general cannot be explained by movements in the rational expectation of future dividends and interest rates.

Schwert (1989) hypothesises that volatility could be proportional to the volatility of macroeconomic factors, such as inflation, money growth, industrial production, unemployment and other measures of economic activity. Through his research, which includes analysis of data from 1885 to 1987, he concludes that there is weak evidence of any forecast power of macroeconomic factors volatility to predict stock or bond return volatility. He does, however, determine that financial market variables (interest rates, term and default yield spreads) are more successful in influencing volatility.

Volatility is positively correlated with trading volume (Tauchen and Pitts 1983; Karpoff 1987; Gallant, Rossi and Tauchen 1992). This does not imply that trading volume has a causal effect on volatility, or alternatively that volatility has a causal effect on trading volume. It seems more plausible that there are common factors that influence both trading volume and volatility at the same time. Jiang and Kryzanowski (1997) take a contrary view, where they determine that when volatility is conditioned on the number of trades and quoted liquidity, the trading volume provides no additional explanatory power. They conclude that the “number of trades appears to be a better proxy for information flow” (Jiang and Kryzanowski 1997:199).

It has been determined that volatility responds to news or information that has reached the market. Empirical analysis of the relationship between volatility and information is difficult due to issues associated with identifying relevant information. Mitchell and Mulherin (1994) have determined that US stock market volatility has a weak relationship with daily counts of headlines reported by the Wall Street Journal and the Broadtape. Melvin and Yin (2000) have determined a more discernible impact when comparing volatility with headlines that are selected using economic keywords.

Schwert (1989) concludes that financial leverage affects a small proportion of stock volatility over time. Financial leverage refers to an increase in stock volatility when stock prices fall relative to bond prices, or when firms issue new debt securities in larger proportion to new equity when compared with their previous capital structure.

Stock return volatility rises more during stock price declines, when compared to stock price increases, thereby making stock price volatility asymmetric. Black (1976) and Christie (1982) use the “leveraging effect” to offer an explanation for the phenomenon, in that a decrease in the firm’s stock price raises the financial leverage of the firm, which results in an increase in the volatility of the equity. Another explanation for this phenomenon is that there is asymmetry in the volatility of macroeconomic variables. This can be illustrated by empirical evidence that suggests that real variables are more volatile in recessions (Schwert 1989). Little evidence is found for asymmetries in conditional volatility of bond returns, although conditional correlations between stock and bonds do exhibit asymmetry (Cappiello 2006).

The causes of market volatility therefore remain largely unknown. Volatility does seem in certain circumstances to be influenced by the volatility of other markets. A number of authors have studied the cross-country correlation, or volatility transmission between countries’ stock markets (Bennett and Kelleher 1988; Karolyi 1995; Caporale et al. 2006). This is generally referred to as volatility transmission or spillover from one market to another. Volatility transmission could be considered key to this research report in that it describes the impact volatility of one market has on the volatility of another market. Therefore the relationship between volatility of the South African bond and stock market could be analysed for volatility transmission effects, as described in more detail in Section 2.3.1.

2.3 The relationship between volatility of domestic stock and bond markets

While the causes of market volatility remain largely unknown, this section of the report aims to describe current understanding of the relationship between the volatility of domestic stock and bond markets.

2.3.1 *Rationale for volatility transmission between domestic stock and bond markets*

Merton (1974) introduced the earliest analysis on the relation between stocks and bonds, where he proposed a negative relation of both stocks and bonds during periods of higher volatility. The premise underlying the proposal was that bond holders are regarded as owners of risk-free bonds, who issue a put option to equity holders. Therefore, an increase on the implied volatility of the firm affecting the default risk would cause bond prices to fall while the stock holders benefit from the increased value of the put option. The volatility that is relevant to option values comes from a combination of idiosyncratic and market-wide factors. Campbell and Taksler (2003:2345) provide evidence supporting Merton which illustrates that "the idiosyncratic equity volatility is directly related to the cost of borrowing for corporate issuers". The robust findings reveal that the equity volatility can explain as much cross-sectional variation in yields as can credit ratings. Campbell and Taksler (2003) also confirm that the aggregate corporate yield spreads widen during periods of higher idiosyncratic risk.

Schewrt (1989) notes that stock and long-term bond return volatility have similarities due to real financial and business risk, and therefore should change in similar ways. For example, an increase in the underlying business risk of a firm would cause the risk of the stock and bonds to increase. Similarly, if the leverage of a firm increases, both stocks and bonds of a firm become more risky.

Fleming et al. (1998) identify two sources of linkages between volatility of stock and bonds. These are common information to markets and information spillover from one market to another. Common information would include all information that would simultaneously affect the expectation of the investor in both markets, such as inflation, and would therefore have a simultaneous effect on the markets. The second linkage is related to when information causes investors to alter their expectation of a particular market, and therefore adjust their holdings across both markets in order to maintain their preferred risk profile.

Kim, Moshirian and Wu (2006) propose a flight to quality hypothesis, where a positive shock can have the effect of dampening the alternate markets volatility, as investors remain with their asset allocations. A negative shock, however, can cause

investors to switch to perceived “quality” investments, thereby causing cross market volatility to increase.

2.3.2 *Long-term trends in the relationship between domestic bond market volatility and stock market volatility*

Analysis of the US stock and bond market indicates that the average historical volatility of stocks is approximately three times that of bonds (Schwert 1989; Reilly et al. 2000). Johnson and Young (2002) confirm that the UK ratio of stock volatility is on average approximately double the volatility of the bonds. These findings relate to the average volatility, where the volatility of the UK bond market, on a calendar year basis, had in 1982 varied so much that it exceeded the volatility of the stock market.

Within the above research on the US and UK stock and bond markets by Reilly et al. (2000) and Johnson and Young (2002) respectively, overall trends about the markets’ volatilities can be identified. Both investigations reveal a low and volatile relationship between the volatilities of the stock and bond asset classes, where the relationship between the respective markets is described as unstable.

The overall trend in the long-term US bond market volatility is considered to be increasing relative to stock market volatility (Reilly et al. 2000). This finding, when combined with the increasing correlation between bond returns and stock returns, would have the implication that the effectiveness of bonds in the US as a diversification vehicle has declined over time (Jones 2004). To the contrary, the ratio of bond-stock standard deviation and correlation between bonds and stock in the UK has not changed, as indicated by Johnson and Young (2002). In the UK the stock market volatility roughly followed the same pattern as the US stock market, where the bond market did not. Therefore the effectiveness of bonds as a diversification vehicle has not declined in this market, and emphasises the need to explore trends in separate markets as opposed to assuming that results are externally valid in similar markets.

2.3.3 *Additional evidence of linkages between domestic stock market volatility and bond market volatility*

A number of studies have investigated the linkages between the volatility of the respective domestic stock and the bond markets. Fleming et al. (1998) examine the information and volatility linkages between the S&P 500 stock index futures, the T-bond futures, and the T-bill futures. These futures represent the US stock, bond and money markets respectively. Their results confirm that the linkages between the three markets analysed are strong. The parameter estimates used in their model, which indicate the information flows that drive the trading in the markets, show evidence of contemporaneous correlation that is much stronger than suggested by the cross-market correlations of returns or absolute returns. This is illustrated by the fact that the correlation between the S&P 500 returns and T-bill returns was under 13%; the correlation between absolute returns was around 26%; and the log information flow correlation was calculated to be nearly 67%.

Scruggs and Glabadanidis (2003) investigate the covariance of the New York Stock Exchange AMEX stock index with the long term US government bond total return index. They conclude that conditional bond return variance is virtually unaffected by stock return shocks. The stock variance, however, responds asymmetrically to shocks in the bond market. A substantial increase in the stock market variance is caused by negative shocks in the bond market.

Fang et al. (2006) investigated the market-wide transmission between the stock and bond markets of the US and Japan. Contrary to Scruggs and Glabadanidis (2003), they conclude that within each country there is unidirectional volatility transmission from the stock market to the bond market, without significant transmission of volatility from the domestic bond market to the stock market. The US stock market was found to have a negative effect on its bond market, where a 1% increase in volatility of the stock market resulted in a 0.69% decrease in the US bond market. Japan's stock market volatility of the previous days', or the volatility persistence, had a positive effect on the local bond market.

Further research by Fang (2007) reveals that a 1% increase in UK stock volatility causes a negative 0,155% change in the UK domestic bond market volatility. The effect of the previous days' volatility of the German stock market also results in a negative relation to the current day's German bond volatility.

Volatility transmission from the UK and German bond markets to the relative stock markets was found to be statistically insignificant.

2.3.4 *The expected nature and size of the relationship the South African stock market volatility has with the South African bond market volatility*

As previously mentioned in Section 1.4, the relationship that the volatility of the stock market has with the bond market has not been investigated in South Africa. Therefore, in order to determine the nature and size of the relationship, assumptions are made based on aforementioned studies on the US, Japanese, UK and German markets (Fang et al. 2006; Fang 2007).

These studies found that in all cases the stock market volatility did have a significant effect on the local bond market, with the nature of the relationship being negative in three of the four cases. The influence of the stock market volatility varied in terms of the way in which it influenced the bond markets. This is illustrated in that the USA and UK stock market volatility, due to news or shocks, influenced the bond market volatility on the same day. In comparison, the previous days' stock volatility influenced the bond market volatility in Japan and Germany. The South African stock and bond markets would be seen to be vastly smaller than the USA and UK stock and bond markets, and therefore could be expected to be more similar to Japan and Germany in the previous comparison.

2.3.5 *Hypothesis 1*

It is proposed that there is volatility transmission from the South African stock market to the South African bond market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the South African stock market to the South African bond market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{SAs_SAb} = g_{SAs_SAb} = 0$$

$$H_A: a_{SAs_SAb} \neq 0 \text{ or } H_A: g_{SAs_SAb} \neq 0$$

where a_{SAs_SAb} is the measure of the effects of shocks or news on the variance of the South African bond market, conditional on the variance of the South African stock market

g_{SAs_SAb} is the measure of the effects of past conditional variances on the variance from the South African stock market to the South African bond market.

The nature of the relationship, based on similar markets previously discussed, is expected to be negative, with the stock volatility of the previous day influencing the current day's bond volatility. Therefore the null hypothesis of $H_0: a_{SAs_SAb} = 0$ is expected to be rejected, while the secondary null hypothesis of $H_0: b_{SAs_SAb} = 0$ is not expected to be rejected.

Should a_{SAs_SAb} or b_{SAs_SAb} be determined to be significantly different from zero, the value of this a_{SAs_SAb} or b_{SAs_SAb} would represent the size of the effect of the South African stock market on the South African bond market.

2.3.6 *Hypothesis 2*

It is proposed that there is volatility transmission from the South African bond market to the South African stock market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the South African bond market to the South African stock market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{SAb_SAs} = g_{SAb_SAs} = 0$$

$$H_A: a_{SAb_SAs} \neq 0 \text{ or } H_A: g_{SAb_SAs} \neq 0$$

where a_{SAb_SAs} is the measure of the effects of shocks or news on the variance of the stock market, conditional on the variance of the bond market

g_{SAb_SAs} is the measure of the effects of past conditional variances on the variance from the bond market to the stock market.

The nature and size of the relationship, based on similar markets previously discussed, is expected to be not significantly different from zero. Therefore the null

hypothesis of H_0: $a_{SAb_SAs} = 0$ and the secondary null hypothesis of H_0: $g_{SAb_SAs} = 0$ is not expected to be rejected.

Should a_{SAb_SAs} or g_{SAb_SAs} be determined to be significantly different from zero, the value of this a_{SAb_SAs} or g_{SAb_SAs} would represent the size of the effect of the South African bond market on the South African stock market.

2.4 The relationship between volatility of international stock and bond markets

The relationship between volatility of international stock and bond markets is in many respects similar to that of domestic stock and bond markets. A key difference discussed in this section of the report is the influence of the stock and bond market residing in different countries.

2.4.1 *Rationale for volatility transmission between international stock and bond markets*

Fang (2007) argues that the stock bond relationship proposed by Merton (1974), discussed in Section 2.3.1, is confined to domestic markets. This is noted as the causal effects between the international stock and bond markets are not explicitly examined within the framework of Merton's model. Fang (2007) further argues that the source of an international stock and bond volatility spillover effect is less likely to emanate from idiosyncratic volatility, which is tending to be limited to local markets, and more likely to emanate from market-wide volatility. The underlying rationale is that "market-wide risk cannot be diversified within a local market" (Fang 2007:1).

The context for volatility transmission between international stock and bond markets proposed by Fang (2007) would broadly agree with the two sources of linkages between volatility of stock and bonds, identified by Fleming et al. (1998). As discussed in Section 2.3.1, the first linkage relates to common information that would simultaneously affect the expectation of the investor in both markets. Solnik, Boucrelle and Fur (1996) indicate that factors could be internationally linked factors, such as globally higher interest rate volatility. In periods of high interest rate

volatility, stock markets could seem more attractive in their respective markets, even if few cross-country investments existed.

The second linkage relates to information that causes investors to alter their expectation of a particular market, resulting in an adjustment in their holdings across both markets in order to maintain their preferred risk profile. The second linkage would therefore relate to the rationale for international volatility transmission proposed by Fang (2007) of diversifying market risk.

Solnik et al. (1996) indicate the effect of global institutional investors as a factor linking volatility of international stock and bond markets. They influence the volatility through their "tending to herd together in moving out of stocks and into bonds (and vica versa)" (Solnik et al. 1996:31).

2.4.2 *Evidence of linkages between international stock market volatility and bond market volatility*

A number of empirical studies, including Solnik et al. (1996), investigate international linkages between stocks and bonds focus on the correlation linkages of the markets, i.e. the first order dependence in a linear regression framework.

Higher order dependence between stock and bond markets, arising from the interactions between the volatility have generally been investigated between domestic stock and bond markets, as discussed in Section 2.3.3. International stock and bond market volatility transmission have been studied by Kim, Moshirian and Wu (2006) and Fang (2007).

Kim et al. (2006) investigate the integration of a number of first world stock and bond markets. The particular stock and bond markets are separated into two groups: Euro zone members, comprising of France, Germany, Italy and Spain; and non-Euro zone members, comprising of UK, Japan and US. Findings from the study include that Euro zone markets have unidirectional volatility transmission, in that shocks in the bond market have an effect on the stock market volatility, yet shocks in the stock market do not have an effect on the bond market volatility. Non-Euro zone members are identified as having bidirectional volatility transmission between stock and bond markets. Therefore shocks in either stock or bond markets effect the volatility of the other markets.

Kim et al. (2006) also find that stock market volatilities are more responsive to shocks in the bond market than bond market volatilities are to stock market return shocks.

Fang (2007) investigates the conditional volatility transmission between the US stock market and the Japanese, UK and German bond markets. He determines that the US stock market has little influence on the government bond indices of the other three countries. The Japanese and British government bond indices have a small negative influence on the conditional volatility of the US stock market, explained through cross-border portfolio diversification. The influence of the German government bond index on the US stock market is considered insignificant at the 1% level, and implying that there is not a volatility transmission relationship in either direction between the German bond and US stock markets.

2.4.3 *The expected nature and size of the relationship the US stock market volatility has with the South African bond market volatility*

As previously mentioned, the relationship that the volatility of the US stock market has with the South African bond market has not been investigated. The conditional volatility relationship, based on findings from Kim et al. (2006) and Fang (2007) would seem to imply that the international stock bond conditional volatility relationship is dependent on the particular countries studied. As the South African bond market could be considered relatively small when compared with the UK and Japanese bond markets, the nature of the conditional volatility relationship could be assumed to be most similar to that of the German market identified by Fang (2007).

2.4.4 *Hypothesis 3*

It is proposed that there is volatility transmission from the US stock market to the South African bond market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the US stock market to the South African bond market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{USs_SAb} = g_{USs_SAb} = 0$$

$$H_A: a_{USs_SAb} \neq 0 \text{ or } H_A: g_{USs_SAb} \neq 0$$

where a_{USs_SAb} is the measure of the effects of shocks or news on the variance of the South African bond market, conditional on the variance of the US stock market

g_{USs_SAb} is the measure of the effects of past conditional variances on the variance from the US stock market to the South African bond market.

The nature of the relationship, based on similar markets previously discussed, is not expected to indicate a significant relationship. Therefore both the null hypotheses of $H_0: a_{USs_SAb} = 0$ and $H_0: b_{USs_SAb} = 0$ are not expected to be rejected.

Should a_{USs_SAb} or b_{USs_SAb} be determined to be significantly different from zero, the value of this a_{USs_SAb} or b_{USs_SAb} would represent the size of the effect of the US stock market on the South African bond market.

2.4.5 *Hypothesis 4*

It is proposed that there is volatility transmission from the South African bond market to the US stock market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the South African bond market to the US stock market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{SAb_USs} = g_{SAb_USs} = 0$$

$$H_A: a_{SAb_USs} \neq 0 \text{ or } H_A: g_{SAb_USs} \neq 0$$

where a_{SAb_USs} is the measure of the effects of shocks or news on the variance of the US stock market, conditional on the variance of the South African bond market

g_{SAb_USs} is the measure of the effects of past conditional variances on the variance from the South African bond market to the US stock market.

The nature and size of the relationship, based on similar markets previously discussed, is not expected to indicate a significant relationship. Therefore both the null hypotheses of $H_0: a_{SAb_USs} = 0$ and $H_0: b_{SAb_USs} = 0$ are not expected to be rejected.

Should a_{SAb_USs} or g_{SAb_USs} be determined to be significantly different from zero, the value of this a_{SAb_USs} or g_{SAb_USs} would represent the size of the effect of the South African bond market on the US stock market.

2.5 The relationship between volatility of international stock markets

International stock market volatility transmission has been more widely investigated than volatility transmission between stocks and bonds. This section of the report describes some of the current findings relating to US stock market volatility transmission with other stock markets.

2.5.1 *Rationale for volatility transmission between international stock markets*

Lin, Engle and Ito (1994) describe a potential reason for volatility transmission between international stock markets as being due to the economies being related through trade and investment. News relating to economic fundamentals of the first country could therefore have implications for the second country. An international asset pricing model can therefore take into account correlations between stock returns in different countries. Caporale et al. (2006) indicate that empirical evidence does not support trade linkages between countries as the key source of volatility transmission between international stock markets.

King and Wadhwani (1990) hypothesise a contagion model which is based on rationale attempts of investors to use imperfect information about events relevant to equity values. As investors map complex signals from the one market in order to determine prices in the second market, a dependence of price changes in one market on the other market is formed. Mistakes or idiosyncratic changes in one market can therefore be transmitted to other markets as an alternative to news. King and Wadhwani (1990) also find that an increase in volatility leads to an

increase in the size of contagion effects. Lin et al. (1994) find results consistent with the contagion hypothesis. They indicate that price movements can also be driven across borders by a herd instinct or fads.

King, Sentana and Wadhwani (1994) identify that only a small portion of on the covariance between stock markets can be explained by observable economic variables. They conclude that changes occur due to unobservable economic variables, including variables ignored in their study as well as investor sentiment.

Liu and Pan (1997) determine cross-country equity investing or market contagion alone cannot explain international volatility transmissions. They therefore investigate if regulations such as exchange control or stock ownership controls have an impact on the extent of volatility spillover between stock markets. Their findings indicate that the volatility transmission is not significantly related to the controls in place.

2.5.2 *Evidence of linkages between US and other stock markets' volatility*

There have been studies into the transmission of volatility between the US market and international stock markets. Studies relating to international stock markets relationship with the US stock market are discussed in this section.

Caporale et al. (2006) investigate the 1997 South East Asian crisis, and determine a bidirectional volatility transmission between the US stock market and the South East Asian countries prior to the crisis. Innovations of the US stock market caused a decrease in the South East Asian conditional variance during this time. However, post the crisis the nature of the relationship changed to a positive unidirectional volatility transmission from the South East Asian stock markets to the US stock market.

Liu and Pan (1997) determine that the US stock market is more influential than Japan in the transmission of volatility to the combined Hong Kong, Singapore, Taiwan and Thailand stock markets. There is, however, no evidence of volatility spillover in the above research if robust standard errors are calculated.

Hamao, Masulis and Ng (1990) observes a unidirectional volatility transmission from US New York stock market to both Japanese and UK stock markets. Theodossiou and Lee (1993) confirm that significant volatility spillovers radiate from the US stock market to the Japanese, UK, Canadian and German stock markets. Lin et al. (1994) identify bidirectional volatility transmission between US stock markets and Japanese stock markers, contrary to the afore mentioned findings. Fang (2007) finds evidence in support of Hammao et al. (1990) where he determines a unidirectional volatility transmission from the US stock market to the Japanese stock market. A bidirectional volatility transmission between the US stock market and both the UK and German stock markets is also identified by Fang (2007).

Susmel and Engle (1994) investigate the hourly volatility transmission between the US and UK stock markets. They conclude that there is no strong evidence of volatility spillover between the relevant markets at this time interval.

Karolyi (1995) indicates that the volatility relationship between the US stock market and the Canadian stock market has changed over time.

2.5.3 *The expected nature and size of the relationship the US stock market volatility has with the South African stock market volatility*

The US stock market was identified as having a unidirectional or bidirectional volatility transmission relationship with other markets investigated, and was described as being dominant in a number of instances.

Therefore the nature and size of the relationship that the US stock market has with the South African stock market is expected to reflect the US being the dominant market. The volatility relationship is therefore expected to either be unidirectional, from the US stock market to the South African stock market, or bidirectional. Should it be bidirectional, it is expected that shocks in the US stock market influence the South African volatility more than shocks in the South African stock market would influences the volatility of the US stock market.

2.5.4 *Hypothesis 5*

It is proposed that there is volatility transmission from the US stock market to the South African stock market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the US stock market to the South African stock market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{USs_SAs} = g_{USs_SAs} = 0$$

$$H_A: a_{USs_SAs} \neq 0 \text{ or } H_A: g_{USs_SAs} \neq 0$$

where a_{USs_SAs} is the measure of the effects of shocks or news on the variance of the South African stock market, conditional on the variance of the US stock market

g_{USs_SAs} is the measure of the effects of past conditional variances on the variance from the US stock market to the South African stock market.

The nature of the relationship, based on similar markets previously discussed, is expected to be significant through the influence of US shocks, or US volatility persistence. Therefore the null hypothesis of $H_0: a_{USs_SAs} = 0$ or $H_0: b_{USs_SAs} = 0$ is not expected to be rejected.

Should a_{USs_SAs} or b_{USs_SAs} be determined to be significantly different from zero, the value of this a_{USs_SAs} or b_{USs_SAs} would represent the size of the effect of the US stock market on the South African stock market.

2.5.5 *Hypothesis 6*

It is proposed that there is volatility transmission from the South African stock market to the US stock market.

In order to test the proposition, a null hypothesis of the unidirectional transmission of volatility from the South African stock market to the US stock market is assumed to be equal to zero, at a 99% confidence interval, i.e.:

$$H_0: a_{SAs_USs} = g_{SAs_USs} = 0$$

$$H_A: a_{SAs_USs} \neq 0 \text{ or } H_A: g_{SAs_USs} \neq 0$$

where a_{SAs_USs} is the measure of the effects of shocks or news on the variance of the US stock market, conditional on the variance of the South African stock market

g_{SAs_USs} is the measure of the effects of past conditional variances on the variance from the South African stock market to the US stock market.

The nature and size of the relationship, based on similar markets previously discussed, is expected less influential than the effect of the US stock market on SA volatility. Therefore either the null hypothesis of $H_0: a_{SAs_USs} = 0$ or the secondary null hypothesis of $H_0: g_{SAs_USs} = 0$ is not expected to be rejected.

Should a_{SAs_USs} or g_{SAs_USs} be determined to be significantly different from zero, the value of this a_{SAs_USs} or g_{SAs_USs} would represent the size of the effect of the South African stock market on the US stock market.

2.6 Conclusion of literature review

The literature review has explained some basic reasons which may explain stock and bond prices diverging from one another. It then confirmed that the basic correlation between the US stock and bond market has changed over time (Darbar and Deb 2002).

Various types of volatility have been defined. Historical volatility is used for the remainder of this research report, although conditional volatility is used in order to determine this relationship.

Research into the causes of market volatility revealed that the causes of market volatility remain mostly unexplained, although aspects of the volatility can be explained through, amongst other things, information arrivals to the respective markets.

The literature review identified aspects of volatility between domestic stock and bond markets; international stock and bond markets; and international stock markets. These were discussed in detail, providing rationale for the volatility transmission, and empirical evidence of transmission in particular markets.

A potential explanation of the rationale behind volatility transmission between the stock and bond markets. Merton (1974) is accredited with describing the first potential relationship between stock and bonds during times of high volatilities. This was later supported by Campbell and Taksler (2003), who directly relate the idiosyncratic equity volatility to the cost of borrowing for corporate borrowers. Fleming et al. (1998) propose two potential linkages between the volatilities of stocks and bonds. The first linkage relates to the information that arrives and is relevant to both markets. The second linkage relates to information that changes investors' expectation of a market, which results in an adjustment to the portfolio resulting in an adjustment to the other market. Strong linkages suggesting both types of transmission have been identified between the volatilities of the US stock and bond markets.

A further rationale for volatility transmission between stocks and bonds relates to the herding effect of fund managers.

The nature of stock market volatilities when compared to bond market volatilities was discussed for domestic and international relations separately. The average US bond market volatility when compared with the domestic stock market volatility is found to be increasing over time (Reilly et al. 2000), where the nature of the UK relationship of volatility of bonds to UK stocks is found to be on average remaining the same (Johnson and Young 2002). Both markets describe the relationship of market volatilities as volatile.

Results of research into the bi-directional transmission of volatility between domestic stock and bond markets were discussed (Fang et al. 2006; Fang 2007). Volatility was determined to have been transmitted from stock markets to domestic bond markets, yet no evidence of transmission from bond markets to domestic stock markets was found. The volatility of the US and UK bond markets was found to be negatively influenced by the volatility of their relative stock markets, where the previous days' volatility of the particular domestic stock market had an influence on the Japanese and German bond market volatilities. The nature of the influence of the previous days' stock volatility was determined to be positive in relation to the Japanese bond volatility, and negative in relation to the German bond volatility.

Evidence of international stock and bond volatility relationship is provided by Kim et al. (2006) who find that stock market volatilities are more responsive to shock in the

bond market than bond market volatilities are to shock in the stock market. They also derive a unidirectional volatility transmission relationship from bonds to stocks for Euro-zone members, and a bidirectional volatility transmission relationship between stock and bond markets for non-Euro zone members. Fang (2007) finds little evidence of transmission of volatility from the US stock market to the Japanese, UK and German bond market, although shocks in the Japanese and UK bond markets have a negative influence on the conditional volatility of the US stock market.

Rationale for stock market volatility transmission to another stock market is based on, to varying extents, trade and investment linkages in the economy; cross country equity investing or the effect of contagion (King and Wadhwani 1990). Only a small portion of covariance between stock markets can be explained by observable economic variables (King et al. 1994). Regulatory controls, such as exchange control or stock ownership controls, are not significantly related to the extent of volatility transmission (Liu and Pan 1997).

The US stock market was identified as having a unidirectional or bidirectional volatility transmission relationship with a number of other stock markets. The US stock market is also described as being the dominant partner in the relationships.

Six hypotheses were put forward, as follows:

2.6.1 *Hypothesis 1*

The nature and size of the relationship of volatility transmission from the South African stock market to the local bond market is tested through the determination of the hypothesis test:

$$H_0: a_{SAs_SAb} = g_{SAs_SAb} = 0$$

$$H_A: a_{SAs_SAb} \neq 0 \text{ or } H_A: g_{SAs_SAb} \neq 0$$

2.6.2 *Hypothesis 2*

The nature and size of the relationship of volatility transmission from the South African bond market to the local stock market is tested through the determination of the hypothesis test:

$$H_0: a_{SAb_SAs} = g_{SAb_SAs} = 0$$

$$H_A: a_{SAb_SAs} \neq 0 \text{ or } H_A: g_{SAb_SAs} \neq 0$$

2.6.3 *Hypothesis 3*

The nature and size of the relationship of volatility transmission from the US stock market to the South African bond market is tested through the determination of the hypothesis test:

$$H_0: a_{USs_SAb} = g_{USs_SAb} = 0$$

$$H_A: a_{USs_SAb} \neq 0 \text{ or } H_A: g_{USs_SAb} \neq 0$$

2.6.4 *Hypothesis 4*

The nature and size of the relationship of volatility transmission from the South African bond market to the US stock market is tested through the determination of the hypothesis test:

$$H_0: a_{SAb_USs} = g_{SAb_USs} = 0$$

$$H_A: a_{SAb_USs} \neq 0 \text{ or } H_A: g_{SAb_USs} \neq 0$$

2.6.5 *Hypothesis 5*

The nature and size of the relationship of volatility transmission from the US stock market to the South African stock market is tested through the determination of the hypothesis test:

$$H_0: a_{USs_SAs} = g_{USs_SAs} = 0$$

$$H_A: a_{USs_SAs} \neq 0 \text{ or } H_A: g_{USs_SAs} \neq 0$$

2.6.6 *Hypothesis 6*

The nature and size of the relationship of volatility transmission from the South African stock market to the US stock market is tested through the determination of the hypothesis test:

$$H_0: a_{SAs_USs} = g_{SAs_USs} = 0$$

$$H_A: a_{SAs_USs} \neq 0 \text{ or } H_A: g_{SAs_USs} \neq 0$$

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research paradigm

The research paradigm used in this report is quantitative in nature. Generally, a quantitative approach is appropriate when the research aims to develop knowledge through the use of post-positivist claims, including cause-and-effect thinking. A quantitative research paradigm also uses measurement and observation to test theories. Data is also often collected on predetermined instruments that yield statistical data with this paradigm.

Therefore the quantitative approach is applicable to this research proposal, as the aim of the proposal is to determine if there is a relationship between the volatility of the bond and stock market. As bond and stock markets are measured through published data, and the volatility is calculated from this data, it follows that the best method of investigating the variables is through a statistical empirical study. The statistical data yielded from this investigation is therefore considered to be an appropriate means of analysing the information.

3.2 Research design

The approach that will be adopted in this research proposal will be that of mathematical modelling. The proposed empirical study is consistent as it will reveal, for example, whether the relationship between the stock and the bond market volatility has existed historically. Therefore the detailed historical data available for both the stock and bond market allows this sort of research to be effectively performed.

Four different methodologies have been used to try to measure how shocks are transmitted across markets, namely: market correlation coefficients; ARCH and GARCH models (which are explained later in this chapter); cointegration techniques; and direct estimation of specific transmission mechanisms (Forbes and Rigobon 2002; Creswell 2008).

Fleming et al. (1998) developed a stochastic volatility model where the variance of returns is proportional to the information flow. In this case the information flow was

modelled as an AR(1) process. This model is used instead of a GARCH model as it is straightforward to implement, and yields a direct estimate of the desired correlation which indicates the strength of the volatility linkages between markets. Fleming et al. (1998:114) also state that their "approach is consistent with the view that information flows, and therefore volatilities, are stochastic. Because GARCH models lack this characteristic, they seem less likely to capture salient features of the return generating process".

Fleming et al. (1998) explain their choice of an alternate model by referring to the two ways that a bivariate GARCH or Generalised Autoregressive Conditional Heteroskedasticity model can be used to estimate the correlation between the information flows. The first approach is to fit the model through the use of a maximum likelihood procedure and measure fitted volatilities, which yields noisy estimates. The second approach is to adapt the model to the Generalised Method of Moments approach of Hansen (1982), and estimate correlation directly. This second approach involves complex moment restrictions that complicate the estimation.

A number of studies have provided relevant research on transmission of volatility between international stock markets or domestic stock and bond markets by adapting mathematical models from the GARCH model (Karolyi 1995; Darbar and Deb 2002; Fang et al. 2006; Fang 2007).

3.2.1 Univariate ARCH and GARCH models

The origins of the GARCH model lie in the Autoregressive Conditional Heteroskedasticity (ARCH) model proposed by Engle (1982). An ARCH model determines the unobservable second moments by specifying a functional form for the conditional variance, and then modelling the first and second moments jointly. While different functional forms are possible, Engle (1982) suggests that the conditional variances depend on elements in the information set in an autoregressive manner, called the ARCH model.

The model allows for the means and variance to depend on past information, and therefore allows the conditional means and variances to jointly evolve over time. When considering a return, defined as

(5) $$r_t = \ln \frac{p_t}{p_{t-1}}$$

where p_t is the relative index daily closing price at time *t*.

The linear univariate ARCH(p) regression model, using p lags can be written as

(6) $$r_t | \mathrm{I}_{t-1} \sim N(\mu_t, h_t)$$

(7) $$h_t = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \cdots + \alpha_p \epsilon_{t-p}^2$$

(8) $$\epsilon_t = r_t - \mu_t$$

where r_t is the return of a variable at period t

I_{t-1} is the information set available at time $t-1$

h_t is the conditional variance of the random variable y_t measurable with respect to I_{t-1}

μ_t is the mean of y

ϵ_t is the error term, or residual

$\alpha_0, \ldots, \alpha_p$ are unknown parameters

and the notation is used as follows:

$X|Y$ indicates that random variable X is conditional on another variable Y

$X \sim N(u, \sigma)$ indicates that the distribution of X is normal, with mean u and variance σ.

(9) $$\epsilon_t | \mathrm{I}_{t-1} \sim N(0, h_t)$$

A standardised residual, z_t, can be defined as

(10) $$z_t = \frac{r_t - \mu_t}{\sqrt{h_t}}$$

Which has a conditional distribution of

(11) $$z_t | \mathrm{I}_{t-1} \sim N(0,1)$$

All standardised residuals, z_t, are independent and identically distributed. It therefore follows that

(12) $$r_t = \mu_t + h_t^{1/2} z_t, \quad z_t \sim i.i.d. N(0,1)$$

The unknown parameters $\alpha_0, \dots, \alpha_p$ can be determined through the maximisation of a likelihood function. Engle (1982) proposes that the a log likelihood function, l, for the ARCH(p) model, with a sample size of T, would be

(13) $$l = \frac{1}{T}\sum_{t=1}^{T} -\frac{1}{2}\log h_t - \frac{1}{2}y_t^2 \Big/ h_t$$

Bollerslev (1986) then extends the ARCH model to a Generalised ARCH model, or GARCH model. This was achieved through, in addition to the form of the ARCH model, including past conditional variances in the current conditional variance equation.

The variance equation of the GARCH(p,q) is therefore modelled as

(14) $$h_t = \alpha_0 + \alpha_1\epsilon_{t-1}^2 + \cdots + \alpha_p\epsilon_{t-p}^2 + \beta_1 h_{t-1}^2 + \cdots + \beta_q h_{t-q}^2$$

Again, the unknown parameters $\alpha_0, \dots, \alpha_p, \beta_0, \dots, \beta_q$, are estimated through the maximisation of a likelihood function.

The simple GARCH(1,1) model often provides "a parsimonious description of the data" (Engle and Kroner 1995:124). Taylor (2005) describes the popularity of the GARCH(1,1) model as being due to three observations, namely: the model has only easily estimated parameters; the model provides an explanation for the major daily returns stylised facts; and it provides similar accuracy volatility forecasts to more complicated specifications.

The GARCH(1,1) distribution of the return for period t, conditional on all previous returns, can be defined as

(15) $$r_t|\mathrm{r}_{t-1}, \mathrm{r}_{t-2}, \dots \sim N(\mu, h_t)$$

(16) $$h_t = \omega + \alpha\epsilon_{t-1}^2 + \beta h_{t-1}^2$$

The following constraints are required to be imposed to ensure that the conditional variance is never negative, i.e. $\omega \geq 0, \alpha \geq 0, \beta \geq 0$. The process is stationary if $\alpha + \beta < 1$.

3.2.2 Multivariate GARCH models

It is useful to extend the univariate GARCH(1,1) to a multivariate model in order to determine a causal relationship of the volatility of one market on another, as required by this research. Engle and Kroner (1995) describe the vec, diagonal vec, and BEKK representations for this purpose.

The bivariate case of the vec and diagonal vec GARCH(1,1) models will now be briefly discussed. The GARCH(1,1) with BEKK representation will then discussed in more detail, as it is used in this research.

a. *Vec and Diagonal Vec GARCH(1,1) models*

The extension of the univariate GARCH(1,1) model to a bivariate model requires allowing a conditional variance-covariance matrix of the bi-dimensional zero mean random variables ϵ_t to depend on the elements of the information set.

(17) $$\epsilon_t|\mathrm{I}_{t-1} \sim N(0, H_t)$$

where H_t is parameterised as a function of the information set. H_t therefore depends on lagged values of the squares and cross-products of ϵ_t, as well as squares and cross-products of H_t.
The following vectors are defined:

(18) $$h_t = vecH_t$$

(19) $$\eta_t = vec(\epsilon_t \epsilon_t')$$

where $vec(.)$ is the vector operator that stacks the columns of the matrix.

The vec parameterisation without exogenous influences for h_t can be written for the GARCH(1,1) case as

(20) $$h_t = C_0 + A_1 \eta_{t-1} + G_1 h_{t-1}$$

where C_0 is a 4x1 parameter vector, and G_1 are 4x4 parameter matrices.
This can be expanded to become

$$(21)\quad h_t = \begin{bmatrix} h_{11,t} \\ h_{12,t} \\ h_{22,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \epsilon_{1,t-1}^2 \\ \epsilon_{1,t-1}\epsilon_{2,t-1} \\ \epsilon_{2,t-1}^2 \end{bmatrix} + \begin{bmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{bmatrix} \begin{bmatrix} h_{11,t-1} \\ h_{12,t-1} \\ h_{22,t-1} \end{bmatrix}$$

In the above case, $h_{21,t}$ has been omitted, resulting in no coefficient for $\epsilon_{2,t-1}\epsilon_{1,t-1}$, as these have become redundant. Therefore nine free parameters are left in matrices A_1 and G_1. The above bivariate representation therefore requires estimation of 21 variables.

For empirical implementation, the diagonal representation restricts the parameterisation further. The restriction of making A_1 and G_1 diagonal has the effect that each element of the covariance matrix $h_{jk,t}$ depends only on past values of itself and past values of $\epsilon_{j,t}\epsilon_{k,t}$,. Thus the diagonal representation for the above example is simply

$$(22)\quad h_t = \begin{bmatrix} h_{11,t} \\ h_{12,t} \\ h_{22,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \epsilon_{1,t-1}^2 \\ \epsilon_{1,t-1}\epsilon_{2,t-1} \\ \epsilon_{2,t-1}^2 \end{bmatrix} + \begin{bmatrix} g_{11} & 0 & 0 \\ 0 & g_{22} & 0 \\ 0 & 0 & g_{33} \end{bmatrix} \begin{bmatrix} h_{11,t-1} \\ h_{12,t-1} \\ h_{22,t-1} \end{bmatrix}$$

For both the vec and the diagonal vec, it is required that H_t is positive definite for all values of ϵ_t. This is very difficult to check or impose during estimation. Therefore a BEKK representation is proposed by Engel and Kroner (1995) which is positive definite due to its construction.

b. *GARCH (1,1) with BEKK representation*

The BEKK model was originally proposed in an unpublished manuscript by Baba, Engle, Kraft, and Kroner, and hence the name BEKK (Baba, Engle, Kraft and Kroner 1989). As previously mentioned, the key feature of the BEKK parameterisation is that positive definite covariance matrices are generated by essentially unrestricted parameterisations. The representation is described based on the model by Engle and Kroner (1995), as adapted for its use in this research report.

The process first requires that the conditional variances are estimated from the GARCH(1,1) model

$$(23)\qquad R_t = \gamma + \beta\, \mathrm{R}_{t-1} + \eta_t$$

where R_t denotes the returns on the stock index SI_t and bond index BI_t, therefore $R_t = (SI_t, BI_t)$.

The residual vector $\eta_t = (\epsilon_{1,t}, \epsilon_{2,t})$ is bivariate and normally distributed $\eta_t | I_{t-1} \sim (0, Ht)$. The corresponding conditional variance covariance matrix of ηt is given by

(24) $$H_t = \begin{bmatrix} h_{11t} & h_{12t} \\ h_{21t} & h_{22t} \end{bmatrix}$$

The parameter vector of the mean return equation (23) is defined by: $\gamma = (\gamma_1, \gamma_2)$ where γ is a constant; and $\beta = (\beta_1, \beta_2)$, where β is the autoregressive or GARCH term.

The parameter matrices for the variance equation (24) are defined as C_0, A_{11} and G_{11}. C_0 is restricted to be lower triangular, while A_{11} and G_{11} are unrestricted matrices. The second moment therefore takes the following general form:

(25) $$H_t = \mathrm{C}_0'\mathrm{C}_0 + A'\epsilon_{t-1}\epsilon_{t-1}'A + G'H_{t-1}G$$

For the bivariate case, the GARCH(1,1) model without exogenous factors can be expanded as per equation (26):

(26) $$H_t = \mathrm{C}_0'\mathrm{C}_0 + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \epsilon_{1,t-1}^2 & \epsilon_{1,t-1}\epsilon_{2,t-1}' \\ \epsilon_{1,t-1}\epsilon_{2,t-1}' & \epsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}$$

Caporale et al. (2002:237) explain that equation (24) models the "dynamic process of H_t as a linear function of its own past values H_{t-1} as well as the past values of the squared innovations $(\epsilon_{1,t-1}, \epsilon_{2,t-1})$, hence allowing both own-market and cross-market influences in the conditional variance". The specification allows the influence of the two series' conditional variances and covariance on each other, and therefore the impact of information arrival on two different markets can be observed. Testing of the null hypothesis of no volatility spillover effects in one or

both directions is possible. This can be further illustrated by illustrating the causality of H_t, as

(27) $h_{11,t} = c_{11}^2 + c_{21}^2 + a_{11}^2\epsilon_{1,t-1}^2 + 2a_{11}a_{21}\epsilon_{1,t-1}\epsilon_{2,t-1} + a_{21}^2\epsilon_{2,t-1}^2 + g_{11}^2 h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g_{21}^2 h_{22,t-1}$

(28) $h_{12,t} = c_{21}c_{22} + a_{11}a_{12}\epsilon_{1,t-1}^2 + (a_{21}a_{12} + a_{11}a_{22})\epsilon_{1,t-1}\epsilon_{2,t-1} + a_{21}a_{22}\epsilon_{2,t-1}^2 + g_{11}g_{12}h_{11,t-1} + g_{12}g_{21}h_{21,t-1} + g_{11}g_{22}h_{12,t-1} + g_{21}g_{22}h_{22,t-1}$

(29) $h_{22,t} = c_{22}^2 + a_{12}^2\epsilon_{1,t-1}^2 + 2a_{12}a_{22}\epsilon_{1,t-1}\epsilon_{2,t-1} + a_{22}^2\epsilon_{2,t-1}^2 + g_{12}^2 h_{11,t-1} + 2g_{11}g_{12}h_{12,t-1} + g_{22}^2 h_{22,t-1}$

In order to test the null hypothesis of no volatility spillover, a hypothesis test is assumed of no conditional variance between market 1 and market 2. Matrices A and G are restricted to be upper triangular, thereby allowing for the investigation of the causality effect of $h_{11,t}$ on $h_{22,t}$. The hypothesis test of H_0: $a_{12} = g_{12} = 0$, combined with the restriction on the matrices, implies that $h_{11,t}$ does not have a causal effect on $h_{22,t}$.

In order to test the causality of each market on the other one, the restricted model is run twice, while swapping the variables each time. Each variable therefore has a chance to be the independent variable respectively, and the full model is simulated (Fang et al. 2006). This is opposed to the method of Caporale et al. (2006), who vary the restrictions of A_{11} and $G_{11}$to upper triangular and lower triangular, thereby allowing testing of causality in either direction.

Caporale et al. (2006) further indicate that under the null hypothesis H_0: $a_{21} = g_{21} = 0$, which allows causality in variance in one direction at a time, requires $T \geq 3000$ for empirical rejection frequencies to be within a reasonable range of the nominal 5% significance level, thereby avoiding a Type-1 error. In this research report, a significance level of 1% was used as suggested by Karolyi (1995).

The parameters of the BEKK representation, as in the univariate case, are estimated through the maximisation of the log likelihood function, L. The log likelihood function used in this research is illustrated in equation 30 and 31 (Estima 2007a).

(30) $$L = \sum_{t=1}^{T} f(R_t|I_{t-1};\theta)$$

(31) $$f(R_t|I_{t-1};\theta) = -\frac{1}{2}(2\log 2\pi + \log|H_t| + \epsilon_t'(H_t^{-1})\epsilon_t)$$

where θ is the vector of unknown parameters.

T is the number of observations in the sample

R_t is the vector of returns

Caporale et al. (2006) propose that the log likelihood function be maximised numerically using the Broyden, Fletcher, Goldfarb and Shanno algorithm in order to yield maximum likelihood estimates. Standard errors are proposed to be calculated using the quasi-maximum likelihood methods of Bollerslev and Wooldridge (1992), which are robust to the distribution of the underlying residuals.

Engle and Kroner (1995) indicate that there is a covariance stationary condition that requires that all the eigenvalues of $A_{11}\otimes A_{11} + G_{11}\otimes G_{11}$must be less than one in modulus.

3.3 Population and sample

3.3.1 Population

The research population in this research proposal would include the volatility of the following:

- All equity investments for listed companies in South Africa. While the findings of this report may be applicable to unlisted companies, the research report deals primarily with publicly traded and tracked companies on the JSE. Therefore the population is confined to include companies for whom information is publicly available. As the the JSE is the primary listed equity

market in South Africa, the population for this study was considered to be all firms listed on the JSE.

- All publicly traded bonds that are traded on BESA.
- All equity investments for listed companies in the US. As equity shares are traded on a number of stock exchanges in the US, the Dow Jones Industrial index in used to represent the US market.

As the population refers to the total market, the analysis of volatility of the respective populations is based on market-wide, or systematic, factors as opposed to more idiosyncratic factors.

3.3.2 Sample and sampling method

The proposed sampling method for this research report is related to obtaining data for both the relevant stock and bond markets. The period from 1 January 1999 to 27 February 2009 will be discussed in this report, and therefore the sample is related to all the data that is applicable for the relevant time period.

This specific time period is chosen because stock and bond information is easily accessible for this period; it is also sufficiently long to determine long-term trends, and yet allows for the cross-sectional, long-term relationship between the volatility of stocks and bonds to be adequately identified. The time period allows for 2672 bond and stock trading days to be analysed.

The data that is analysed on the JSE Securities Exchange is the JSE All Share Index. Therefore the All Share Index is not necessarily a sample as it is comprised from all relevant daily stocks on the JSE within the time period under consideration. The All Share Index is therefore a composite of all JSE share trading, and is not materially influenced by the volatility that may be introduced by individual stocks. The data on the stock indices are daily (five trading days per week).

The bond market will be represented by the All Bond Total Return Index or ALBI. The ALBI is a bond index administered by BESA and the Actuarial Society of SA, which provides a measure of the total returns of the bonds represented in the index. The ALBI is a sample of the bond market and is comprised of the top 20

listed bonds, ranked by market capitalisation and liquidity (BESA 2008). It therefore has the advantage that it is an aggregation of bonds within the bond market. The total return index reinvests the gross coupons received back into the bonds of the index, in order to replicate the total return. This also compensates for the sharp drop in accrued interest when a bond goes ex-dividend. Data for the index is also daily (five trading days per week).

The US stock market is represented by the Dow Jones Industrial Index. The Dow Jones Industrial Index measures the stock performance of thirty leading blue-chip US companies, and therefore is not restricted to industrial shares (Dow Jones 2009). The index has grown in line with expansion in the US economy from originally analysing 12 component shares in 1896, to its current size of 30 component shares. The stock index data observed daily (five trading days per week).

Care is taken to sample the markets in a consistent way, and therefore daily sampling of the relevant markets is proposed for this research. The appropriate frequency for observations depends on the data that is available as well as the questions that are of interest to the researcher (Taylor 2005). Daily prices offer a frequency that is convenient and appropriate to both markets. This choice of frequency also avoids effects from uneven flow of transactions during the day, which in turn creates intraday effects as discussed by many authors, including Wood, McInish and Ord (1985).

3.4 The research instrument

The research instrument used in this research report is that of a mathematical model. The particular model to be used is a multivariate GARCH(1,1) with BEKK representation (Engle and Kroner 1995). The bivariate case can therefore used in order to model the relationship between the bond and the stock market volatilities. The proposed instrument is the same instrument used by Fang et al. (2006) and Fang (Fang 2007), which was adapted from a similar research related to causality in variance (Caporale et al. 2002).

As discussed in Section 2.5.2, the instrument is applicable for two or more variables, and is an extension of the GARCH(1,1) model on which it is based. Due

to the BEKK parameterisation of the variance-covariance matrix, it does not require excessive estimation of parameters. This therefore alleviates complexities of other models that arise from re-parameterisation. The model takes into account that volatility can be transmitted from one market to another market, and estimates the unidirectional transmissions of these volatilities.

The statistical program used to implement the model was RATS v7.2. A full version of the research instrument program can be found in Appendix A. The research instrument is developed in line with the research design discussed in Section 2.5.2, with the exception that the standard errors were calculated through the "Robusterrors" option in RATS v7.2. This method of standard error calculation produces a covariance matrix that is asymptotically the same as those proposed in the research design section of this report (Trevor 1994).

The algorithm used to maximise the likelihood function is the Broyden, Fletcher, Goldfarb and Shanno algorithm as per Caporale et al. (2006). Preliminary refinement of the initial guess values is performed with iterations of the simplex algorithm, prior to the Broyden, Fletcher, Goldfarb and Shanno hill-climbing method (Estima 2007b).

The research instrument was checked against published results of Fang et al. (2006), and therefore shown to be reliable.

3.5 Procedure for data collection

Daily data for the respective indices and relevant time periods was obtained from Datastream. The final daily transaction price per day is used in this research.

The data collected was analysed for completeness, ensuring that 2672 data points, representing the number of trading days during the time period under investigation, are present in each data set. The information was visually inspected in graphical form to ensure that all information is relatively consistent with an expected visual trend, and obvious outliers investigated. This is to ensure that there are no obvious potential typing errors that are included in the information.

Random samples of the information were triangulated against other data sources, such as information from Sharenet. Therefore reliability and consistency of the data were observed.

3.6 Data analysis and interpretation

Time series data was analysed for stylised facts and applicability of the GARCH framework to the particular data set. This is intended to confirm that the time series does in fact exhibit autoregressive characteristics.

The data was then analysed according to the bivariate case of the GARCH(1,1) with BEKK representation, as described by Engle and Kroner (1995) and Caporale et al. (2002).

The maximisation of the log likelihood function estimates unknown parameters of the BEKK representation, namely $c_{11}, c_{21}, c_{22,} g_{11}, g_{12}, g_{22}, a_{11}, a_{12}, a_{22}$ ($a_{21}$and $g_{21}$are set to 0). In terms of this research proposal, interpretation of the relationship between the respective markets is based on the values of the coefficients a_{12}, and g_{12}, where the naming convention is relative to the influence of market 1 on market 2. Fang (2006) explains that should the coefficients not be significantly different from 0, it would imply that the unidirectional transmission of volatility between the particular markets does not exist, and the markets do not exert an influence over one another. Should the value of a_{12} be significant, it would indicate the level of influence that news or shocks from the initial market have on the secondary market volatility. This can be directly interpreted as the coefficient being the percentage change that a 1% shift in the volatility of the primary market would have on the secondary market. Similarly, a significant value of g_{12} indicates the influence the primary market volatility persistence, or previous days' volatility, has on the secondary market volatility.

The effect of news or shocks can be graphically represented through a news impact surface, as proposed by Kroner and Ng (1998). The news impact surface is achieved through setting the respective historical variance and covariance to historical average levels in order to determine the effect news will have on the predicted variance and covariance. In this report, a convention is assumed where

coefficients not statistically different from 0 at the 1% level are set to 0 in the news impact curves.

3.7 Limitations of the study

- The period under consideration may include structural breaks or changes in trends of the volatility of the South African stock market, South African bond market, or the US stock market, yet the period is being considered as a whole continuous time series. This could have an impact on the derived relationship and interpretation between the volatilities of the respective markets, if shorter time periods were to be studied.
- The study investigates aggregated indices, and therefore is analysing the market-related relationships. These relationships may not describe individual shares or bonds.
- Fleming et al. (1998) have identified the process of using a maximum likelihood procedure with a GARCH(1,1) model as yielding noisy estimates. This could therefore influence the analysis of the information.

3.8 Validity and reliability

Kirk and Miller (1986) refer to the three types of reliability in quantitative research, namely:

- the degree to which measurement, which is given repeatedly, remains the same
- the stability of the measurement over time
- the similarity of measurements within a given time period.

As the instrument proposed in this research proposal is a mathematical model, the outcome of the model, given the same inputs, will prove to be extremely reliable. This is largely due to the same process that is followed within the model. As data or information on which the mathematical process is based comprises historical data, it will not change with time. Therefore, any study of the same markets over the same time periods will produce the same result, thereby confirming the first two types of reliability according to the Kirk and Miller (1986) definition.

Validity of the mathematical model requires the model to actually be measuring what it is intended to measure (Golafshani 2003).

3.8.1 External validity

"External validity examines whether or not an observed causal relationship should be generalized to and across different measures, persons, settings, and times" (Calder, Phillips and Tybout 1982:240). As the literature review has revealed, the volatility of markets changes over time, and these underlying reasons for these changes are not thoroughly understood. The literature review also detailed volatility transmission relationships that exists between markets. The influence and degree of the transmission varied in nature (positive and negative), as well as in strength, depending on the particular market. The volatility transmission relationship between markets is market-specific and therefore needs to be tested on a market-by-market basis. Therefore, it is not proposed that the findings of research be generalised to other markets.

The research deals primarily with aggregated indices of the particular markets, and therefore the relationships that are identified cannot without further research be assumed to be true for individual stocks or bonds within the respective markets.

The nature of the transmission relationship between the volatility of markets is shown to have changed in certain countries following a structural shift. Therefore it is proposed that the findings of this research are not necessarily relevant to the South African stock market, bond market and US stock market in the future should the respective markets undergo a structural shift or crisis.

Likewise, the findings of this research should not automatically be assumed as relevant within the South African context historically before 1999.

3.8.2 Internal validity

Internal validity is concerned with whether or not an observed covariation should be considered a causal relationship (Calder et al. 1982). There are three types of internal validity in common use, namely: content, criterion-related and construct validity (Lynn 1986).

Lynn (1986) differentiates between content validity and face validity, as it is argued that face validity is defined as the validity conferred by the lay person's acceptance that the statement, procedure or instrument appears to be relevant and sound, and therefore is not quantifiable. Content validity is proposed to be the quantifiable measure of the extent to which an instrument measures what it is intended to measure. The content validity of the instrument proposed in this research report is considered to be internally valid with regard to content validity. This is can be confirmed through the use of an instrument that has previously been used for similar applications (Engle and Kroner 1995; Caporale et al. 2002, 2006; Fang et al. 2006; Fang 2007). Caporale et al. (2002) not only test the initial data to validate well-known stylised facts about time series data, but also perform Monte Carlo experiments on the research instrument to validate their confidence intervals for their hypothesis tests are reasonable.

Construct validity is broadly defined as the extent to which an operation measures the concept it is supposed to measure (Bagozzi, Yi and Phillips 1991). As the application of the generic GARCH(1,1) model through the GARCH(1,1) with BEKK representation, which decomposes the initial model into the multivariate constituents, has been generally used, it is considered to have construct validity. Construct validity is also confirmed for the instrument as the instrument produces similar results to other instruments (Fleming et al. 1998), and is able to discriminate between similar constructs through its decomposition into multivariate constituents. The application of transmission of volatility as a result of analysing the multivariate constituents is considered to be within the framework of the GARCH(1,1) with BEKK representation. An important aspect of the validity is that a standard error is calculated to illustrate potential concerns with moulding the GARCH model onto the data. The standard error calculation therefore compensates for the concern of Fleming et al. (1998) that maximum likelihood procedures used in GARCH modelling can yield noisy estimates.

3.8.3 Reliability

As previously mentioned, Kirk and Miller (1986) analyse quantitative reliability in terms of: the degree to which measurement, which is given repeatedly, remains the same; the stability of the measurement over time; and the similarity of measurements within a given time period.

As this research report aims to use data with a mathematical model, the outcome of the model should remain stable and therefore the accuracy of the model will remain high, even with repeated testing.

In order to ensure that the model used in this research is in fact consistent and reliable with relevant theory, the findings of published research were replicated using the GARCH(1,1) with BEKK parameterisation model. Research by Fang et al. (2006) into the relationship between the volatility of the Dow Jones Industrial Index and the JP Morgan Government Bond Index was successfully verified with the model used in this research. The results of the verification process are illustrated in Appendix D and are considered appropriate for the hill-climbing search algorithm used. Interpretation of the results takes into account that due to the positive definite nature of the BEKK representation, “changing the signs of all elements of C, B or A will have no effect on the function value” (Estima 2007b:428).

However, the data used could have an effect on the effectiveness of the research proposal, and hence on the reliability of the conclusions from the research. The collection of data is therefore of vital importance to ensure the reliability of the research. For this reason, respectable data sources are used as described in the data collection section of this report, and are also cross-verified or triangulated to ensure that the information is reliable. Interpretation of the data with respect to potential structural breaks within the time series could influence the results. Therefore, the potential error introduced by different investigators or different samples, or equivalence, is considered a potential issue.

CHAPTER 4: PRESENTATION OF RESULTS

4.1 Introduction

This chapter provides a description of data from the South African stock market, bond market and US stock market. The results of all the hypotheses tests proposed in Chapter 2 are also presented. Results of the tests are discussed in Chapter 5.

4.2 Description of data

The daily closing price information was obtained from 31 December 1998 to 27 February 2009 for the South African JSE All Share Price Index, All Bond Total Return Index and US Dow Jones Industrial Index. The information was obtained from Datastream. The covered period is analysed as daily returns.

Table 1 presents descriptive statistics and preliminary diagnostics for the daily returns of the respective stock and bond indices.

Table 1: Summary statistics of daily returns of ALBI, JSE All Share Index and Dow Jones Industrial Index

	ALBI	ALLSHARE	DJI
Mean	0.000505	0.000530	-0.000062
Median	0.000369	8.85E-05	0.000000
Maximum	0.049544	0.068340	0.105083
Minimum	-0.075633	-0.078968	-0.082005
Std. Dev.	0.004563	0.013167	0.012769
Skewness	-1.475923	-0.168442	0.030566
Kurtosis	41.88500	6.834081	11.11658
Jarque-Bera	169247.5	1648.638	7332.185
Probability	0.000000	0.000000	0.000000
Sum	1.349864	1.415686	-0.166118
Sum Sq. Dev.	0.055586	0.462875	0.435333
Observations	2671	2671	2671

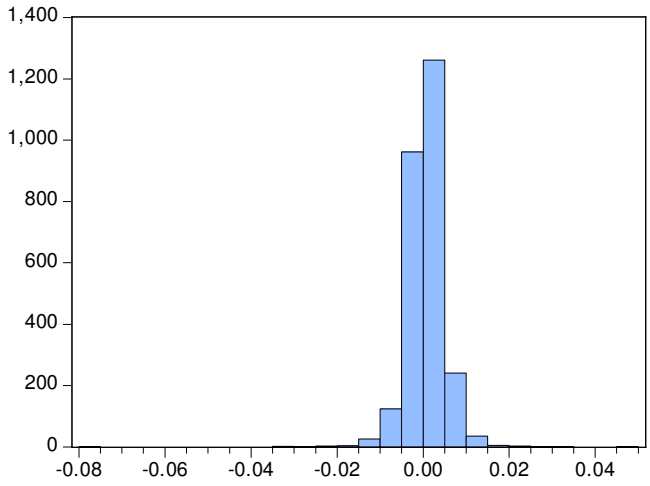


Figure 2: Distribution of daily returns of South African All Bond Total Return Index

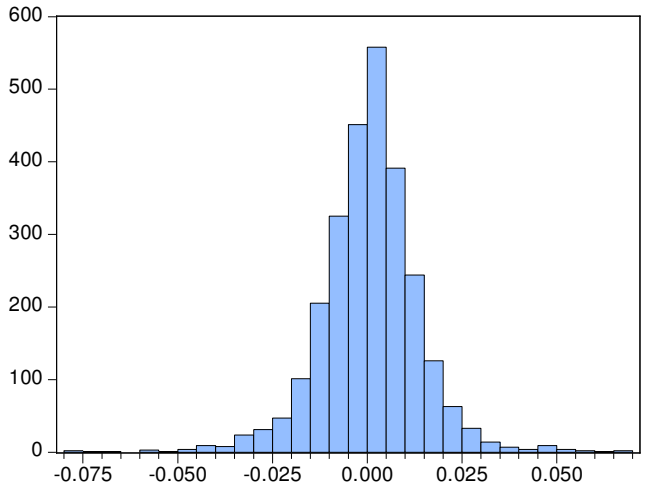


Figure 3: Distribution of daily returns of JSE All Share Index

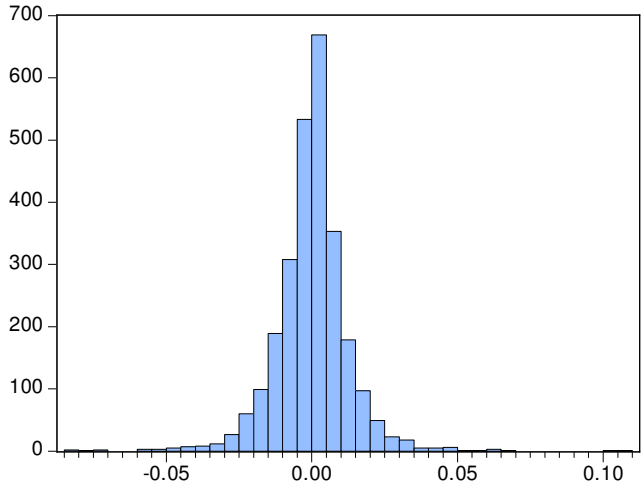


Figure 4: Distribution of daily returns of US Dow Jones Industrial Index

The standard deviation of the JSE All Share stock index and Dow Jones Industrial Index are seen to be nearly three times that of the bond index. This is consistent with the general impression that the stock market is more risky than the bond market. Both South African time series exhibit negative skewness, implying that both series' tail of the distribution is heavier on the right, with the Dow Jones Index indicating slightly positive skewness. Excess kurtosis can be observed in all three series, with the distribution being far more peaked or leptokurtic relative to normal in the case of the bond index. The Jarque-Bera test statistic rejects the null hypothesis of a normal distribution in all cases.

Visual inspection of the time series, as illustrated in Figures 5, 6, 7 and 8, indicates that they exhibit volatility clustering with periods of low volatility and periods of high volatility. This is a sign of the presence of an ARCH effect in the time series.

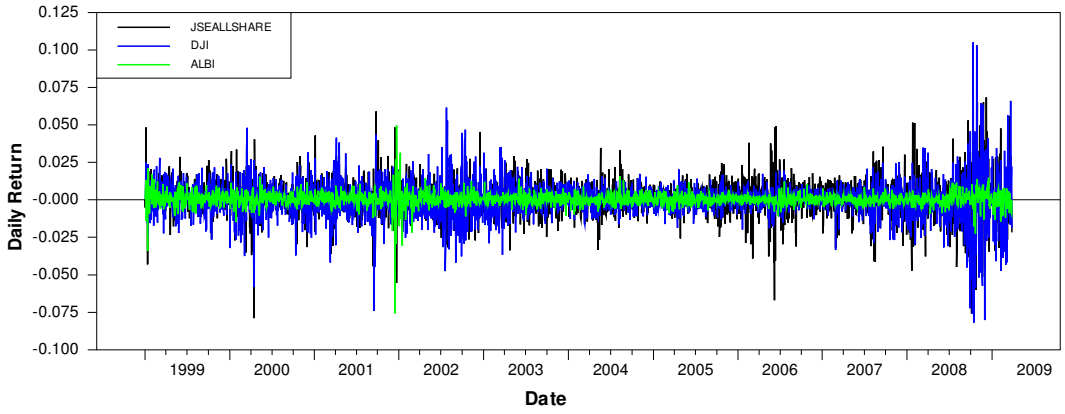


Figure 5: South African All Bond Total Return Index, JSE All Share Index and Dow Jones Industrial Index daily returns

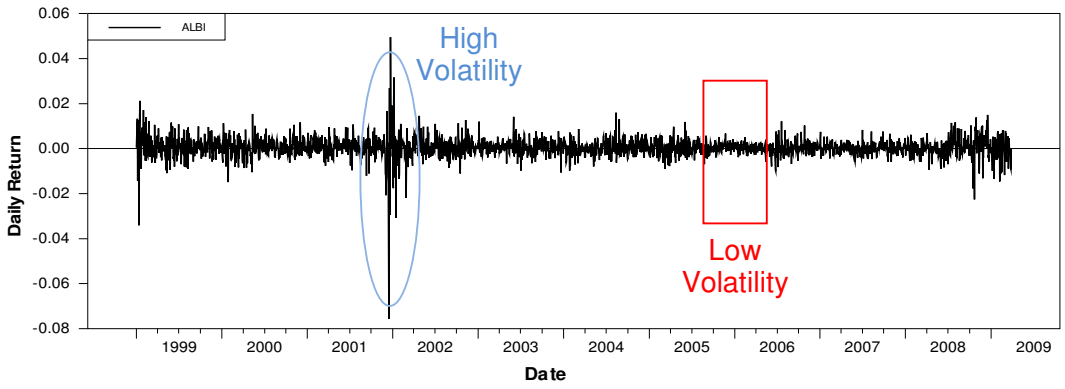


Figure 6: South African All Bond Total Return Index illustrating volatility clustering

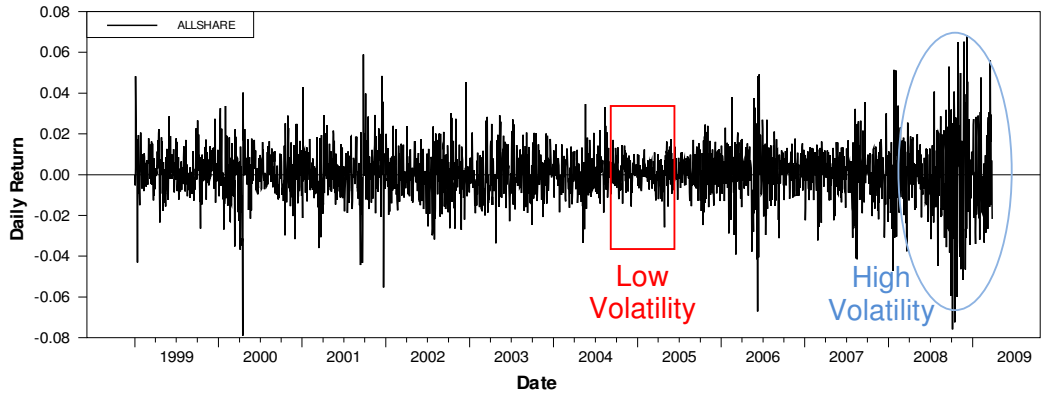


Figure 7: South African JSE All Share Index illustrating volatility clustering

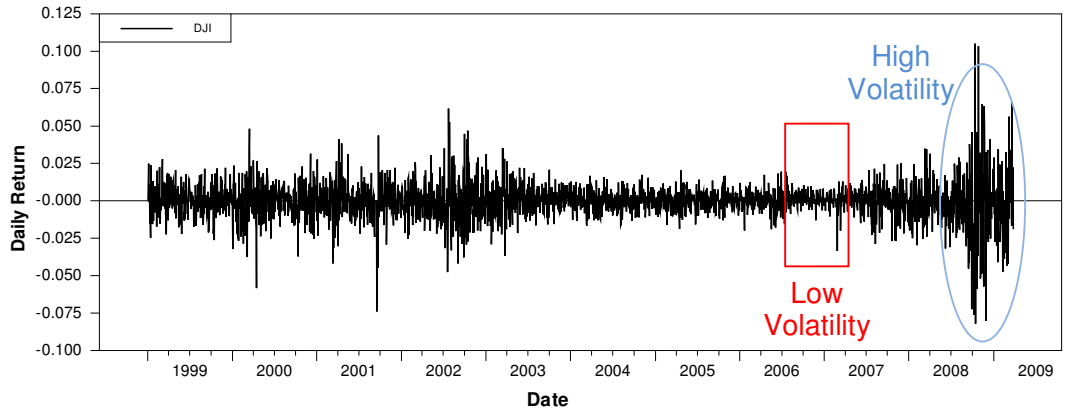


Figure 8: Dow Jones Industrial Index illustrating volatility clustering

An ARCH test on the three series, as proposed by Engle (1982), rejects the null hypothesis of no ARCH effects in the series, thereby confirming the presence of ARCH terms. Therefore, estimation using a GARCH model can be considered appropriate. Results of these tests are illustrated in Appendix C.

Visual inspection of the autocorrelogram of the squared returns (with 36 lags) can also be used to visually explain the volatility clustering. Figures 9 ,10 and 11 suggest that the squared returns of the All Share Index and Bond Index are strongly autocorrelated, exhibiting volatility clustering.

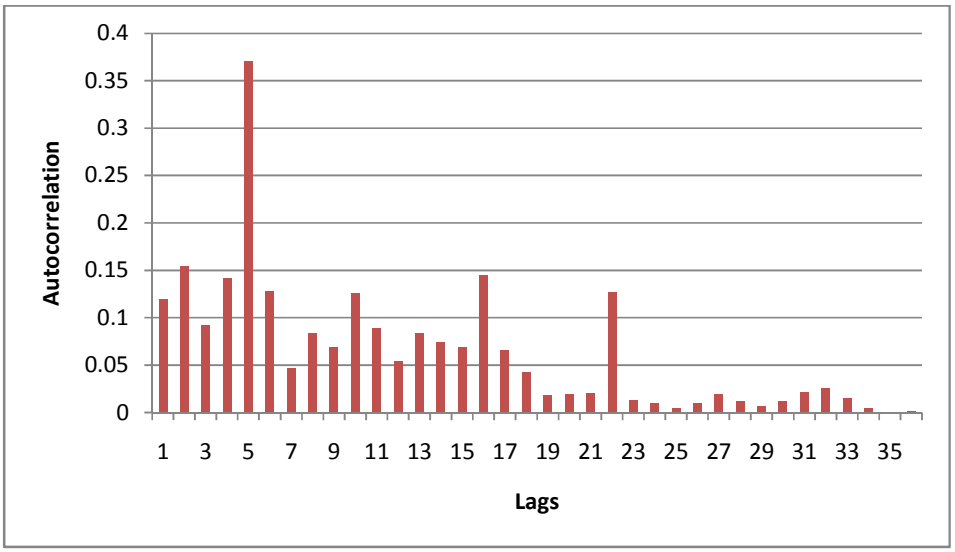


Figure 9: Autocorrelogram of the squared returns of South African All Bond Total Return

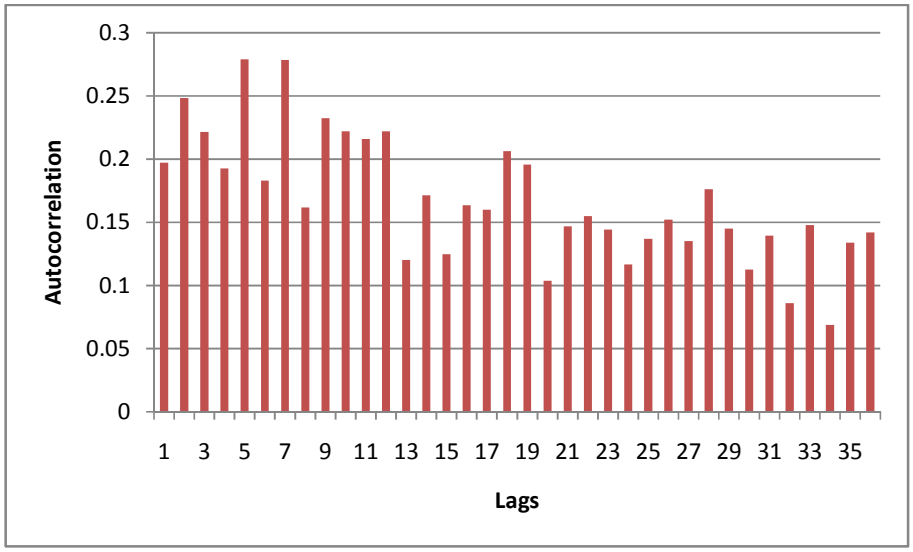


Figure 10: Autocorrelogram of the squared returns of JSE All Share Index

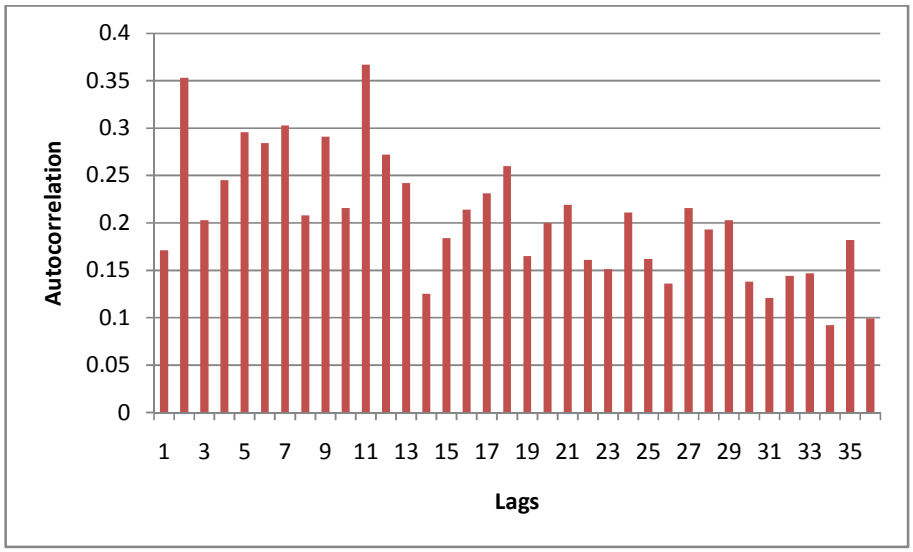


Figure 11: Autocorrelogram of the squared returns of Dow Jones Industrial Index

The Ljung-Box test statistic for raw and squared returns rejects the null hypothesis of white noise in all cases at the 95% level. Details of these test results can be found in Appendix B. This further suggests evidence of non-linear dependence of the return series, which could be due to changing conditional volatility over time.

4.3 Results pertaining to Hypothesis 1

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the South African stock market to the local bond market are illustrated in Table 2. The results illustrate the coefficients, and their respective standard errors and significance, for the previously discussed BEKK variance covariance equation (25):

(25) $$H_t = \mathrm{C}_0'\mathrm{C}_0 + A'\epsilon_{t-1}\epsilon_{t-1}'A + G'H_{t-1}G$$

Table 2: Volatility transmission from South African stock market to South African bond market

Variable	Coefficient		Standard Error	T-Stat	Significance
B(1)	0.0009	*	0.0003	3.7107	0.0002
B(2)	0.0005	*	0.0001	6.8499	0.0000
C(1,1)	0.0021	*	0.0003	7.4472	0.0000
C(2,1)	-0.0005	*	0.0001	-4.4864	0.0000
C(2,2)	0.0000		0.0000	-0.0001	0.9999
A(1,1)	0.3139	*	0.0210	14.9212	0.0000
A(2,1)					
A(1,2)	0.0089		0.0096	0.9317	0.3515
A(2,2)	0.2777	*	0.0393	7.0612	0.0000
G(1,1)	-0.9368	*	0.0101	92.3034	0.0000
G(2,1)					
G(1,2)	-0.0571	*	0.0111	5.1449	0.0000
G(2,2)	0.9528	*	0.0115	-82.9195	0.0000

* Indicates significance at the 1% level
Results satisfy covariance stationary conditions of Engle and Kroner (1995)

Table 2 indicates that all coefficients except c_{22} and a_{12} are statistically significant at the 1% level.

The estimated coefficient G(2,2) representing for the degree of volatility persistence of the South African bond market on itself is highly persistent.

The null hypothesis of volatility transmission from stock to bond, or H_0: $a_{SAs_SAb} = a_{12} = 0$, cannot be rejected at the 1% significance level.

The null hypothesis of H_0: $g_{SAs_SAb} = g_{12} = 0$ can, however, be rejected, confirming that the coefficient of the influence of past conditional variances from the stock market on the bond market is significant at the 1% level.

The news impact surface for the variance and covariance, conditional on news from the South African stock market(ϵ_1) and the South African bond market (ϵ_2), is illustrated in figure 12.

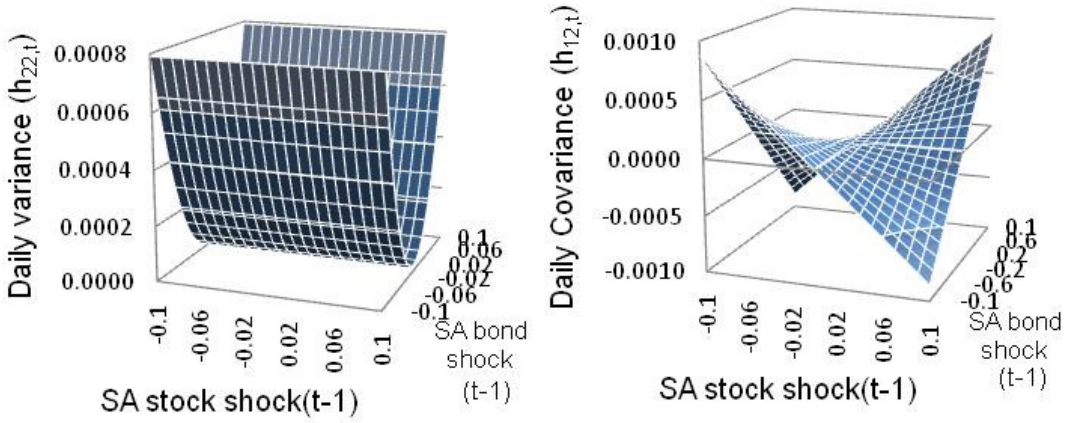


Figure 12: News impact surface for the variance and covariance of the South African bond market using South African bond and stock market shocks

4.4 Results pertaining to Hypothesis 2

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the South African stock market to the bond market are illustrated in Table 3.

Table 3: Volatility transmission from South African bond market to South African stock market

Variable	Coefficient		Standard Error	T-Stat	Significance
B(1)	0.0005	*	0.0001	8.5984	0.0000
B(2)	0.0009	*	0.0002	4.3501	0.0000
C(1,1)	0.0006	*	0.0001	4.5282	0.0000
C(2,1)	0.0021	*	0.0003	6.8960	0.0000
C(2,2)	0.0000		0.0006	-0.0003	0.9997
A(1,1)	0.2822	*	0.0453	6.2238	0.0000
A(2,1)					
A(1,2)	-0.0318		0.0428	-0.7435	0.4572
A(2,2)	0.3103	*	0.0238	13.0258	0.0000
G(1,1)	-0.9513	*	0.0145	65.7566	0.0000
G(2,1)					
G(1,2)	-0.0813		0.1336	0.6086	0.5428
G(2,2)	0.9378	*	0.0097	-96.2835	0.0000

* Indicates significance at the 1% level
Results satisfy covariance stationary conditions of Engle and Kroner (1995)

Table 3 indicates that all coefficients except c_{22}, a_{12} and g_{12} are statistically significant at the 1% level.

The estimated coefficient G(2,2), representing the degree of volatility persistence of the South African stock market on itself, is highly persistent.

The null hypothesis of volatility transmission from stock to bond, or H_0: $a_{SAb_SAs} = a_{12} = 0$, as well as the hypothesis H_0: $g_{SAb_SAs} = g_{12} = 0$, cannot be rejected at the 1% significance level. This suggests that the South African bond market volatility has no influence on the volatility of the South African stock market.

The news impact surface for the variance and covariance, conditional on news from the All Bond Index (ϵ_1) and the South African stock market (ϵ_2), is illustrated in figure 13.

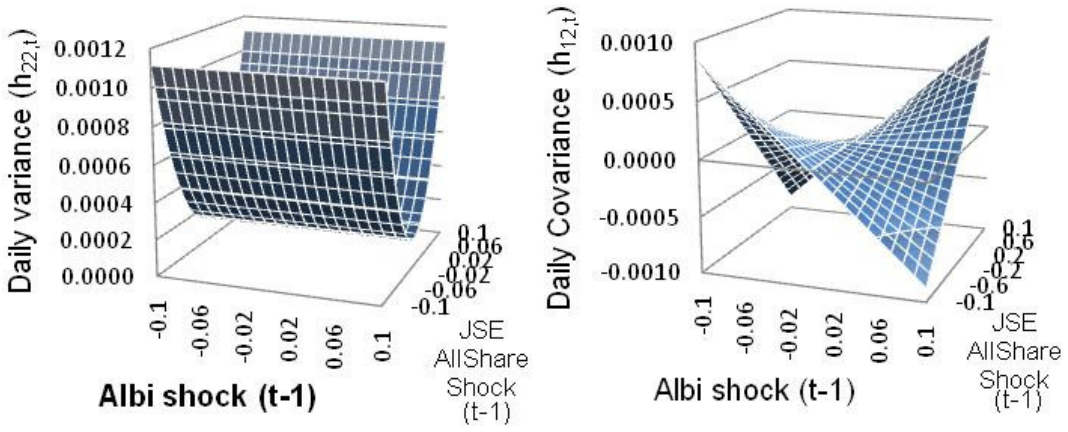


Figure 13: News impact surface for the variance and covariance of the South African stock market using South African bond and stock market shocks.

4.5 Results pertaining to Hypothesis 3

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the US stock market to the South African bond market are illustrated in Table 4.

Table 4: Volatility transmission from the US stock to the South African bond market

Variable	Coeff		Standard Error	T-Stat	Significance
B(1)	0.0003		0.0002	1.5728	0.1158
B(2)	0.0005	*	0.0001	8.3335	0.0000
C(1,1)	0.0009	*	0.0002	3.8209	0.0001
C(2,1)	-0.0002		0.0001	-1.3198	0.1869
C(2,2)	0.0006	*	0.0001	4.8765	0.0000
A(1,1)	0.2414	*	0.0197	12.2288	0.0000
A(2,1)					
A(1,2)	-0.0236		0.0119	-1.9900	0.0466
A(2,2)	0.2947	*	0.0432	6.8186	0.0000
G(1,1)	0.9689	*	0.0055	175.5625	0.0000
G(2,1)					
G(1,2)	0.0072		0.0033	2.1931	0.0283
G(2,2)	0.9443	*	0.0127	74.5923	0.0000

* indicates significance at the 1 % level
Results satisfy covariance stationary conditions
of Engle and Kroner (1995)

Table 4 indicates that all coefficients except c_{21}, a_{12} and g_{12} are statistically significant at the 1% level.

The estimated coefficient G(2,2), representing the degree of volatility persistence of the South African bond market on itself, is highly persistent.

The null hypothesis of volatility transmission from South African bond to US stock market, or $H_0: a_{USs_SAb} = a_{12} = 0$, as well as the hypothesis $H_0: g_{USs_SAb} = g_{12} = 0$, cannot be rejected at the 1% significance level. This suggests that the US stock market volatility has no influence on the volatility of the South African market.

The news impact surface for the variance and covariance, conditional on news from the US stock market (ϵ_1) and the South African bond market (ϵ_2), is illustrated in figure 14.

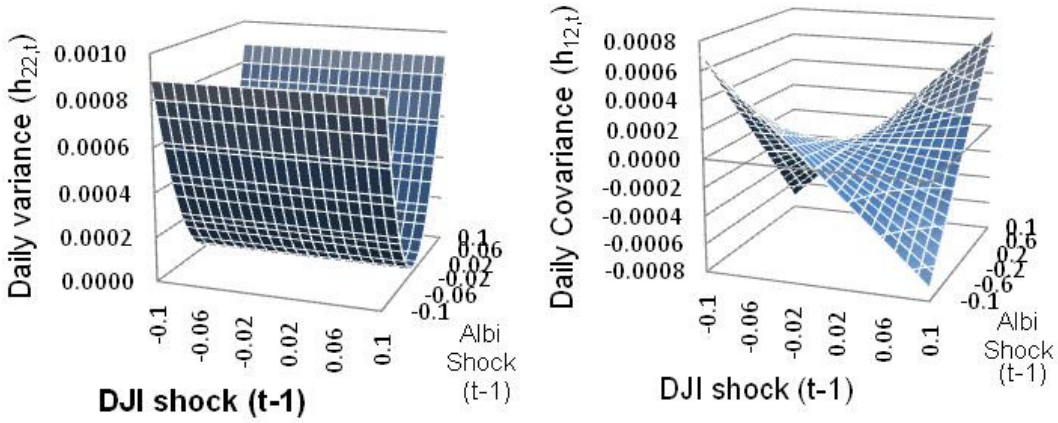


Figure 14: News impact surface for the variance and covariance of the South African bond market using US stock and South African bond market shocks.

4.6 Results pertaining to Hypothesis 4

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the South African bond market to the US stock market are illustrated in Table 5.

Table 5: Volatility transmission from the South African bond market to US stock market

Variable	Coeff		Standard Error	T-Stat	Significance
B(1)	0.0005	*	0.0001	7.3403	0.0000
B(2)	0.0003		0.0002	1.9254	0.0542
C(1,1)	0.0005	*	0.0001	4.6873	0.0000
C(2,1)	0.0000		0.0002	0.0156	0.9875
C(2,2)	-0.0009	*	0.0002	-3.7616	0.0002
A(1,1)	0.2910	*	0.0424	6.8707	0.0000
A(2,1)					
A(1,2)	-0.0107		0.0335	-0.3207	0.7484
A(2,2)	0.2400	*	0.0178	13.4520	0.0000
G(1,1)	0.9496	*	0.0133	71.5548	0.0000
G(2,1)					
G(1,2)	0.0067		0.0137	0.4886	0.6252
G(2,2)	0.9691	*	0.0047	204.0889	0.0000

* indicates significance at the 1 % level
Results satisfy covariance stationary conditions
of Engle and Kroner (1995)

Table 5 indicates that all coefficients except c_{21}, a_{12} and g_{12} are statistically significant at the 1% level.

The estimated coefficient G(2,2), representing the degree of volatility persistence of the US stock market on itself, is highly persistent.

The null hypothesis of volatility transmission from South African bond to US stock markets, or H_0: $a_{SAb_USs} = a_{12} = 0$, as well as the hypothesis H_0: $g_{SAb_USs} = g_{12} = 0$, cannot be rejected at the 1% significance level. This suggests that the South African bond market has no influence on the volatility of the US stock market.

The news impact surface for the variance and covariance, conditional on news from the South African bond market (ϵ_1) and the US stock market (ϵ_2), is illustrated in figure 15.

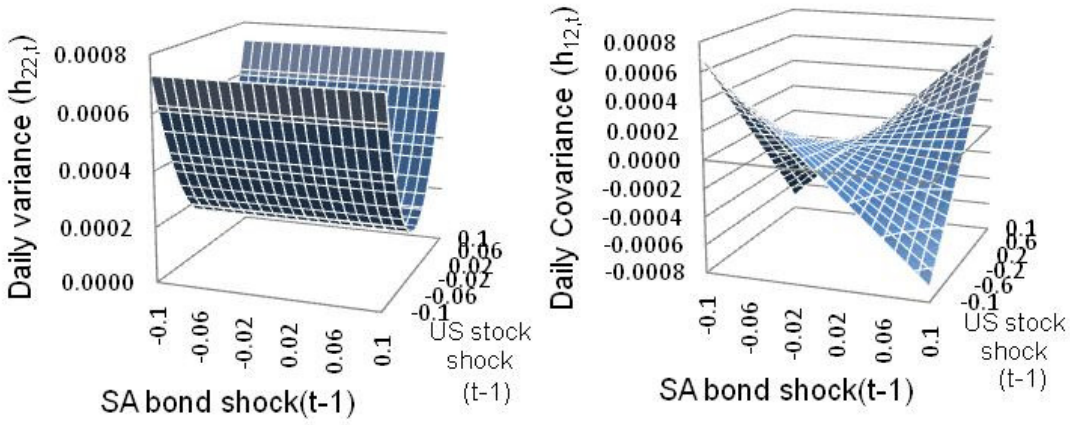


Figure 15: News impact surface for the variance and covariance of the US stock market using US stock and South African bond market shocks.

4.7 Results pertaining to Hypothesis 5

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the US stock market to the South African stock market are illustrated in Table 6.

Table 6: Volatility transmission from the US stock market to South African stock market

Variable	Coeff		Standard Error	T-Stat	Significance
B(1)	0.0004		0.0002	2.1318	0.0330
B(2)	0.0010	*	0.0003	3.7972	0.0001
C(1,1)	0.0009	*	0.0002	4.3680	0.0000
C(2,1)	0.0020	*	0.0002	9.8429	0.0000
C(2,2)	0.0000		0.0008	0.0024	0.9981
A(1,1)	0.2242	*	0.0194	11.5382	0.0000
A(2,1)					
A(1,2)	0.1290	*	0.0369	3.4993	0.0005
A(2,2)	0.2573	*	0.0187	13.7574	0.0000
G(1,1)	-0.9727	*	0.0042	231.4651	0.0000
G(2,1)					
G(1,2)	-0.4901	*	0.0382	12.8363	0.0000
G(2,2)	0.9460	*	0.0074	-127.1135	0.0000

* indicates significance at the 1 % level
Results satisfy covariance stationary conditions of Engle and Kroner (1995)

Table 6 indicates that all coefficients except c_{21} are statistically significant at the 1% level.

The estimated coefficient G(2,2), representing the degree of volatility persistence of the South African stock market on itself, is highly persistent.

The null hypothesis of volatility transmission from US stock market to the South African stock markets, or $H_0: a_{USs_SAs} = a_{12} = 0$, as well as the hypothesis $H_0: g_{USs_SAs} = g_{12} = 0$, is rejected at the 1% significance level. This suggests that the South African stock market volatility is influenced by shocks in the US stock market as well as volatility persistence of the US stock market.

The news impact surface for the variance and covariance, conditional on news from the US stock market (ϵ_1) and the South African stock market (ϵ_2), is illustrated in figure 16.

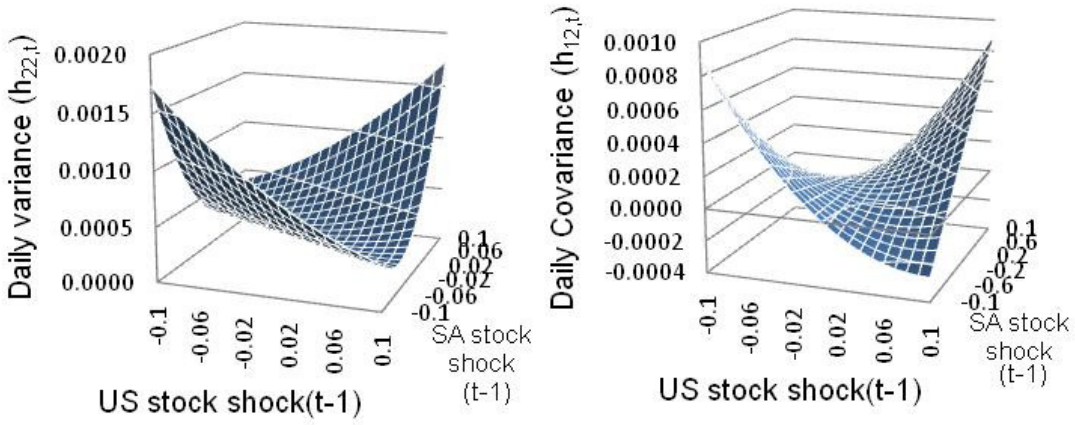


Figure 16: News impact surface for the variance and covariance of the South African stock market using US stock and South African stock market shocks.

4.8 Results pertaining to Hypothesis 6

Estimation results of the bivariate GARCH model with BEKK representation for the variance equation for the transmission of volatility from the South African stock market to the US stock market are illustrated in Table 7.

Table 7: Volatility transmission from the South African stock market to US stock market

Variable	Coeff		Standard Error	T-Stat	Significance
B(1)	0.0011	*	0.0002	5.0529	0.0000
B(2)	0.0004		0.0002	2.0891	0.0367
C(1,1)	0.0021	*	0.0003	7.2417	0.0000
C(2,1)	0.0012	*	0.0002	6.3451	0.0000
C(2,2)	0.0000		0.0002	-0.0001	0.9999
A(1,1)	-0.3154	*	0.0252	-12.5282	0.0000
A(2,1)					
A(1,2)	-0.0601	*	0.0147	-4.0941	0.0000
A(2,2)	0.2146	*	0.0193	11.1154	0.0000
G(1,1)	-0.9364	*	0.0103	-90.6010	0.0000
G(2,1)					
G(1,2)	-0.3820	*	0.0323	-11.8233	0.0000
G(2,2)	0.9736	*	0.0047	207.8575	0.0000

* indicates significance at the 1 % level
Results satisfy covariance stationary conditions
of Engle and Kroner (1995)

Table 7 indicates that all coefficients except c_{22} are statistically significant at the 1% level.

The estimated coefficient G(2,2), representing the degree of volatility persistence of the US stock market on itself, is highly persistent.

The null hypothesis of volatility transmission from South African stock market to the US stock markets, or H_0: $a_{SAs_USs} = a_{12} = 0$, as well as the hypothesis H_0: $g_{SAs_USs} = g_{12} = 0$, is rejected at the 1% significance level. This suggests that the US stock market volatility is negatively influenced by shocks in the South African stock market as well as volatility persistence of the South African stock market.

The news impact surface for the variance and covariance, conditional on news from the South African stock market (ϵ_1) and the US stock market (ϵ_2), is illustrated in figure 17.

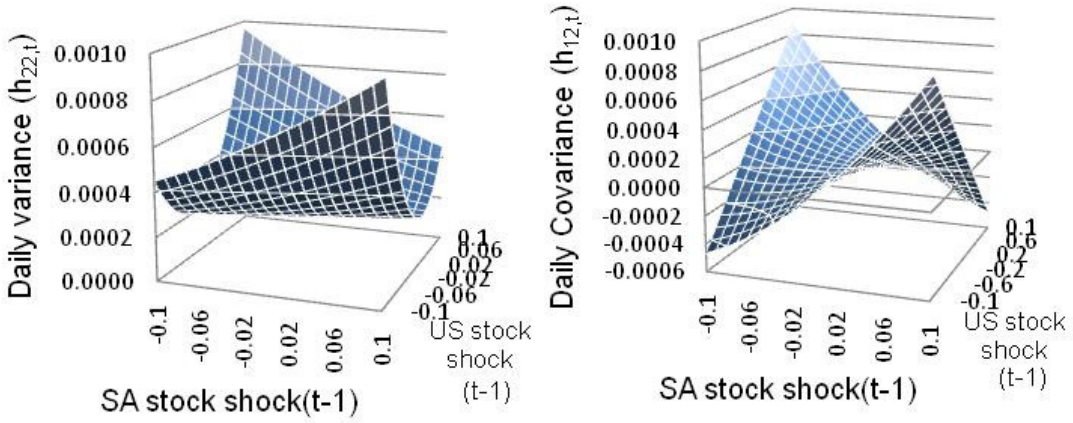


Figure 17: News impact surface for the variance and covariance of the US stock market using South African stock and US stock market shocks.

4.9 Summary of the results

The descriptive statistics for the daily returns of the JSE All Share Index, the ALBI Total Return Index and the Dow Jones Index have been described. The South African bond index displays less volatility than the stock markets, where both all markets data display excess kurtosis. The South African stock and bond index display negative skewness, with the Dow Jones index revealing a slight positive skewness over the sample tested. The results of the kurtosis and skewness lead to a rejection of the null hypothesis of a normal distribution in the Jarque-Bera test for all series.

All series also display volatility clustering, which is visually observed as well as tested for using an ARCH test. An autocorrelogram confirms that the time series are strongly autocorrelated, and it has been confirmed that this is not due to white noise.

The results of the GARCH(1,1) model with BEKK representation determining the potential causal effect of the respective South African stock market, South African bond market and the US stock market on each other are illustrated in Tables 2 to 7. All GARCH(1,1) with BEKK representation results in this chapter meet the covariance stationary requirement of Engle and Kroner (1995).

The estimate of a_{12} and g_{12} for the causality of market 1 on market 2 are estimated to not be significantly different from zero at the 1% level in a number of cases.

Instances where shocks in market 1 are significantly estimated to be transmitted to the market 2, i.e. a_{12} is significant at 1% level, include from the US stock market to the South African stock market, and from the South African stock market to the US stock market.

Instances where volatility persistence of market 1 significantly transmits to the volatility of market 2, i.e. g_{12} is significant at 1% level, include from the South African stock to South African bond market; from the US stock market to the South African stock market; and from the South African stock market to the US stock market.

CHAPTER 5: DISCUSSION OF THE RESULTS

5.1 Introduction

This chapter interprets the results that were discussed in Chapter 4, and illustrates the economic implications of the results.

5.2 Results pertaining to Hypothesis 1

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the South African stock market on the South African bond market are illustrated in Table 2.

The coefficient a_{22} of 0.2777 indicates that the bond market conditional variance is significantly positively affected by its own past innovations. The estimate coefficient of g_{22} of 0.9528 reflects that the bond market volatility is highly persistent.

The cross-market volatility due to shocks in the South African stock market is found to be statistically insignificant. The lack of influence on the volatility of the bond market can be seen in the trough shape of the news impact surface illustrated in Figure 12.

The cross-market volatility from the stock market to the bond market is represented by a significant estimated coefficient g_{12} of -0.0571. This measure of volatility persistence indicates that the previous days' volatility of the stock market has a negative influence on the current bond market's volatility. It is suspected that the influence of portfolio diversification may be the cause of this relationship between the volatility of the stock market and the bond market.

The existence of volatility transmission from a domestic stock market to the particular bond market is consistent with the findings of Fang (2007), who examined the US, UK, Japanese and German markets. The negative influence of the volatility persistence from the stock to the bond market is similar only to that of Germany.

The relationship determined in this study will allow estimation of the time-varying covariance matrix, which will assist in the determination of asset pricing, portfolio selection and risk management, as alluded to in Section 1.4.

5.3 Results pertaining to Hypothesis 2

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the South African bond market on the South African stock market are illustrated in Table 3.

The coefficient a_{22} of 0.3103 indicates that the stock market conditional variance is significantly positively affected by its own past innovations. The estimate of coefficient g_{22} of 0.9378 reflects that the stock market volatility is highly persistent.

The results pertaining to the relationship between the bond and the stock market indicate that there is no volatility transmission from the bond market to the stock market, and therefore no influence is exerted. This is determined from the estimates of the cross-market conditional variances of a_{12} and g_{12}, which individually cannot be proven to be statistically different from zero.

This would therefore have the implication that volatility transmission is unidirectional from the stock market to the bond market. This finding is consistent with that of Fang et al. (2006) when analysing domestic stock and bond market relationships.

5.4 Results pertaining to Hypothesis 3

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the US stock market on the South African bond market are illustrated in Table 4.

The coefficient a_{22} of 0.2947 indicates that the South African bond market conditional variance is significantly positively affected by its own past innovations. The estimate coefficient of g_{22} of 0.9443 reflects that the bond market volatility is highly persistent.

The cross-market volatility, represented by a_{12} and g_{12}, is not significant at the 1% level. This therefore implies that there is no volatility transmission from the US stock market to the South African bond market.

A lack of volatility transmission from the US stock market to an international bond market is consistent with the case of the German bond market (Fang 2007).

5.5 Results pertaining to Hypothesis 4

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the South African bond market on the US stock market are illustrated in Table 5.

The coefficient a_{22} of 0.2400 indicates that the US stock market conditional variance is significantly positively affected by its own past innovations. The estimate coefficient of g_{22} of 0.9691 reflects that the US stock market volatility is highly persistent.

The cross-market volatility, represented by a_{12} and g_{12}, is not significant at the 1% level. This therefore implies that there is no volatility transmission from the South African bond market to the US stock market. This finding, in combination with that of hypothesis 3, leads to the conclusion of no volatility transmission relationship existing between the South African bond and the US stock market.

A lack of volatility transmission between the US stock market and an international bond market is consistent with the case of the German bond market (Fang 2007).

5.6 Results pertaining to Hypothesis 5

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the US stock market on the South African stock market are illustrated in Table 6.

The coefficient a_{22} of 0.2573 indicates that the South African stock market conditional variance is significantly positively affected by its own past innovations. The estimate coefficient of g_{22} of 0.9460 reflects that the South African stock market volatility is highly persistent.

The cross-market volatility due to shocks in the US stock market, a_{12}, is found to be statistically significant. The positive coefficient therefore reflects that there is a positive transmission of volatility due to shocks in the US stock market. The influence can be observed in the news impact surface in Figure 16. The figure therefore illustrates the effect on the South African stock market of shocks origionating from the US stock market.

The cross-market volatility from changes in the persistence or previous days' volatility of the US stock market to the South African stock market is represented by coefficient g_{12} of -0.4901. The previous days' volatility of the US stock market therefore has a negative influence on the current South African stock market volatility. The magnitude of the volatility spillover is far larger than that identified between the South African stock and bond market.

The existence of volatility transmission from a the US stock market to the particular international stock markets is consistent with most of the findings of Section 2.5.2, where the US market is described as a dominant market.

5.7 Results pertaining to Hypothesis 6

The results of the GARCH(1,1) with BEKK representation for the variance covariance matrix of the effect of the South African stock market on the US stock market are illustrated in Table 7.

The coefficient a_{22} of 0.2146, as with findings of hypothesis 4, indicates that the US stock market conditional variance is significantly positively affected by its own past innovations. The estimate coefficient of g_{22} of 0.9736 reflects that the US stock market volatility is highly persistent.

The cross-market volatility due to shocks in the South African market, a_{12}, is found to be statistically significant. The coefficient of -0.0601 therefore reflects that there is a negative transmission of volatility due to shocks in the South African stock market. The magnitude of the volatility influence is noted to be approximately half the size of the influence that shocks in the US stock market have on the South African stock market. The influence can be observed in the news impact surface in Figure 17. The figure therefore illustrates the effect on the US stock market of shocks originating from the South African stock market.

The cross-market volatility from changes in the persistence or previous days' volatility of the South African stock market to the US stock market is represented by coefficient g_{12} of -0.3820. The previous days' volatility of the South Africa stock market therefore has a negative influence on the current US stock market volatility, albeit a smaller influence than the volatility transmission in the opposite direction from US stock to South African stock markets. It is, however, larger than the volatility transmission relationship from the South African stock to the South African bond market.

The existence of volatility transmission from the US stock market to the particular international stock markets is consistent with most of the findings of Section 2.5.2. The bidirectional volatility transmission relationship identified through hypothesis 5 and 6 is consistent with studies of the US stock market and other international stock markets (Lin et al. 1994; Caporale et al. 2006; Fang 2007). The volatility influence of the US stock market on the South African stock market is larger in magnitude than the influence of the South African stock market on the US stock market volatility. This finding is consistent with expectation indicating that the US stock market is the dominant partner in the bidirectional volatility transmission relationship.

5.8 Conclusion

The South African bond, stock and US stock market display strong evidence of volatility persistence from their respective markets. Furthermore, the conditional variance in each market is significantly positively affected by its own past innovations**.**

The cross-market volatility dependence varied in magnitude and nature depending on the pairs of markets investigated. Unidirectional volatility transmission was identified from South African stock to South African bond markets. The influence of previous days' stock market volatility was identified to have a negative influence on the current day's bond volatility. No evidence of volatility spillover was identified between the US stock market and the South African bond market. The US stock market was found to have a bidirectional volatility transmission relationship with the South African stock market. The US stock market was determined to be the dominant partner in the relationship due to the magnitude of the volatility linkages.

Linkages were observed in terms of a shock in either market influencing the other market's volatility, as well as changes in the volatility persistence of a market influencing the other market's volatility.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The conclusions and recommendations chapter summarises the findings of the research, and compares these findings with the aforementioned published research. The recommendations from the study are then discussed before suggestions for further research associated with the topic are provided.

6.2 Conclusions of the study

The study concludes that the South African stock market, bond market and the US stock market display time-varying returns, as well as time-varying conditional volatility. The modelling of the volatility through a GARCH(1,1) model with BEKK representation for the conditional variance provides meaningful information about the nature of the respective markets' volatility, as well the relationship between the markets.

The study found that there was strong volatility persistence from all markets on itself, as well as the conditional variance of each market being positively affected by its past innovations.

The study further found that the South African stock market transmitted volatility to the bond market, whereas the bond market volatility had no influence on that of the stock market. The negative relation of the volatility transmission was identified as being significant from the previous days' volatility of the stock market to the current bond market volatility. The unidirectional transmission of volatility from a domestic stock market to a bond market was consistent with findings of other domestic stock and bond markets (Fang 2007).

The South African bond market was found to not be linked to the US stock market in terms of volatility. This finding is consistent with research between US stock markets and the German bond market (Fang 2007).

The volatility transmission relationship between the US stock and South African stock market was identified as bidirectional and far larger than the relationship

between the South African stock and bond market. The nature of volatility transmission between the international stock markets was found to be in terms of shocks or news in one market influencing the volatility of the other market, as well as changes in the previous days' volatility in one market influencing the other market's volatility. The US stock market is determined to have a stronger influence on the volatility of the South African market than is the case for volatility transmission in the opposite direction.

While the volatility relationship between the US stock and South African stock markets had previously not been investigated, the findings are consistent with findings regarding the US market and certain other international stock markets (Lin et al. 1994; Caporale et al. 2006; Fang 2007).

6.3 Recommendations

The determination of a unidirectional transmission of volatility from the South African stock market to the South African bond market has implications for the estimation of their time-varying covariance matrix. Similarly, the bidirectional volatility transmission between the US stock market and the South African stock market has implications for these markets covariance matrix. As described in Section 1.4 of this report, it influences pricing of assets, portfolio selection and risk management.

The effectiveness of diversification strategies and hedging strategies, would therefore benefit from the results presented in this research report.

6.4 Suggestions for further research

Further research could include the following:

- Investigation into the asymmetrical volatility transmission between South African stock and bond markets.
- Investigation of the transmission of volatility between the industry segments of the JSE Securities Exchange.
- Investigation of the volatility transmission of the South African stock or bond market and other asset classes.

- As the nature of volatility transmission is time varying, future research could involve determining whether the nature of volatility transmission between stocks and bonds has changed due to structural breaks, such as the current global recession.

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APPENDIX A – RATS Research instrument code

```
*****************************************
*  Input and Check Data
*****************************************

calendar(d) 1998:12:31
open data ThesisDataFinal_v2US.xls
data(for=xls,org=col) 1998:12:31 2009:03:27 JSEAllShare ALBI DJI
close data "ThesisDataFinal_v2US.xls"

table /JSEAllShare ALBI DJI

*  Test for the presence of ARCH terms, as proposed by Engle (1982)
*  Source file for test downloaded from
*  http://www.estima.com/procs_perl/mainproclistwrapper.shtml
*  Null Hypothesis is that there is no ARCH terms

@ARCHtest(lags=1)  ALBI
@ARCHtest(lags=1)  JSEAllShare
@ARCHtest(lags=1)  DJI

***********************************************
*  Estimation of GARCH using MAXIMIZE
*  This code is relatively generic for bivariate garch at this stage.
*  The initial few lines of this set the estimation range, which needs to be
*  done explicitly, and the number of variables. Then, vectors for the dependent
*  variables, residuals and residuals formulas are set up. The SET instructions
*  copy the dependent variables over into the slots in the vector of series.
*
*  The data is loaded from a xls file, which ahs already converted the price
*  time series into a return = ln(P(t)/P(t-1)
*
*  A title for the output of the GARCH estimate is also set here for convenience.
```

```
*
*********************************************
compute gstart=2,gend=2672
compute n=2
dec vect[series] y(n) u(n)
dec vect[frml] resid(n)
set y(1) = ALBI
set y(2) = JSEAllshare

dec string tempTitle
compute tempTitle = "SA bond to SA stock"

*************************************
*  This is specific to a mean-only model. It sets up the formulas (the &i are
*  needed in the formula definitions when the FRML is defined in a loop), and
*  estimates them using NLSYSTEM. This both initializes the mean parameters,
*  and computes the unconditional covariance matrix. If you want more general
*  mean equations, the simplest way to do that would be to define each FRML
*  separately.
*
*  nlsystem estimates a system of non-linear equations using multivariate
*  non-linear lease squares or GMM. The use of the funtion below takes in
*  formulas resid(1)and resid(2), and places the residuals in u(1) and
*  u(2). b() can therefore be estimated as the mean. Residuals are placed in
*  u(), and the output of b() estimation is not printed due tothe noprint
*  option.
*  %sigma is the cavariance matrix of residuals, which is copied in "rr"
*************************************

*  This section of code determines the residuals
dec vect b(n)
nonlin(parmset=meanparms) b
do i=1,n
   frml resid(i) = (y(&i)-b(&i))
end do i
```

```
nlsystem(parmset=meanparms,resids=u,noprint) gstart gend resid
compute rr=%sigma

*
*  The paths of the covariance matrices and uu' are saved in the SERIES[SYMM]
*  names H and UU. H and UU series will be used for the variance and squared
*  residuals respectively. UX and HX are used temporarily to pull in residuals
*  and H matrices.
*
declare series[symm] h uu

*
*  ux is used when extracting a u vector in the log liklihood formula
*
declare symm hx(n,n)
declare vect ux(n)

*
*  These are used to initialize pre-sample variances.
*
gset h  * gend = rr
gset uu * gend = rr

************************************
*  This is a standard (normal) log likelihood formula for any multivariate GARCH
*  model. The difference among these will be in the definitions of HF and RESID.
*  The function %XT pulls information out of a matrix of SERIES.
************************************

*  The hf formula is decllared here, but it described later, when it is set to BEKK
*  representation
declare frml[symm] hf

*  The log likelihood formula is set up as below.
*  A number of lines of code simply pull information into variables,
```

```
*  eg. into symmetrical 2x2 hx, and vect ux
*  As the variance depends on the lagged residuals, and the regerssion function
*  depends on the variance, simple formulas cannot be written down without
*  referencing itself. This issue is overcome by saving residuals in series.
*
*  h(t) is set to the BEKK representation of hf, which is set later in the program.
*  The %outerxx(ux) will return the outer cross product of ux ux'
*  The %logdensity(hx,ux) returns the log density for a multivariate normal
*  with covariance matrix hx evaluated at the deviations from mean ux.
frml logl = $
   hx = hf(t) , $
   %do(i,1,n,u(i)=resid(i)) , $
   ux = %xt(u,t), $
   h(t)=hx, uu(t)=%outerxx(ux), $
   %logdensity(hx,ux)

****************************************************
*
*  Positive definite parameterization (BEKK,EK)
*  This enforces a positive definite covariance matrix by writing the covariance
*  matrix evolution as
*
*    H(t) = C'C + A'u(t)u(t)'A + B'H(t-1)B
*
*  Note that the parameters are not globally identified: changing the signs of all
*  members of C, A or B will have no effect on the function value. Using
*  PMETHOD=SIMPLEX to begin is quite important with this setup, to pull the
*  estimates away from zero before starting the derivative-based methods.
*
****************************************************

*  Define the coefficients of the BEKK representation
dec rect   a(n,n) g(n,n)
dec packed c(n,n)
```

```
nonlin(parmset=garchparms) c a g

*  Set A and G matrix to upper triangular in order to test unidirectional
*  volatility transmission
nonlin(parmset=restrictions) a(2,1)=0.0 g(2,1)=0.0

*  Define the hf variance covariance matrix of to the BEKK representation
*  %ltouterxx(c)  returns cc' of the lower-triangular portion
*  %mqform(x,a) returns A'X A.
*  {1}refers to the value are time t-1
frml hf = $
  hx=h{1},uux=uu{1},$
  %ltouterxx(c)+%mqform(uux,a)+%mqform(hx,g)

*
*  Initialize c's from the decomp of the covariance matrix
*
compute c = %decomp(rr)
compute a = %mscalar(.05) , g = %mscalar(.05)

*
*  Maximise the log liklihood function (indicated as the function after the
*  options in brackets) using the Broyden, Fletcher, Goldfarb and Shanno
*  algorithm is used as per Caporale (2006).
*  The "robusterrors" function, as reported by Trevor (1994), produces
*  standard errors that are assymptotically the same as that produced by the
*  Bollersllev and Wooldridge (1992).
*
*  The simpex algorithm is used initially for 5 interations, and then BFGS
*  algorithm is used.
*
maximize(parmset=meanparms+garchparms+restrictions,pmethod=simplex,piters=
5,method=bfgs,iters=100,cvcrit=0.0000001,robusterrors,Title=tempTitle)  logl  gstart
gend
```

```
* check eigenvalues are less than 1 in modulus required for stationarity (see
* Engle and Kroner 1995)
eigen %kroneker(a,a)+%kroneker(g,g) stattest
display "BEKK stationarity test"
display "Require all eigen values to be less than 1 in modulus"
display "See Engle and Kroner (1995)"
display stattest
```

APPENDIX B – CORRELLOGRAMS

Correllogram for ALBI Returns, including Ljung-Box statistics

Date: 07/13/09 Time: 15:43
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
|* |	|* |	1	0.112	0.112	33.839	0.000
*| |	*| |	2	-0.104	-0.118	62.667	0.000
| |	| |	3	-0.005	0.022	62.729	0.000
|* |	|* |	4	0.112	0.101	96.474	0.000
*| |	*| |	5	-0.069	-0.098	109.28	0.000
*| |	| |	6	-0.070	-0.027	122.56	0.000
| |	| |	7	0.008	0.004	122.73	0.000
| |	| |	8	0.055	0.031	130.73	0.000
| |	| |	9	0.006	0.015	130.84	0.000
| |	|* |	10	0.065	0.078	142.04	0.000
| |	| |	11	0.014	-0.012	142.56	0.000
| |	| |	12	-0.036	-0.035	146.06	0.000
| |	| |	13	-0.011	0.006	146.37	0.000
| |	| |	14	0.062	0.048	156.69	0.000
| |	| |	15	-0.028	-0.035	158.83	0.000
*| |	| |	16	-0.085	-0.056	178.36	0.000
*| |	*| |	17	-0.076	-0.072	193.73	0.000
| |	| |	18	-0.009	-0.029	193.93	0.000
| |	| |	19	0.055	0.063	201.96	0.000
| |	| |	20	0.006	0.003	202.06	0.000
| |	| |	21	0.026	0.039	203.82	0.000
| |	| |	22	0.023	0.003	205.26	0.000
| |	| |	23	-0.014	-0.033	205.80	0.000
| |	| |	24	-0.012	0.001	206.22	0.000
| |	| |	25	-0.014	-0.004	206.74	0.000
| |	| |	26	-0.001	0.019	206.74	0.000
| |	| |	27	-0.014	-0.006	207.24	0.000
| |	| |	28	0.011	0.007	207.55	0.000
| |	| |	29	0.059	0.044	216.95	0.000
| |	| |	30	0.014	0.002	217.48	0.000
| |	| |	31	0.008	0.026	217.65	0.000
| |	| |	32	0.017	0.007	218.47	0.000
| |	| |	33	0.045	0.024	224.07	0.000
| |	| |	34	-0.005	-0.009	224.15	0.000
| |	| |	35	0.013	0.028	224.62	0.000
| |	| |	36	0.016	0.017	225.30	0.000

Correllogram for Squared ALBI Returns, including Ljung-Box statistics

Date: 07/13/09 Time: 12:27
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
|* |	|* |	1	0.120	0.120	38.258	0.000
|* |	|* |	2	0.154	0.142	101.79	0.000
|* |	| |	3	0.092	0.061	124.35	0.000
|* |	|* |	4	0.141	0.108	177.57	0.000
|*** |	|** |	5	0.371	0.344	546.05	0.000
|* |	| |	6	0.128	0.049	590.17	0.000
| |	*| |	7	0.047	-0.073	595.98	0.000
|* |	| |	8	0.084	0.023	614.91	0.000
| |	| |	9	0.069	-0.015	627.64	0.000
|* |	| |	10	0.125	-0.035	669.80	0.000
|* |	| |	11	0.089	0.024	690.97	0.000
| |	| |	12	0.054	0.040	698.82	0.000
|* |	| |	13	0.084	0.040	717.97	0.000
|* |	| |	14	0.074	0.035	732.63	0.000
| |	| |	15	0.069	0.014	745.50	0.000
|* |	|* |	16	0.145	0.100	801.95	0.000
| |	| |	17	0.065	0.010	813.45	0.000
| |	| |	18	0.043	-0.047	818.38	0.000
| |	| |	19	0.018	-0.048	819.29	0.000
| |	| |	20	0.019	-0.035	820.27	0.000
| |	*| |	21	0.020	-0.084	821.40	0.000
|* |	|* |	22	0.127	0.108	864.83	0.000
| |	| |	23	0.013	0.019	865.28	0.000
| |	| |	24	0.010	-0.011	865.57	0.000
| |	| |	25	0.005	0.012	865.64	0.000
| |	| |	26	0.010	0.006	865.92	0.000
| |	*| |	27	0.019	-0.081	866.89	0.000
| |	| |	28	0.012	-0.018	867.27	0.000
| |	| |	29	0.006	0.013	867.38	0.000
| |	| |	30	0.012	-0.006	867.74	0.000
| |	| |	31	0.022	0.024	869.01	0.000
| |	| |	32	0.026	0.038	870.86	0.000
| |	| |	33	0.015	0.014	871.46	0.000
| |	| |	34	0.004	-0.003	871.50	0.000
| |	| |	35	-0.000	-0.013	871.50	0.000
| |	| |	36	0.002	-0.021	871.51	0.000

Correllogram for Squared JSE ALSI Returns, including Ljung-Box statistics

Date: 07/13/09 Time: 15:42
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
| |	| |	1	0.068	0.068	12.407	0.000
| |	| |	2	0.026	0.021	14.209	0.001
| |	*| |	3	-0.062	-0.066	24.655	0.000
| |	| |	4	-0.008	-0.000	24.836	0.000
| |	| |	5	-0.034	-0.030	27.871	0.000
| |	| |	6	-0.037	-0.037	31.562	0.000
| |	| |	7	0.034	0.041	34.675	0.000
| |	| |	8	0.022	0.015	35.989	0.000
| |	| |	9	0.007	-0.002	36.135	0.000
| |	| |	10	-0.035	-0.033	39.373	0.000
| |	| |	11	-0.028	-0.024	41.451	0.000
| |	| |	12	-0.031	-0.025	43.990	0.000
| |	| |	13	0.020	0.025	45.071	0.000
| |	| |	14	0.016	0.011	45.719	0.000
| |	| |	15	0.010	0.001	46.011	0.000
| |	| |	16	0.021	0.018	47.181	0.000
| |	| |	17	0.001	-0.002	47.182	0.000
| |	| |	18	-0.019	-0.018	48.168	0.000
| |	| |	19	-0.009	0.001	48.393	0.000
| |	| |	20	0.020	0.022	49.477	0.000
| |	| |	21	0.007	0.001	49.618	0.000
| |	| |	22	-0.030	-0.035	52.058	0.000
| |	| |	23	-0.000	0.004	52.058	0.000
| |	| |	24	-0.022	-0.022	53.401	0.001
| |	| |	25	0.026	0.029	55.194	0.000
| |	| |	26	0.036	0.039	58.704	0.000
| |	| |	27	0.029	0.018	61.013	0.000
| |	| |	28	0.054	0.049	68.970	0.000
| |	| |	29	0.009	0.004	69.180	0.000
| |	| |	30	-0.000	-0.001	69.180	0.000
| |	| |	31	0.003	0.018	69.209	0.000
| |	| |	32	0.014	0.017	69.744	0.000
| |	| |	33	0.024	0.022	71.332	0.000
| |	| |	34	-0.036	-0.041	74.865	0.000
| |	| |	35	-0.044	-0.042	80.191	0.000
| |	| |	36	-0.036	-0.026	83.634	0.000

Correllogram for Squared JSE ALSI Returns, including Ljung-Box statistics

Date: 07/13/09 Time: 15:42
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
|* |	|* |	1	0.197	0.197	103.80	0.000
|** |	|** |	2	0.248	0.218	268.77	0.000
|** |	|* |	3	0.222	0.153	400.10	0.000
|* |	|* |	4	0.193	0.098	499.45	0.000
|** |	|* |	5	0.279	0.187	707.88	0.000
|* |	| |	6	0.183	0.058	797.73	0.000
|** |	|* |	7	0.279	0.156	1005.7	0.000
|* |	| |	8	0.162	0.010	1075.7	0.000
|** |	|* |	9	0.232	0.093	1220.6	0.000
|** |	| |	10	0.222	0.071	1352.8	0.000
|** |	| |	11	0.216	0.073	1477.9	0.000
|** |	| |	12	0.222	0.048	1610.3	0.000
|* |	| |	13	0.120	-0.045	1649.2	0.000
|* |	| |	14	0.171	-0.005	1728.2	0.000
|* |	| |	15	0.125	-0.026	1770.1	0.000
|* |	| |	16	0.164	0.010	1842.0	0.000
|* |	| |	17	0.160	0.015	1910.9	0.000
|* |	|* |	18	0.207	0.090	2025.7	0.000
|* |	| |	19	0.196	0.057	2128.9	0.000
|* |	| |	20	0.104	-0.038	2157.9	0.000
|* |	| |	21	0.147	-0.008	2216.0	0.000
|* |	| |	22	0.155	0.039	2280.8	0.000
|* |	| |	23	0.144	0.006	2336.9	0.000
|* |	| |	24	0.117	-0.018	2373.7	0.000
|* |	| |	25	0.137	0.020	2424.2	0.000
|* |	| |	26	0.152	0.035	2486.6	0.000
|* |	| |	27	0.135	0.019	2536.1	0.000
|* |	| |	28	0.176	0.043	2620.0	0.000
|* |	| |	29	0.145	0.015	2676.8	0.000
|* |	| |	30	0.113	-0.028	2711.1	0.000
|* |	| |	31	0.140	0.027	2763.8	0.000
|* |	| |	32	0.086	-0.035	2783.7	0.000
|* |	| |	33	0.148	0.030	2842.9	0.000
| |	| |	34	0.069	-0.056	2855.8	0.000
|* |	| |	35	0.134	0.026	2904.3	0.000
|* |	| |	36	0.142	0.032	2958.8	0.000

Correllogram for Dow Jones Index Returns, including Ljung-Box statistics

Date: 07/31/09 Time: 02:42
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
*| |	*| |	1	-0.080	-0.080	17.099	0.000
*| |	*| |	2	-0.067	-0.074	29.286	0.000
| |	| |	3	0.058	0.047	38.356	0.000
| |	| |	4	-0.014	-0.010	38.848	0.000
| |	| |	5	-0.027	-0.022	40.834	0.000
| |	| |	6	-0.026	-0.035	42.646	0.000
| |	| |	7	-0.021	-0.028	43.796	0.000
| |	| |	8	0.053	0.048	51.434	0.000
| |	| |	9	-0.023	-0.016	52.878	0.000
| |	| |	10	0.015	0.020	53.513	0.000
| |	| |	11	-0.009	-0.016	53.716	0.000
| |	| |	12	-0.008	-0.007	53.902	0.000
| |	| |	13	0.043	0.040	58.803	0.000
| |	| |	14	-0.019	-0.010	59.731	0.000
| |	| |	15	-0.027	-0.022	61.715	0.000
| |	| |	16	0.033	0.020	64.622	0.000
| |	| |	17	0.017	0.023	65.435	0.000
| |	| |	18	-0.050	-0.043	72.156	0.000
| |	| |	19	-0.009	-0.014	72.366	0.000
| |	| |	20	0.015	0.005	72.942	0.000
| |	| |	21	-0.033	-0.033	75.841	0.000
| |	| |	22	-0.010	-0.010	76.125	0.000
| |	| |	23	0.027	0.021	78.159	0.000
| |	| |	24	-0.043	-0.043	83.254	0.000
| |	| |	25	0.028	0.022	85.299	0.000
| |	| |	26	-0.010	-0.014	85.569	0.000
| |	| |	27	-0.003	0.001	85.597	0.000
| |	| |	28	0.024	0.021	87.197	0.000
| |	| |	29	0.022	0.027	88.447	0.000
| |	| |	30	0.012	0.016	88.813	0.000
| |	| |	31	0.007	0.013	88.958	0.000
| |	| |	32	-0.018	-0.011	89.812	0.000
| |	| |	33	0.011	0.000	90.116	0.000
| |	| |	34	-0.053	-0.045	97.658	0.000
*| |	*| |	35	-0.072	-0.076	111.71	0.000
| |	| |	36	0.007	-0.019	111.82	0.000

Correllogram for Squared Dow Jones Index Returns, including Ljung-Box statistics

Date: 07/31/09 Time: 02:47
Sample: 1 2672
Included observations: 2671

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
|* |	|* |	1	0.171	0.171	78.384	0.000
|*** |	|** |	2	0.353	0.333	411.35	0.000
|* |	|* |	3	0.203	0.123	521.98	0.000
|** |	|* |	4	0.245	0.114	682.98	0.000
|** |	|* |	5	0.296	0.196	917.70	0.000
|** |	|* |	6	0.284	0.158	1133.1	0.000
|** |	|* |	7	0.303	0.140	1378.8	0.000
|* |	| |	8	0.208	0.019	1495.1	0.000
|** |	|* |	9	0.291	0.105	1721.7	0.000
|** |	| |	10	0.216	0.043	1846.5	0.000
|*** |	|* |	11	0.367	0.186	2207.6	0.000
|** |	|* |	12	0.272	0.098	2406.1	0.000
|** |	| |	13	0.242	-0.006	2562.9	0.000
|* |	*| |	14	0.125	-0.139	2604.8	0.000
|* |	| |	15	0.184	-0.047	2695.6	0.000
|** |	| |	16	0.214	0.019	2819.2	0.000
|** |	| |	17	0.231	0.026	2963.3	0.000
|** |	| |	18	0.260	0.046	3145.6	0.000
|* |	| |	19	0.165	-0.022	3218.5	0.000
|* |	| |	20	0.200	-0.000	3326.1	0.000
|** |	|* |	21	0.219	0.083	3455.5	0.000
|* |	| |	22	0.161	-0.053	3525.5	0.000
|* |	*| |	23	0.151	-0.093	3587.1	0.000
|* |	| |	24	0.211	0.052	3707.3	0.000
|* |	| |	25	0.162	0.066	3778.0	0.000
|* |	| |	26	0.136	-0.018	3828.2	0.000
|** |	| |	27	0.216	0.063	3953.7	0.000
|* |	| |	28	0.193	0.050	4054.4	0.000
|* |	| |	29	0.203	0.015	4165.9	0.000
|* |	| |	30	0.138	-0.041	4217.6	0.000
|* |	| |	31	0.121	-0.051	4257.0	0.000
|* |	| |	32	0.144	-0.008	4313.1	0.000
|* |	| |	33	0.147	0.004	4371.8	0.000
|* |	*| |	34	0.092	-0.069	4394.8	0.000
|* |	| |	35	0.182	0.061	4485.0	0.000
|* |	| |	36	0.099	-0.043	4511.3	0.000

APPENDIX C – OUTPUT FROM RESEARCH INSTRUMENT

Matrices A and G are positive definite in the BEKK representation. Therefore "changing the signs of all elements of C, B or A will have no effect on the function value" (Estima 2007b:428). A22 and G22 are reported in this document as being positive, and therefore the other components of the A and G matrices are changed in sign accordingly.

F-test of no ARCH vs. ARCH in ALBI
Using data from 1999:01:01 to 2009:03:27

Lags	Statistic	Signif. Level
1	38.727	0.00000

F-test of no ARCH vs. ARCH in JSEALLSHARE
Using data from 1999:01:01 to 2009:03:27

Lags	Statistic	Signif. Level
1	107.781	0.00000

F-test of no ARCH vs. ARCH in DJI
Using data from 1999:01:01 to 2009:03:27

Lags	Statistic	Signif. Level
1	80.577	0.00000

SA stock to SA bond - Estimation by BFGS
Convergence in 61 Iterations. Final criterion was 0.0000000 <= 0.0000001
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1999:01:01 To 2009:03:27
Usable Observations 2671
Function Value 19276.85168055

Variable	Coeff	Std Error	T-Stat	Signif
1. B(1)	0.000931671	0.000251081	3.71065	0.00020673
2. B(2)	0.000485881	0.000070933	6.84989	0.00000000
3. C(1,1)	0.002074310	0.000278535	7.44722	0.00000000
4. C(2,1)	-0.000477238	0.000106374	-4.48642	0.00000724
5. C(2,2)	-0.000000003	0.000032596	-1.04162e-004	0.99991689
6. A(1,1)	0.313910925	0.021037984	14.92115	0.00000000
7. A(2,1)	0.000000000	0.000000000	0.00000	0.00000000
8. A(1,2)	0.008933395	0.009588816	0.93165	0.35151880
9. A(2,2)	0.277706353	0.039328541	7.06119	0.00000000
10. G(1,1)	0.936805067	0.010149196	92.30338	0.00000000
11. G(2,1)	0.000000000	0.000000000	0.00000	0.00000000
12. G(1,2)	0.057093550	0.011097039	5.14494	0.00000027

13. G(2,2) -0.952832221 0.011491052 -82.91950 0.00000000

BEKK stationarity test
Require all eigen values to be less than 1 in modulus
See Engle and Kroner (1995)
0.98501 0.97614 -0.80544 -0.80544

All Bond Index to All Share Index - Estimation by BFGS

Convergence in 71 Iterations. Final criterion was 0.0000000 <= 0.0000001
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1999:01:01 To 2009:03:27
Usable Observations 2671
Function Value 19266.85575795

Variable	Coeff	Std Error	T-Stat	Signif
1. B(1)	0.000482307	0.000056093	8.59840	0.00000000
2. B(2)	0.000910858	0.000209387	4.35011	0.00001361
3. C(1,1)	0.000558613	0.000123364	4.52816	0.00000595
4. C(2,1)	0.002096327	0.000303994	6.89596	0.00000000
5. C(2,2)	-0.000000184	0.000563347	-3.25919e-004	0.99973995
6. A(1,1)	0.282194389	0.045341337	6.22378	0.00000000
7. A(2,1)	0.000000000	0.000000000	0.00000	0.00000000
8. A(1,2)	-0.031820434	0.042797360	-0.74351	0.45717058
9. A(2,2)	0.310336926	0.023824757	13.02582	0.00000000
10. G(1,1)	0.951289352	0.014466831	65.75658	0.00000000
11. G(2,1)	0.000000000	0.000000000	0.00000	0.00000000
12. G(1,2)	0.081341325	0.133644377	0.60864	0.54276303
13. G(2,2)	-0.937769111	0.009739664	-96.28352	0.00000000

BEKK stationarity test
Require all eigen values to be less than 1 in modulus
See Engle and Kroner (1995)
0.98458 0.97572 -0.80452 -0.80452

US stock to SA bond - Estimation by BFGS

Convergence in 53 Iterations. Final criterion was 0.0000000 <= 0.0000001
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1999:01:01 To 2009:03:27
Usable Observations 2671
Function Value 19616.53993426

Variable	Coeff	Std Error	T-Stat	Signif
1. B(1)	0.000293972	0.000186916	1.57275	0.11577610
2. B(2)	0.000487059	0.000058446	8.33349	0.00000000
3. C(1,1)	0.000876640	0.000229432	3.82092	0.00013296
4. C(2,1)	-0.000154075	0.000116745	-1.31976	0.18691617
5. C(2,2)	0.000550446	0.000112876	4.87654	0.00000108
6. A(1,1)	0.241354526	0.019736642	12.22875	0.00000000
7. A(2,1)	0.000000000	0.000000000	0.00000	0.00000000
8. A(1,2)	-0.023619031	0.011868785	-1.99001	0.04658955

9. A(2,2)	0.294738779	0.043225731	6.81860	0.00000000
10. G(1,1)	0.968928388	0.005518993	175.56254	0.00000000
11. G(2,1)	0.000000000	0.000000000	0.00000	0.00000000
12. G(1,2)	0.007226144	0.003294970	2.19308	0.02830136
13. G(2,2)	0.944260635	0.012658957	74.59229	0.00000000

BEKK stationarity test
Require all eigen values to be less than 1 in modulus
See Engle and Kroner (1995)
0.99707 0.98606 0.98606 0.97850

SA bond to US Share - Estimation by BFGS

Convergence in 53 Iterations. Final criterion was 0.0000000 <= 0.0000001
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1999:01:01 To 2009:03:27
Usable Observations 2671
Function Value 19612.24636876

Variable	Coeff	Std Error	T-Stat	Signif
1. B(1)	0.000477745	0.000065085	7.34030	0.00000000
2. B(2)	0.000321788	0.000167131	1.92537	0.05418354
3. C(1,1)	0.000543970	0.000116052	4.68728	0.00000277
4. C(2,1)	0.000002452	0.000156858	0.01563	0.98752745
5. C(2,2)	-0.000859602	0.000228521	-3.76159	0.00016884
6. A(1,1)	0.291031338	0.042358432	6.87068	0.00000000
7. A(2,1)	0.000000000	0.000000000	0.00000	0.00000000
8. A(1,2)	-0.010747181	0.033511993	-0.32070	0.74844034
9. A(2,2)	0.239955660	0.017837966	13.45196	0.00000000
10. G(1,1)	0.949568087	0.013270503	71.55479	0.00000000
11. G(2,1)	0.000000000	0.000000000	0.00000	0.00000000
12. G(1,2)	0.006702827	0.013719853	0.48855	0.62516068
13. G(2,2)	0.969142479	0.004748630	204.08888	0.00000000

BEKK stationarity test
Require all eigen values to be less than 1 in modulus
See Engle and Kroner (1995)
0.99682 0.99010 0.99010 0.98638

US stock to SA stock - Estimation by BFGS

Convergence in 67 Iterations. Final criterion was 0.0000000 <= 0.0000001
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1999:01:01 To 2009:03:27
Usable Observations 2671
Function Value 16627.49160044

Variable	Coeff	Std Error	T-Stat	Signif
1. B(1)	0.000351102	0.000164699	2.13178	0.03302526
2. B(2)	0.000950629	0.000250353	3.79715	0.00014637
3. C(1,1)	0.000878688	0.000201163	4.36804	0.00001254
4. C(2,1)	0.002039008	0.000207155	9.84292	0.00000000

5. C(2,2)	0.000001966	0.000805173	0.00244	0.99805204
6. A(1,1)	0.224160848	0.019427774	11.53816	0.00000000
7. A(2,1)	0.000000000	0.000000000	0.00000	0.00000000
8. A(1,2)	0.129022302	0.036870914	3.49930	0.00046649
9. A(2,2)	0.257294183	0.018702267	13.75738	0.00000000
10. G(1,1)	0.972725562	0.004202472	231.46507	0.00000000
11. G(2,1)	0.000000000	0.000000000	0.00000	0.00000000
12. G(1,2)	0.490057357	0.038177597	12.83625	0.00000000
13. G(2,2)	-0.946034773	0.007442442	-127.11349	0.00000000

BEKK stationarity test
Require all eigen values to be less than 1 in modulus
See Engle and Kroner (1995)

0.99644	0.96118	-0.86256	-0.86256

APPENDIX D – RESEARCH INSTRUMENT VERIFICATION

Results from RATSmodel used in research

DowJ - US Bond - Estimation by BFGS
Convergence in 41 Iterations. Final criterion was 0.0000000 <= 0.0000010
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1988:01:05 To 2004:02:13
Usable Observations 4204
Function Value
32888.43264036

	Variable	Coeff	Std Error	T-Stat	Signif
1	B(1)	0.00063	0.00014	4.39177	0.00001
2	B(2)	0.00006	0.00004	1.42646	0.15374
3	VCR(1,1)	0.00090	0.00018	5.01813	0.00000
4	VCR(2,1)	0.00016	0.00004	4.43058	0.00001
5	VCR(2,2)	0.00028	0.00004	7.02499	0.00000
6	VAR(1,1)	0.20108	0.02938	6.84394	0.00000
7	VAR(2,1)	0.00000	0.00000	0.00000	0.00000
8	VAR(1,2)	-0.00751	0.00379	-1.97920	0.04779
9	VAR(2,2)	0.17311	0.01510	11.46114	0.00000
10	VBR(1,1)	-0.97549	0.00698	-139.66146	0.00000
11	VBR(2,1)	0.00000	0.00000	0.00000	0.00000
12	VBR(1,2)	-0.00037	0.00087	-0.42999	0.66720
13	VBR(2,2)	-0.97801	0.00378	-258.75674	0.00000

Published results from Fang, Lim and Lin (2006)

Panel 1

Volatility Transmission from domestic stock market to domestic bond market U.S.

μ11	0.0006	4.97*
μ12	0.0001	1.6
Ω11	0.0009	13.65*
Ω12	0.0002	5.77*
Ω22	0.0005	4.44*
α11	0.209	33.68*
α12	-0.0069	-3.06*
α22	0.1738	20.65*
β11	0.9736	554.00*
β12	0.0003	0.4
B22	0.9779	430.59*

* indicates significance at the 1 percent level

US Bond to DowJ - Estimation by BFGS
Convergence in 57 Iterations. Final criterion was 0.0000000 <= 0.0000010
With Heteroscedasticity/Misspecification Adjusted Standard Errors
Daily(5) Data From 1988:01:05 To 2004:02:13
Usable Observations 4204

Function Value 32878.51913099

Panel 2

Volatility Transmission from domestic bond market to domestic stock market

U.S. Japan U.S. Japan

	Variable	Coeff	Std Error	T-Stat	Signif			
1	B(1)	0.00005	0.00005	1.00336	0.31569	μ11	4.90E-05	1.26
2	B(2)	0.00062	0.00013	4.75466	0.00000	μ12	0.0006	4.95*
3	VCR(1,1)	0.00029	0.00004	6.85047	0.00000	Ω11	0.0003	11.48*
4	VCR(2,1)	0.00047	0.00024	1.96451	0.04947	Ω12	0.0005	4.44*
5	VCR(2,2)	0.00081	0.00015	5.44402	0.00000	Ω22	0.0008	12.91*
6	VAR(1,1)	0.17618	0.01336	13.18773	0.00000	α11	0.1771	22.13*
7	VAR(2,1)	0.00000	0.00000	0.00000	0.00000			
8	VAR(1,2)	-0.00472	0.05755	-0.08200	0.93465	α12	-0.0017	-0.05
9	VAR(2,2)	0.20643	0.02667	7.73924	0.00000	α22	0.2145	33.50*
10	VBR(1,1)	-0.97884	0.00333	-293.74479	0.00000	β11	0.9786	479.97*
11	VBR(2,1)	0.00000	0.00000	0.00000	0.00000			
12	VBR(1,2)	0.00847	0.01637	0.51722	0.60500	β12	-0.0103	-1.24
13	VBR(2,2)	-0.97445	0.00635	-153.49319	0.00000	B22	0.9724	536.86*

* indicates significance at the 1 percent level