The Relationships between Silver Price, Gold Price and U.S. Dollar Index Before and After the Subprime Crisis

by

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Abstract

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This paper analyzes the relationship between silver price, gold price and U.S. dollar index and its change before and after the U.S. subprime mortgage crisis, especially focusing on the dynamics of silver price. The data used covers a period from January 2, 1986 to January 31, 2012. The methodology in this study includes cointegrated VAR model and Granger causality test. The findings show that there is a cointegration relationship between the three variables and silver price is unidirectionally Granger caused by the other two variables before the subprime crisis but such relationship has weakened after the subprime crisis.

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Chapter 1

Introduction

1.1 Introduction

Silver is one of the most important and popular investments in the precious metals investment market. History shows silver had been used as a main form of payment for thousands of years before the silver standard has been ended less than 100 years ago. Since the end of the silver standard, silver's monetary function has been replaced gradually, but it is still used as an important investment. In other sides, silver's industrial use has greatly extended in industrial areas, such as electronics, photography, energy, medicine, and so on.

The silver investment market developed quickly since 2006 when the world economy has begun to worsen. The global economy gradually was be in a bad condition because of the outbreaks of the U.S. subprime mortgage crisis, the European sovereign debt crisis and the great eastern Japan earthquake. In order to stimulate the economy, governments and central banks around the world responded with unprecedented fiscal stimulus, monetary policy expansion and institutional bailouts, which brought great inflationary pressure worldwide. To hedge against the economic uncertainty and the inflation, more and more investors crowded into the gold and silver markets. As a result, the increase of the investment demand causes a rapid rise in the prices of gold and silver and makes them more volatile than before. Particularly, the fluctuations for silver price are larger than that for gold, which have greatly affected the entire silver production to consumption chain.

1.2 Rationale of Study

Before studying silver price, the study of gold price should be introduced because silver and gold have certain characteristics in common. Both are widely traded and actively in commodity trading centers. Also, they are considered as a safe hedge tool against global economic depression, and used as sound money and a store of value for a long history. Therefore, their prices have moved in unison over a long period of time. However, the current uses of silver and gold are quite different. For gold, the majority of demand comes from the jewelry market and central banks, only a very small proportion of demand comes from industrial use and dental market. In contrast, silver's industrial uses are much more diverse and over half of silver production is used in industry and photography. In recent years, although the relationship between the prices of silver and gold is still positive in general, they have shown different patterns of price movement.

In fact, many researchers have studied the dynamics of precious metals prices especially gold price. Hillier et al. (2006), have classified the literature on the role of gold and other precious metals in financial markets into five types: (1) the investment and diversification properties of precious metals when combined with stock market investments in financial portfolios. (2) The role of gold as a potential hedging variable in intertemporal asset-pricing models. (3) The properties of the return distribution and the possibilities for earning excess returns in gold and silver markets, i.e. the efficiency of these markets. (4) The relationships of gold and silver to macro-economic variables and government policy. (5) The particular features and characteristics of gold (and silver) and market processes. They emphasize that the five-way characterization above should not be taken to imply that each area is independent of the others and varying degrees of overlap characterize the various previous papers.

Since the prices of silver and gold are usually denominated in U.S. dollars, their prices are influenced by changes in the exchange rate of the U.S. dollar. In fact, the U.S. dollar depreciation has at least two impacts on the prices of gold and silver. First, the dollar depreciation will lower the gold and silver prices for investors outside of the USA to increase their demand for gold and silver, which will raise the gold and silver prices in the U.S. dollar. Second, the dollar depreciation will likely to raise the U.S. inflation rate. As a result, gold and silver, as inflation hedges, attract more investors in the USA. Finally the price of itself goes high in the U.S. dollar. The prices of gold and silver will increase when the U.S. dollar gets weak, and vice versa.

The U.S. dollar index is a common measurement of the relative value of the U.S. dollar against other currencies, or a measurement of the relative purchasing power of U.S. dollar. In general, when the U.S. dollar gets weak, the U.S. dollar index goes down. But that is not always the case because the U.S. dollar index reflects RELATIVE purchasing power rather than REAL purchasing power. Something interesting might be found through the test of the relationship between silver and the U.S. dollar index.

1.3 Objective of Study

Despite the widespread interest in gold, it is surprising that there are only a few studies studying the silver price movements. This paper is to fill the gap. Specifically, the dynamics of spot silver price and its co-movement with spot gold prices and U.S. dollar index will be investigated to examine the change in the relationships between these three variables before and after the U.S. subprime mortgage crisis. Daily data covering 1986 to January, 2012, will be used. The methodology includes cointegrated VAR model and Granger causality test. This study will be helpful for investors to understand better the movement of silver price to make better investment decisions.

1.4 Outline of Study

The study proceeds through four chapters. Chapter 2 will present the literature review. Chapter 3 will introduce the data and basic statistical information. Chapter 4 will discuss the empirical results. And Chapter 5 will draw conclusion.

Chapter 2

Literature Review

In this chapter, the literature related to silver price will be reviewed. This can be divided into three general areas: co-movement of silver and gold, relationship between silver and macroeconomics, and other characteristics of silver price.

2.1 Co-movement of Silver and Gold

It is not surprising that most research silver price have studied the impact of gold price. Ma (1985), found a short-term parity between gold and silver cash prices based on rational expectation framework. The stability of this parity allowed investors to earn above-average returns on a frequent basis before transaction costs. Moreover, Ma and Soenen (1988), found arbitrage opportunities between gold and silver futures, where the transaction costs are less than in the cash market.

Chan and Mountain (1988), used an arbitrage model and time series models to expain the pricing relationship and test the causality between gold and silver prices. The weekly data they used covered the period from the second week of March in 1980 to the first week of February in 1983. To determine the appropriate number of lags, to identify the appropriate interaction, and to examine the exogeneity between the gold and silver prices and the rate of interest, they used Schwarz's Bayesian information criterion and Akaike's final prediction error criterion, and the estimation results suggested a "simultaneous relationship between the price of gold, the price of silver, and the treasury bill rate".

Wahab et al. (1994), tested the cointegration between gold and silver prices with daily spot and futures prices. They used daily cash price and daily futures price and establish that there is cointegration between gold and silver in both markets. They also examined whether the cointegration property and error-correction models can be exploited to generate positive trading profits. They found that after transaction costs, it was not possible to obtain positive trading profits for an ordinary market participant.

However, silver and gold do not belong to one great pool because they have their own different characteristics and economic uses. Thus, they have different sensitivities to exogenous shocks. More and more current studies have shown the difference between the prices of silver and gold.

According to Escribano and Granger (1998), the relationship between silver and gold has weakened since 1990. The monthly price data they used covered from 1971 to mid-1990s and were split into two subsamples. They estimated the cointegration between 1971 and 1990 at first. Then they used observations from July, 1990 and June, 1994 in an out-of-sample to verify the stability of the estimated relationship. They found that the dependency between gold and silver became less and less after 1990, which indicated that the two markets were separate.

Ciner (2001), investigated the interactions between gold and silver future prices using cointegration techniques and daily data from the beginning of 1992 to the end of 1998. He found that the stable relationship between gold and silver prices on the Tokyo Commodity Exchange has disappeared in the 1990s. Hence, those two markets should be approached as separate markets and the change of gold-silver ratio should not be used to predict prices in the future. This implication is contrary to the arguments raised in Ma (1985), Ma and Soenen (1988) and Wahab et al. (1994).

2.2 Relationship between Silver and Macroeconomics

Frankel and Hardouvelis (1985), investigated the reactions of the price of silver, gold and other seven commodities to money supply announcements using weekly data from July 7, 1980 to November 5, 1982. They set up a theoretical model and the results of regression showed that gold responded more strongly than silver did to the surprise component of weekly releases of money supply announcements.

Christie-David et al. (2000), used intraday data to examine the responses of gold and silver future prices to macroeconomic news releases. Different from Frankel and Hardouvelis (1985), they used monthly macroeconomic information because “major economic news is issued through these announcements”. The data covers a period of 4 year (1992-1995) and 23 monthly macroeconomic news releases were followed. They used robust nonparametric tests and regression tests, and the overall results showed that the release of Unemployment Rate have affected gold and silver prices, while the release of CPI, Hourly Wages, Business Inventories and Construction Spending have little effects on silver price.

Soytas et al. (2009), examined the long-run and short-run transmissions of information between the world oil price, Turkish spot gold and silver price, and Turkish interest rate and exchange rate using daily series data from May 2, 2003 to March 1, 2007. Followed the Toda-Yamamoto procedure, they tested a VAR model and a Granger causality test and found that the world oil price has no predictive power of the precious metal prices, but transitory positive initial impacts of innovations in oil prices on gold and silver markets were observed. The Turkish interest rate can unidirectionally Granger causes the prices of silver and gold, and the exchange rate also unidirectionally Granger causes domestic gold spot price but its effect on silver was not clearly observed.

Sari et al. (2010), investigated the relationship between spot prices of oil and precious metals (silver and gold are included), and the U.S./Euro exchange rate. They used daily data for the period between January 4, 1999 and October 19, 2007 and found evidence of a weak long-run relationship but strong feedbacks in the short-run. The spot precious metal markets responded significantly but temporarily to the change of the exchange rate.

2.3 Other Characteristics of Silver Price

Varela (1999), examined the relation between 15-, 30-, 45-, and 60-day gold, silver and copper futures traded on the New York Mercantile Exchange, and their realized cash or delivery settle prices, for deliveries on the first, middle and last business day of delivery month. He found that the cross-section of cash, settle, and futures price data are by their nature stationary, as the Phillips-Perron and Dickey-Fuller unit root tests bear out. Then he run a simple regression using levels of the delivery date cash or settle prices against a futures price with a fixed pre-delivery maturity and found that near-term gold, closest to delivery silver and all copper futures are good predictors of the future cash price, except for silver and copper deliveries on the last day of delivery months.

Tully and Lucey (2005), examined the conditional and unconditional mean returns and variance returns of daily gold and silver contracts over the 1982-2002 period under GARCH framework. The main purpose of their research was to test the existence of detectable daily seasonality in these moments. They used COMEX cash and futures data and found that the Monday effect in cash gold and cash silver appears to be weak and statistically not robust. However, the evidence for daily seasonality was strong for the variance. But the evidence from a GARCH model, using a leveraged GARCH specification, showed that the daily seasonality in the mean may not result from seasonality in the variance.

Hillier et al. (2006), investigated the investment role of gold, platinum and silver in financial markets by analysis of daily data from January 1, 1976 to April 1, 2004. They tested the conditional variance properties of each series and then applied the standard GARCH(1,1) model. The results showed that: (1) the above three metals had the potential to play a diversifying role in broad-based investment portfolios; (2) the precious metals exhibited some hedging capability, particularly during periods of abnormal stock market volatility; (3) financial portfolios containing a moderate weighting of gold performed better than portfolios consisting only of financial assets.

Cortazar and Eterovic (2010), tested whether long term oil future prices were helpful to estimate long term silver and copper future prices using daily futures contracts at Nymex, LME and IPE markets. For silver they used future contracts traded at NYMEX from January, 2004 to Octoboer, 2009. They found that their modified multicommodity model behaved better than the original model of Cortazar et al. (2008), for WTI-Brent, WTI-silver and WTI-Copper and their model showed that WTI prices help to estimate long-term silver and copper prices in a much more effective way.

Thenmozhi and Priya (2011), used Granger causality test, Johansen cointegration test and Error Correction Model to examine whether gold, silver and crude oil futures market serve as price discovery vehicle for spot market transactions in developed and emerging commodity markets. The price discovery mechanism had been examined for three exchanges, namely, Multi Commodity Exchange, India, New York Mercantile Exchange, U.S. and Tokyo Commodity Exchange, Japan, which were the topmost commodity exchanges according to the statistics on Gold, Silver and Crude Oil futures volume trading. They used daily data from 2005 to 2007 and found that the futures market exhibits strong evidence of efficiency for all the three commodities in India's Multi Commodity Exchange (MCX), New York's COMEX and Japan's Tokyo Commodity Exchange (TOCOM).

Narayan and Liu (2011), examined the persistence or otherwise of ten commodity prices (silver and gold are included). For silver price, the daily data used was for the period March 1, 1984 to March 23, 2010. They began with the conventional ADF test and found persistence in all ten commodity prices. Then they used a developed two structural break unit root test proposed by Narayan and Popp (2010), which showed that in two cases – iron ore and tin – the unit root null was rejected. They further used the Liu and Narayan (2010), GARCH-based unit root test which accounted for two structural breaks in the data series and found that only shocks to silver, gold, platinum, aluminum and copper were persistent.

This study contributes to this literature through testing the dynamics of spot silver price and its co-movement with spot gold prices and U.S. dollar index and the change in the relationships between these three variables before and after the U.S. subprime mortgage crisis.

Chapter 3

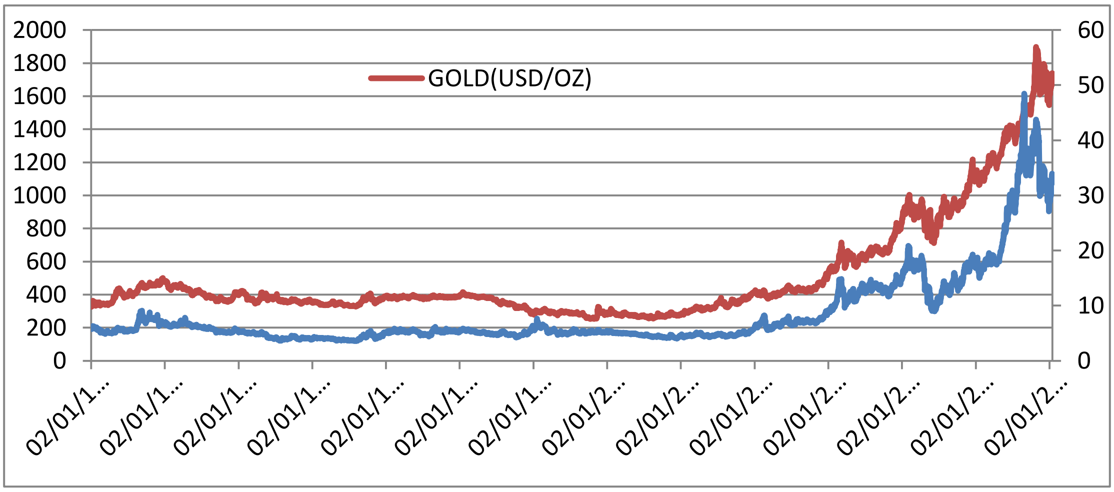
Data and Basic Descriptive Statistics[1]

3.1 Empirical Data

The variables used in this paper are the price of silver (COMEX silver spot price) ($SILVER_t$), the price of gold (COMEX gold spot price) ($GOLD_t$) and the U.S. Dollar Index (USD_t). All data analyzed here are daily observations covering the period from January 2, 1986 to January 31, 2012 and total in 6577 data points available. All data are sourced from Wind Information Co., Ltd[2].

3.1 Silver Price and Gold Price

Figure 3-1 COMEX Silver Price and COMEX Gold Price



[1] Because some studies suggest that oil price may influence silver price, I also test the relationship between silver price and oil price, but the result is not significant and therefore is omitted here.

[2] Website: http://www.wind.com.cn.

Figure 3-1 shows the COMEX silver spot price and the COMEX gold spot price and Table 3-1 shows the basic descriptive statistics of the prices of silver and gold, and the U.S. dollar index.

Table 3-1 Basic Descriptive Statistics

	Period	SILVER (USD/OZ)	GOLD (USD/OZ)	USD	GOLD/SILVER
Mean	1986-2012	8.39136	510.21911	92.43535	66.30558
	1986-2006	5.60226	372.67210	95.64076	68.49854
	2007-2012	19.91108	1078.32475	79.19615	57.24804
Std	1986-2012	7.04632	321.66197	11.04941	11.95020
	1986-2006	1.70221	75.77006	9.74788	11.28035
	2007-2012	8.82964	326.16140	4.03721	10.25465
Max.	1986-2012	48.44	1897.60	124.75	99.72299
	1986-2006	14.83	714.80	124.75	99.72299
	2007-2012	48.44	1897.60	92.44	84.39424
Min.	1986-2012	3.56	252.55	71.31	31.71346
	1986-2006	3.56	252.55	78.33	39.09031
	2007-2012	8.39	510.22	71.31	31.71346

Some interesting facts are revealed in Figure 3-1 and Table 3-1. First, the prices of silver and gold have fluctuated within a relatively narrow band between 1986 and 2006, but the band almost tripled since 2007. From 1986 to 2006, the highest and lowest prices of silver are 14.83 USD/oz and 3.56 USD/oz, while the highest and lowest prices of gold are 714.80 USD/oz and 252.55 USD/oz. Since 2007, the highest and lowest prices of silver are 48.44

USD/oz and 8.39 USD/oz, and the highest and lowest prices of gold have reached 1897.60 USD/oz and 510.22 USD/oz. Second, the silver price is much more volatile than gold price as the price fluctuation band of silver is wider than that of gold. Third, the prices of silver and gold have accelerated strongly since 2007. The average prices of silver and gold from 1986 to 2006 are 5.60 USD/oz and 372.67 USD/oz, much lower than their average prices of 19.91 USD/oz and 1078.32 USD/oz since 2007. Fourth, the price of silver reached a high of 48.44 USD/oz in April 28, 2011 and then fell back, while gold reached a record 1897.6USD/oz in August 22, 2011 and then fell back. Fifth, the price of silver has followed the price of gold reasonably closely during the whole period.

Figure 3-2 Gold/Silver Price Ratio

Figure 3-2 shows the historical price relationship between gold and silver, which is known as the gold/silver ratio. The gold/silver ratio between 1986 and 2006 is higher than that from 2007 to present. According to Table 3-1, the gold/silver ratio ranged from 39.09 to 99.72 and the average ratio was 68.50

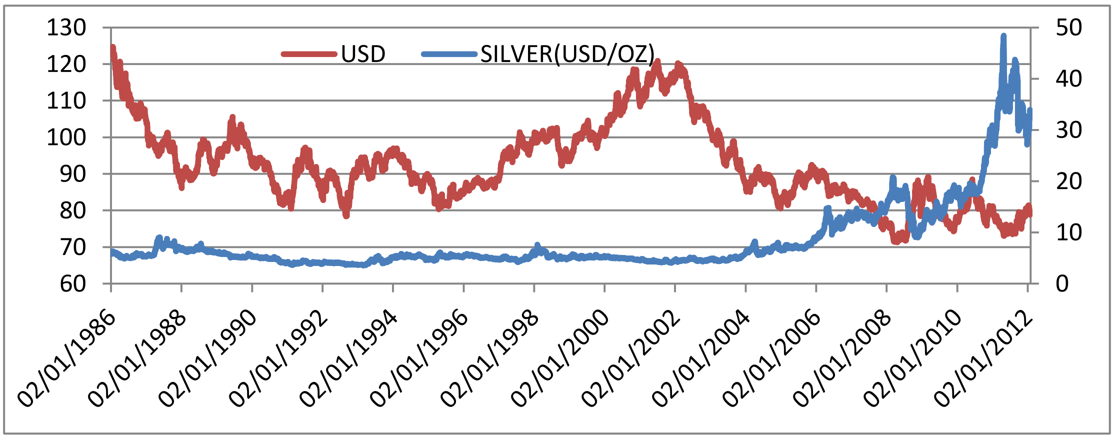
before 2006, while since 2007, the ratio generally has fallen back between 31.71 and 84.39 and the average ratio is 57.25.

The main reason of current gold and silver boom might be the global economic downturn since 2006. In 2006, the bursting of the U.S. housing bubble, which peaked in approximately 2005-2006, triggered the U.S. subprime mortgage crisis. Then the subprime crisis began to affect the U.S. financial market in February 2007, and then quickly deepened and caused panic in financial markets during 2007. In order to handle the crisis, governments and central banks around the world responded with unprecedented fiscal stimulus, monetary policy expansion and institutional bailouts, which are considered as important causes of the 2008-2012 global financial crises. Even now, the global economy is not yet out of recession. More and more investors use gold and silver as important hedging mechanisms against economic uncertainty and the increase of the investment demand for gold and silver not only causes a significant rise in the prices of gold and silver, but also attracts more speculation which makes their prices more volatile than before. Moreover, because the silver market is much smaller than gold market, the silver price is much more volatile than that of gold.

3.2 Silver Price and U.S. Dollar Index

Figure 3-3 shows the relationship between silver price and the U.S. dollar index. It can be seen that the silver price was relatively stable and the fluctuations in U.S. dollar index seemed to have little effect on the silver price before 2006. However, since 2007, the negative relationship between the silver price and U.S. dollar index has becoming pronounced. Table 3-1 also reveals the negative relationship. The average of the U.S. dollar index from 1986 to 2006 is 95.64, which is significantly higher than the average from 2007 to January, 2012, while the silver price was generally upward during the same period.

Figure 3-3 COMEX Silver Price and the U.S. Dollar Index



One important cause of the unobvious negative relationship between the silver price and the U.S. dollar index might be the calculation method for the U.S. dollar index. The U.S. dollar index started in 1973 and currently is calculated by factoring in the exchange rates of six major world currencies: the Euro (weighted at 58.6%), Japanese Yen (weighted at 12.6%), British Pound Sterling (weighted at 11.9), Canadian Dollar (weighted at 9.1%), Swedish Krona (weighted at 4.2%) and Swiss Franc (weighted at 3.6%). Therefore, the

U.S. dollar index is not only influenced by the strength of U.S. economy and U.S. exchange rate policy, but also significantly influenced by the economic performance of Europe, Japan, Britain, Canada, Sweden and Switzerland. From 1999 to 2000, the U.S. Federal Reserve (Fed) used tighten monetary policies and maintained a strong dollar policy and hence the U.S. dollar index gradually went up during this period. From 2001 to early 2008, the net capital outflow from the U.S. increased. Furthermore, because of the U.S government's abandoning its strong dollar policy, the increasing budget deficit and current-account deficit and some important events, like 911 attacks, the U.S. dollar depreciated. Since 2008, although the U.S. has been in a recession, the U.S. dollar index has been relatively stable because of the depreciation of Euro and the Japanese Yen caused by the European sovereign debt crisis in late 2009 and the great east Japan earthquake in 2011. In general, the U.S. dollar index cannot accurately measure the real purchasing power of U.S. dollar so that it may not fully reflect the inherent value of silver.

3.3 Correlation Analysis

Table 3-2 presents the correlation matrix of silver price, gold price and the U.S. dollar index. It's clearly observed that silver price has a strong positive correlation with gold price and a negative correlation with the U.S. dollar index before and after 2007. This result is consistent with previous analysis.

Table 3-2 Correlation Matrix

	1986-2006			2007-		
	L_SILVER	L_GOLD	L_USD	L_SILVER	L_GOLD	L_USD
L_SILVER	1	0.74306	-0.25409	1	0.89859	-0.48521
L_GOLD	0.74306	1	-0.61735	0.89859	1	-0.31997
L_USD	-0.25409	-0.61735	1	-0.48521	-0.31997	1

3.4 Growth Rate Analysis

For comparison purpose, the daily growth rates of silver price, gold price and the U.S. dollar index are calculated by the following formulas:

$$G\_SILVER_t = SILVER_t / SILVER_{t-1}$$

$$G\_GOLD_t = GOLD_t / GOLD_{t-1}$$

$$G\_USD_t = USD_t / USD_{t-1}$$

Figure 3-4 Historical Growth Rates of Silver Price and Gold Price

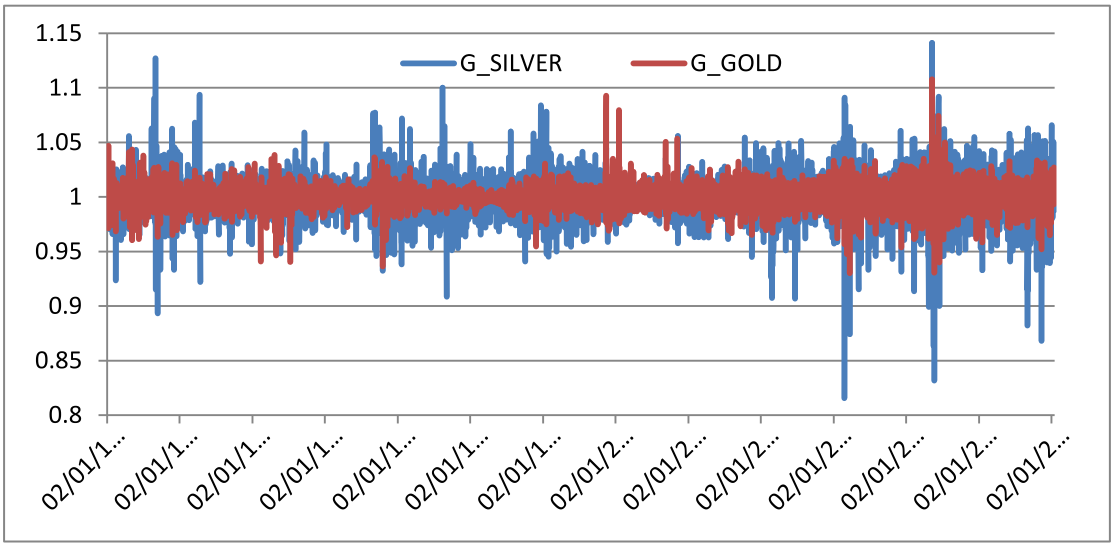


Figure 3-4 shows the historical growth rates of silver and gold and Table 3-3 presents their basic descriptive statistics. In Figure 3-4, the volatility of daily growth rate of silver price is generally greater than that of gold price. This reveals again that the silver price is more volatile than gold price.

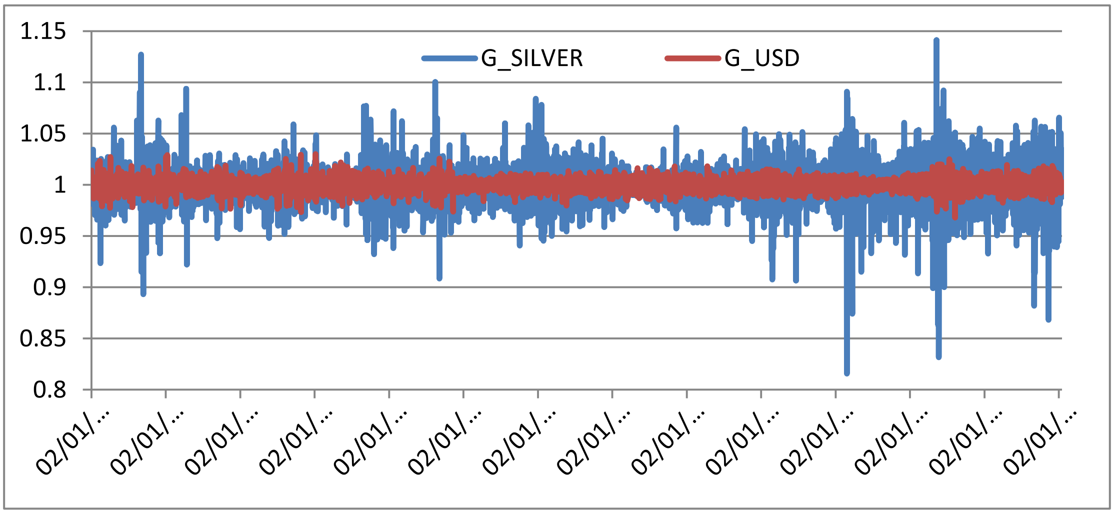
Table 3-3 Basic Descriptive Statistics of Growth Rates

	Period	G_SILVER	G_GOLD	G_USD
Mean	1986-2012	1.00043	1.00031	0.99995
	1986-2006	1.00028	1.00017	0.99994
	2007-2012	1.00104	1.00088	0.99998
Std	1986-2012	0.01808	0.01013	0.00558
	1986-2006	0.01614	0.00906	0.00546
	2007-2012	0.02448	0.01366	0.00602
Max.	1986-2012	1.14122	1.10786	1.02994
	1986-2006	1.12720	1.09276	1.02994
	2007-2012	1.14122	1.10786	1.02487
Min.	1986-2012	0.81565	0.93016	0.96800
	1986-2006	0.81565	0.93016	0.97345
	2007-2012	0.83154	0.93058	0.96800

Table 3-3 indicates that the fluctuations of silver price growth rate and gold price growth rate from 2007 to January, 2012, which are higher than that from 1986 to 2006. The largest one-day increase (and drop) of silver price is also bigger than that of gold price. Furthermore, consistent with Figure 3-1, Table 3-3 shows that the average daily growth rates of silver price and gold price since 2007 are significantly higher than that from 1986 to 2006. From an investment perspective, higher volatility also means more opportunities. Therefore, if investors have an accurate judgment on silver and gold, investing in silver has a higher rate of return than investing in gold.

Figure 3-5 presents the historical growth rates of silver and the U.S. dollar index. It can be seen that the volatility of the silver price is obviously larger than that of the U.S. dollar index. As Table 3-3 reveals, contrary to the changes in silver price, the U.S. dollar index generally decreased with its daily decrease of 0.99995 (i.e. the average daily decline is 0.005%). If the standard deviation is used to measure the volatility, the U.S. dollar index is more volatile since 2007 than before.

Figure 3-5 Historical Growth Rates of Silver Price and the U.S. Dollar Index



3.5 Summary of the Basic Descriptive Statistics

The following two main facts can be seen from the above basic descriptive statistics. First, the silver price has a strong positive correlation with gold price and a negative correlation with the U.S. dollar index. The prices of silver and gold have been generally increasing since 1986, while the U.S. dollar index has been generally declining since 2001. Second, the prices of silver and gold were stable before 2006, and the gold-silver ratio was relatively higher than current ratio. Since 2007, the prices of silver and gold have been rising steeply and their negative relationship with the U.S. dollar index has becoming pronounced.

The change in the global economy might be the main reason causing the remarkably change in the relationship between silver price, gold price and U.S. dollar index. In fact, the global economy has deteriorated since 2007 when the U.S. subprime mortgage crisis deepened and then triggered the global financial crisis in 2008. In order to stimulate the global economy, governments and central banks around the world have introduces a number of economic incentives especially in the forms of monetary policy expansion and fiscal stimulus, which had some positive effects but added global inflationary pressures between late-2008 and mid-2009. More and more investors enter the gold or silver market to use the precious metals as hedging mechanisms against economic uncertainty and global inflation. The greatly increasing demand and the stably supply both cause the prices of silver and gold to steeply rise. Meanwhile, economic uncertainty and continuous government bailouts motivate investors to adjust their portfolio allocations more frequently than before. Therefore, the prices of silver and gold are apparently more volatile since 2007 than before.

Chapter 4

Empirical Analysis

Consistent with convention, the data of silver price, gold price and the U.S. dollar index has been transformed by taking the natural logarithm of the raw data in order to eliminate the heteroskedasticity. According the analysis in chapter 3, there is a certain relationship between the prices of precious metals and the U.S. dollar index and such relationship is influenced by world economy. Since 2007, the prices of silver and gold and the U.S. dollar index are more volatile than before. That means their relationship might have changed. In this chapter, the sample is divided into two subsamples to estimate the relationship and its change before and after the U.S. subprime mortgage crisis: the first subsample covers the period from 1986 to late-2006, named as pre-crisis period, and the second one uses the data from 2007 to January 2012, named as post-crisis period. The methodology in this chapter includes VAR model, Johansen cointegrated test and Granger causality test. The analysis software is Eviews 6.0.

4.1 Stationary Test

Since the results obtained by using non-stationary data may be spurious, test the stationarity of the data should be tested to transform the non-stationary data into stationary data before estimation. Table 4-1 presents the Augmented

Dikey-Fuller (ADF) test and Phillips-Perron test for the silver price, the gold price and the U.S. dollar index in levels and first differences (the first difference of the logarithm is the percentage difference in the original series), where L_SILVER, L_GOLD and L_USD represent the natural logarithm of silver price, gold price and the U.S. dollar index respectively.

Table 4-1 ADF Test Results of Pre-Crisis Period

		Level		First Difference	
Period	Variable	ADF	PP	ADF	PP
Pre-Crisis	L_SILVER	-0.87887	-0.84813	-77.24181*	-77.34998*
	L_GOLD	-0.39723	-0.46123	-76.87672*	-76.89791*
	L_USD	-2.62533***	-2.60122***	-74.31987*	-74.32805*
Post-Crisis	L_SILVER	-0.77471	-0.78288	-35.43515*	-35.43506*
	L_GOLD	-0.67167	-0.62702	-35.35932*	-35.40228*
	L_USD	-2.25205	-2.30857	-35.46358*	-35.46279*

Notes: *, ** and *** indicate statistical significant at the 1%, 5% and 10% level, respectively. The critical values for the ADF test and the PP test are obtained from Dickey-Fuller (1981).

It can be seen from Table 4-1 that either in pre-crisis period or in post-crisis period, the null hypothesis of a unit root at 5% critical significance level in all there series cannot be rejected, i.e. the silver price, the gold price and the U.S. dollar index have unit roots in levels. Table 4-1 also shows that all series in first difference reject the null hypothesis at 1% critical significant level. Hence, consistent with what has been found in most of previous literature using such types of data, the tests show that the logarithm of all three series have a unit root, but the first differences are stationary. In other words, the silver price, the gold price and the U.S. dollar index appear to be first–order integrated (i.e. I(1) process). Because regression models for non-stationary variables may give spurious results, first differenced data should be used to carry out the VAR analysis of the three series or use a VAR-based cointegration test to test whether there exists a (cointegrating) vector of coefficients to form a stationary linear combination of them or not.

4.2 VAR Model and Cointegration Test

The Vector Autoregression (VAR) Model is a statistical model based on statistical characteristics of data rather than economic theory. It provides a multivariate framework and has proven to be especially useful for describing the dynamic behavior of financial time series and for forecasting. Because all data used in this chapter are I(1) processes, an argument that naturally arises is whether levels or first differences in the VAR model should be used. It is common to difference the data before applying the VAR models. However, a VAR model for first differences of variables may lead to biased because some valuable information of original data may be inevitably lost in differencing, as mentioned in Sims, Stock & Watson (1990). Hence, many economists recommend cointegration analysis with VAR models. Cointegration analysis is mainly used to examine the long-term equilibrium relationship, while VAR analysis of stationary time series can be used to determine the short-term relationships. Since all of the three variables are I(1) processes, a cointegrated VAR model is set up to analyze the relationship between them.

4.2.1 VAR Analysis of Pre-Crisis

Table 4-2 Optimal Lag Length of the VAR Model in the Pre-Crisis Period

Lag	LogL	LR	FPE	AIC	SC	HQ
0	9746.141	NA	4.99e-06	-3.694082	-3.690345	-3.692776
1	52934.19	86310.59	3.88e-13	-20.06528	-20.05034	-20.06006
2	52983.06	97.61402	3.82e-13	-20.08040	-20.05424*	-20.07126*
3	52992.59	19.02677	3.82e-13*	-20.08060*	-20.04323	-20.06754
4	52997.24	9.273048	3.82e-13	-20.07895	-20.03037	-20.06197
5	53002.83	11.15882	3.83e-13	-20.07766	-20.01787	-20.05676
6	53016.57	27.36521	3.82e-13	-20.07946	-20.00845	-20.05464
7	53022.26	11.34568	3.83e-13	-20.07820	-19.99599	-20.04947
8	53026.19	7.818840	3.83e-13	-20.07628	-19.98286	-20.04363
9	53038.57	24.61899	3.83e-13	-20.07756	-19.97293	-20.04099
10	53044.06	10.92755	3.83e-13	-20.07623	-19.96039	-20.03574
11	53049.44	10.69364	3.84e-13	-20.07486	-19.94780	-20.03045
12	53054.89	10.80946	3.84e-13	-20.07351	-19.93525	-20.02518
13	53056.47	3.154053	3.85e-13	-20.07070	-19.92122	-20.01845
14	53069.42	25.68162*	3.85e-13	-20.07220	-19.91151	-20.01603
15	53075.52	12.08450	3.85e-13	-20.07110	-19.89920	-20.01101
16	53082.99	14.80113	3.86e-13	-20.07052	-19.88741	-20.00651
17	53084.22	2.447489	3.87e-13	-20.06757	-19.87325	-19.99965
18	53089.35	10.14260	3.87e-13	-20.06610	-19.86057	-19.99426

19	53096.21	13.57794	3.88e-13	-20.06529	-19.84855	-19.98953
20	53102.11	11.65399	3.88e-13	-20.06412	-19.83616	-19.98444

Before estimating with VAR models, the appropriate number of lag length of the VAR model should be determined. Table 4-2 displays five information criteria for all lags up to 20. The table indicates the suggested optimal lags from each column criterion by an asterisk "*", which are the lags with the smallest values of the criterion. As seen, the sequential modified Likelihood Ratio (LR) criteria indicates that a lag length of 14 is optimal, and the Final Prediction Error (FPE) and Akaike Information Criterion (AIC) indicate that the optimal lag order is 3, while the Schwarz Information Criterion (SC) and Hannan-Quinn Information Criterion (HQ) suggested that the optimal lag length is 2. Because the five criteria do not all agree about the optimal lag length, the majority rule is used as a sub-optimal solution. Hence, the optimal lag length should be 2 or 3. Here both models of VAR(2) and VAR(3) were estimated not only to examine the model's sensitivity of the lag lengths, but also to do a robust check. The estimation results are in Table 4-3 and Table 4-4.

According to Table 4-3 and Table 4-4, the VAR(2) and VAR(3) models provide very similar results. The majority of the coefficients have the same sign and do not change much except the coefficient of the gold price (L_GOLD) on two lags of the silver price (L_SILVER(-2)). But this coefficient is not important because it is statistically insignificant in both VAR models and the main purpose of this study is to analyze the dynamics of silver price rather than gold price. Therefore, the results of VAR models are generally robust with respect to lag-length in the pre-crisis period. For brevity, only the results of VAR(2) are analyzed here.

Table 4-3 Estimation Results of the VAR(2) in the Pre-Crisis Period

	L_SILVER	L_GOLD	L_USD
L_SILVER(-1)	0.900866	0.000541	0.000933
	(0.01704)	(0.00953)	(0.00575)
	[52.8626]	[0.05676]	[0.16234]
L_SILVER(-2)	0.096733	-0.000342	-3.27E-05
	(0.01705)	(0.00954)	(0.00575)
	[5.67220]	[-0.03587]	[-0.00568]
L_GOLD(-1)	0.098740	0.929586	0.006705
	(0.03098)	(0.01733)	(0.01045)
	[3.18741]	[53.6393]	[0.64150]
L_GOLD(-2)	-0.095683	0.070530	-0.009347
	(0.03101)	(0.01735)	(0.01046)
	[-3.08577]	[4.06588]	[-0.89345]
L_USD(-1)	-0.097485	-0.094371	0.978720
	(0.04209)	(0.02355)	(0.01420)
	[-2.31604]	[-4.00771]	[68.9146]
L_USD(-2)	0.099443	0.096237	0.016651
	(0.04203)	(0.02351)	(0.01418)
	[2.36622]	[4.09328]	[1.17429]
C	-0.022766	-0.009390	0.035081

	(0.02390)	(0.01337)	(0.00806)
	[-0.95260]	[-0.70230]	[4.35039]
R-squared	0.995731	0.997764	0.996958
Adj. R-squared	0.995726	0.997762	0.996955

Table 4-4 Estimation Results of the VAR(3) in the Pre-Crisis Period

	L_SILVER	L_GOLD	L_USD
L_SILVER(-1)	0.904128	0.002630	0.000414
	(0.01713)	(0.00959)	(0.00579)
	[52.7724]	[0.27428]	[0.07160]
L_SILVER(-2)	0.120233	0.013234	-0.001479
	(0.02298)	(0.01286)	(0.00776)
	[5.23220]	[1.02886]	[-0.19062]
L_SILVER(-3)	-0.026855	-0.015729	0.001972
	(0.01713)	(0.00959)	(0.00578)
	[-1.56809]	[-1.64085]	[0.34096]
L_GOLD(-1)	0.098026	0.925910	0.007705
	(0.03113)	(0.01743)	(0.01051)
	[3.14859]	[53.1333]	[0.73289]
L_GOLD(-2)	-0.129142	0.040443	-0.000228
	(0.04178)	(0.02339)	(0.01411)
	[-3.09095]	[1.72939]	[-0.01618]
L_GOLD(-3)	0.034353	0.033882	-0.010144
	(0.03118)	(0.01745)	(0.01053)
	[1.10171]	[1.94132]	[-0.96345]
L_USD(-1)	-0.094290	-0.094991	0.979032
	(0.04212)	(0.02358)	(0.01422)

	[-2.23859]	[-4.02915]	[68.8361]
L_USD(-2)	0.207220	0.082998	0.013736
	(0.05853)	(0.03276)	(0.01976)
	[3.54067]	[2.53362]	[0.69506]
L_USD(-3)	-0.110906	0.013994	0.002598
	(0.04209)	(0.02356)	(0.01421)
	[-2.63504]	[0.59403]	[0.18278]
C	-0.023954	-0.010606	0.035246
	(0.02393)	(0.01339)	(0.00808)
	[-1.00105]	[-0.79190]	[4.36211]
R-squared	0.995739	0.997766	0.996956
Adj. R-squared	0.995732	0.997762	0.996950

Before using the estimates, the stability test and the cointegration test should be conducted. The stability of a VAR model can be examined by calculating its AR roots. The necessary and sufficient condition for stability is that all the roots have modulus less than one and lie inside the unit circle. If a VAR model is unstable, certain results such as impulse response standard errors are invalid. Table 4-5 presents the calculated AR roots. As seen, the modulus of all roots is less than one. Hence, the estimated VAR(2) satisfies the stability condition.

Table 4-5 AR Roots Table of VAR(2) in the Pre-Crisis Period

Root	Modulus
0.999638	0.999638
0.997592	0.997592
0.996320	0.996320
-0.098185	0.098185
-0.043097 - 0.014225i	0.045384
-0.043097 + 0.014225i	0.045384

No root lies outside the unit circle.

VAR satisfies the stability condition.

Table 4-6 Johansen Cointegration Test in the Pre-Crisis Period

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None	0.003798	27.20096	29.79707	0.0968
At most 1	0.001293	7.057832	15.49471	0.5709
At most 2	3.97E-05	0.210288	3.841466	0.6465

Trace test indicates no cointegration at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None	0.003798	20.14313	21.13162	0.0683

At most 1	0.001293	6.847544	14.26460	0.5073
At most 2	3.97E-05	0.210288	3.841466	0.6465

Max-eigenvalue test indicates no cointegration at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

The cointegration test is used to examine the long-run relationship or equilibrium relationship between unstable time series. According to the stationary test results, silver price, gold price and the U.S. dollar index are all I(1) processes, so test for cointegration is feasible. If the cointegration relationship exists, the three variables satisfy the above relationship estimated by the VAR(2) model. If the cointegration relationship does not exist, the estimates of the VAR model may not be reliable. Table 4-6 reports the results from the Johansen Cointegration test. It can be seen that both of the Trace test statistics and the Maximum Eigenvalue test statistics reject the hypothesis of no cointegration vector at 10% critical significance level since both statistics exceed the corresponding critical values. These results indicate the existence of a long-term relationship between the three variables which estimated by the above VAR(2) model.

According to Table 4-3, the adjusted R-squared of L_SILVER, L_GOLD and L_USD are 0.995726, 0.997762 and 0.996955, which indicate that the model is a very strong predictor of the prices of silver and gold and the U.S.

dollar index. Their relationship can be expressed mathematically as follows:

$$\begin{bmatrix} L\_SILVER_t \\ L\_GOLD_t \\ L\_USD_t \end{bmatrix} = \begin{bmatrix} -0.022766 \\ -0.009390 \\ 0.035081 \end{bmatrix} + \begin{bmatrix} 0.900866 & 0.098740 & -0.097485 \\ 0.000541 & 0.929586 & -0.094371 \\ 0.000933 & 0.006705 & 0.978720 \end{bmatrix} \begin{bmatrix} L\_SILVER_{t-1} \\ L\_GOLD_{t-1} \\ L\_USD_{t-1} \end{bmatrix}$$
$$+ \begin{bmatrix} 0.096733 & -0.095683 & 0.099443 \\ -0.000342 & 0.070530 & 0.096237 \\ -0.000033 & -0.009347 & 0.016651 \end{bmatrix} \begin{bmatrix} L\_SILVER_{t-2} \\ L\_GOLD_{t-2} \\ L\_USD_{t-2} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{4t} \end{bmatrix}$$

The equation shows that the silver price is positively correlated with one lag of the gold price and two lags of the U.S. dollar index, and is negatively correlated with two lags of the gold price and one lag of the U.S. dollar index. These suggest that both of the rise of gold price and the drop of the U.S. dollar index will cause silver price to rise at a decreasing rate.

4.2.2 VAR Analysis of Post-Crisis

Table 4-7 Optimal Lag Length of VAR Model in the Post-Crisis Period

Lag	LogL	LR	FPE	AIC	SC	HQ
0	2412.137	NA	4.68e-06	-3.758404	-3.746338	-3.753874
1	12094.67	19304.64	1.31e-12*	-18.84971*	-18.80145*	-18.83159*
2	12100.39	11.39331	1.31e-12	-18.84461	-18.76015	-18.81290
3	12107.89	14.87453	1.32e-12	-18.84226	-18.72160	-18.79696
4	12115.55	15.16919	1.32e-12	-18.84017	-18.68332	-18.78128
5	12118.75	6.323145	1.33e-12	-18.83113	-18.63807	-18.75864
6	12124.07	10.46965	1.34e-12	-18.82538	-18.59612	-18.73930
7	12130.45	12.55053	1.34e-12	-18.82130	-18.55585	-18.72163
8	12135.40	9.703650	1.35e-12	-18.81498	-18.51333	-18.70172
9	12143.34	15.53998	1.36e-12	-18.81333	-18.47548	-18.68648

10	12150.81	14.57085	1.36e-12	-18.81093	-18.43689	-18.67049
11	12160.24	18.36843	1.36e-12	-18.81161	-18.40137	-18.65758
12	12176.40	31.38079*	1.34e-12	-18.82278	-18.37634	-18.65516
13	12183.79	14.32089	1.35e-12	-18.82027	-18.33763	-18.63905
14	12189.82	11.65710	1.35e-12	-18.81564	-18.29680	-18.62083
15	12197.51	14.82662	1.36e-12	-18.81359	-18.25856	-18.60520
16	12205.35	15.07954	1.36e-12	-18.81178	-18.22055	-18.58979
17	12213.39	15.42411	1.36e-12	-18.81028	-18.18285	-18.57470
18	12221.79	16.08381	1.36e-12	-18.80935	-18.14572	-18.56018
19	12225.20	6.500483	1.37e-12	-18.80062	-18.10079	-18.53786
20	12230.32	9.759035	1.38e-12	-18.79457	-18.05855	-18.51822

Before estimating with a VAR model, the optimal lag length should be determined first. The five information criteria are presented in Table 4-7. The LR criterion indicates that the optimal lag length is 12, while the other four criteria suggest 1 is better. According to the majority rule, a VAR(1) model is used here. The estimation results are in Table 4-8.

Table 4-8 Estimation Results of the VAR(1) in the Post-Crisis Period

	L_SILVER	L_GOLD	L_USD
L_SILVER(-1)	0.996030	-5.41E-05	-0.001697
	(0.00455)	(0.00251)	(0.00110)
	[218.917]	[-0.02153]	[-1.53598]
L_GOLD(-1)	0.005049	0.999482	0.001863
	(0.00558)	(0.00308)	(0.00135)
	[0.90549]	[324.701]	[1.37601]

L_USD(-1)	0.013489	0.005548	0.989541
	(0.01639)	(0.00905)	(0.00398)
	[0.82296]	[0.61324]	[248.653]
C	-0.081710	-0.019716	0.037677
	(0.07156)	(0.03950)	(0.01737)
	[-1.14184]	[-0.49912]	[2.16848]
R-squared	0.996048	0.997874	0.985923
Adj. R-squared	0.996039	0.997869	0.985890

The stability test and the cointegration test of the above VAR(1) model are shown in Table 4-9 and Table 4-10. Since the modulus of all roots is less than 1, the VAR(1) model is stable. But both of the Trace test statistic and the Maximum Eigenvalue test statistics suggest that there is no general equivalence between the prices of silver and gold and the U.S. dollar index or, for that matter, a lack of cointegration in the post-crisis period. Hence, the estimated relationship in Table 4-8 might be unreliable.

Table 4-9 AR Roots Table of VAR(1) in the Post-Crisis Period

Root	Modulus
0.999105	0.999105
0.993318	0.993318
0.992630	0.992630
No root lies outside the unit circle.	
VAR satisfies the stability condition.	

Because the three variables fail the cointegration test in the post-crisis period, the data should be differenced to estimate the VAR model again to examine the short-term relationship between the daily growth rates of the three variables. According to the criteria in Table 4-11, four criteria indicate that the optimal lag order is 0 except the LR criterion which suggests 11. These indicate that the VAR model may not be suitable for analyzing the relationship between the daily growth rates of the prices of silver and gold and the U.S. dollar index. However, a VAR(2) model is still estimated here referring to the analysis in the pre-crisis period. The estimation results are shown in Table 4-12.

Table 4-10 Johansen Cointegration Test in the Post-Crisis Period

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None	0.006493	12.91562	29.79707	0.8954
At most 1	0.003220	4.564191	15.49471	0.8532
At most 2	0.000335	0.429279	3.841466	0.5123

Trace test indicates no cointegration at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None	0.006493	8.351425	21.13162	0.8810
At most 1	0.003220	4.134912	14.26460	0.8448
At most 2	0.000335	0.429279	3.841466	0.5123

Max-eigenvalue test indicates no cointegration at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

Table 4-11 Optimal Lag Length of the First-Differenced VAR Model in the Post-Crisis Period

Lag	LogL	LR	FPE	AIC	SC	HQ
0	12088.21	NA	1.30e-12*	-18.85368*	-18.84161*	-18.84915*
1	12093.72	10.99980	1.31e-12	-18.84824	-18.79998	-18.83012
2	12100.94	14.35748	1.31e-12	-18.84546	-18.76100	-18.81375
3	12108.73	15.44789	1.31e-12	-18.84357	-18.72291	-18.79827
4	12111.73	5.946417	1.33e-12	-18.83421	-18.67736	-18.77532
5	12117.16	10.72721	1.33e-12	-18.82865	-18.63559	-18.75616
6	12123.21	11.91306	1.34e-12	-18.82404	-18.59479	-18.73796
7	12128.30	9.999595	1.35e-12	-18.81793	-18.55248	-18.71827
8	12136.04	15.19188	1.35e-12	-18.81598	-18.51433	-18.70272
9	12143.92	15.41243	1.35e-12	-18.81423	-18.47638	-18.68738
10	12153.38	18.45820	1.35e-12	-18.81494	-18.44090	-18.67450
11	12169.74	31.84766*	1.34e-12	-18.82642	-18.41618	-18.67239
12	12177.11	14.31508	1.34e-12	-18.82388	-18.37744	-18.65626
13	12182.88	11.19013	1.35e-12	-18.81885	-18.33621	-18.63764

14	12190.18	14.10233	1.35e-12	-18.81619	-18.29735	-18.62139
15	12197.99	15.06305	1.35e-12	-18.81434	-18.25930	-18.60594
16	12206.33	16.05255	1.36e-12	-18.81332	-18.22208	-18.59133
17	12214.68	16.01770	1.36e-12	-18.81230	-18.18487	-18.57672
18	12218.11	6.561225	1.37e-12	-18.80360	-18.13998	-18.55444
19	12222.95	9.238673	1.38e-12	-18.79711	-18.09729	-18.53435
20	12229.11	11.74064	1.38e-12	-18.79269	-18.05666	-18.51634

Table 4-12 Estimation Results of the First-Differenced VAR(2) Model in the Post-Crisis Period

	DL_SILVER	DL_GOLD	DL_USD
DL_SILVER(-1)	-0.057212	-0.005673	0.011669
	(0.04631)	(0.02556)	(0.01125)
	[-1.23552]	[-0.22193]	[1.03726]
DL_SILVER(-2)	-0.052859	-0.043688	0.017538
	(0.04628)	(0.02555)	(0.01124)
	[-1.14211]	[-1.71014]	[1.55976]
DL_GOLD(-1)	0.080440	-0.001087	-0.035348
	(0.08138)	(0.04492)	(0.01977)
	[0.98846]	[-0.02420]	[-1.78787]
DL_GOLD(-2)	0.093646	0.040241	-0.054668
	(0.08143)	(0.04495)	(0.01978)
	[1.15003]	[0.89530]	[-2.76339]
DL_USD(-1)	-0.269706	-0.118234	-0.005293
	(0.12841)	(0.07088)	(0.03120)
	[-2.10028]	[-1.66803]	[-0.16967]
DL_USD(-2)	-0.116795	-0.063363	-0.017228

	(0.12853)	(0.07095)	(0.03123)
	[-0.90867]	[-0.89308]	[-0.55171]
C	0.000664	0.000781	5.85E-06
	(0.00069)	(0.00038)	(0.00017)
	[0.95632]	[2.03796]	[0.03470]
R-squared	0.006296	0.004951	0.008756
Adj. R-squared	0.001620	0.000268	0.004091

As seen, the estimation results of the first-differenced VAR(2) model are very poor. Most coefficients are statistically insignificant at 10% critical significance level, and the adjusted R-squared are less than 0.01. Compared with Table 4-3, Table 4-12 suggests that the long-term relationship between the prices of silver and gold and the U.S. dollar index estimated in the pre-crisis period has disappeared since the U.S. subprime mortgage crisis, and the short-term relationship is also insignificant. This may be caused by two important reasons just mentioned before. First, global economic uncertainty forces more and more investors use gold and silver as important hedging mechanisms. The increasing demand for gold and silver also attracts more speculation which makes the gold and silver prices more volatile than before and hence the linkage between their prices and the U.S. dollar index is weakened. Second, the volatility of the U.S. dollar after the U.S. subprime crisis may also weaken the relationship. Since 2007, the United States and the European Union have fallen into economic depression one after another. The burst of subprime crisis caused the U.S dollar decline against other currencies including the Euro, i.e. the U.S. dollar index declined. When the crisis expanded to other countries and caused a worldwide credit crisis, especially when the economy of Europe fell into recession because of the European sovereign-debt crisis, the U.S. dollar index naturally rose because of the Euro's decline. Hence, the U.S. dollar index reflects the relative value of U.S. dollar rather than the real purchasing power of U.S. dollar, and that's why the relationships between prices of gold, silver and the U.S. dollar index have weakened after the U.S. subprime crisis.

4.3 Granger Causality Test

The Granger causality is used here to examine whether the gold price and the U.S. dollar index are useful in forecasting the silver price. The test results are given by Table 4-13 and Table 4-14.

Table 4-13 Granger Causality Test in the Pre-Crisis Period

Excluded	Chi-sq	df	Prob.
L_GOLD	11.69390	2	0.0029
L_USD	5.951221	2	0.0510
All	20.74719	4	0.0004

Table 4-14 Granger Causality Test in the Post-Crisis Period

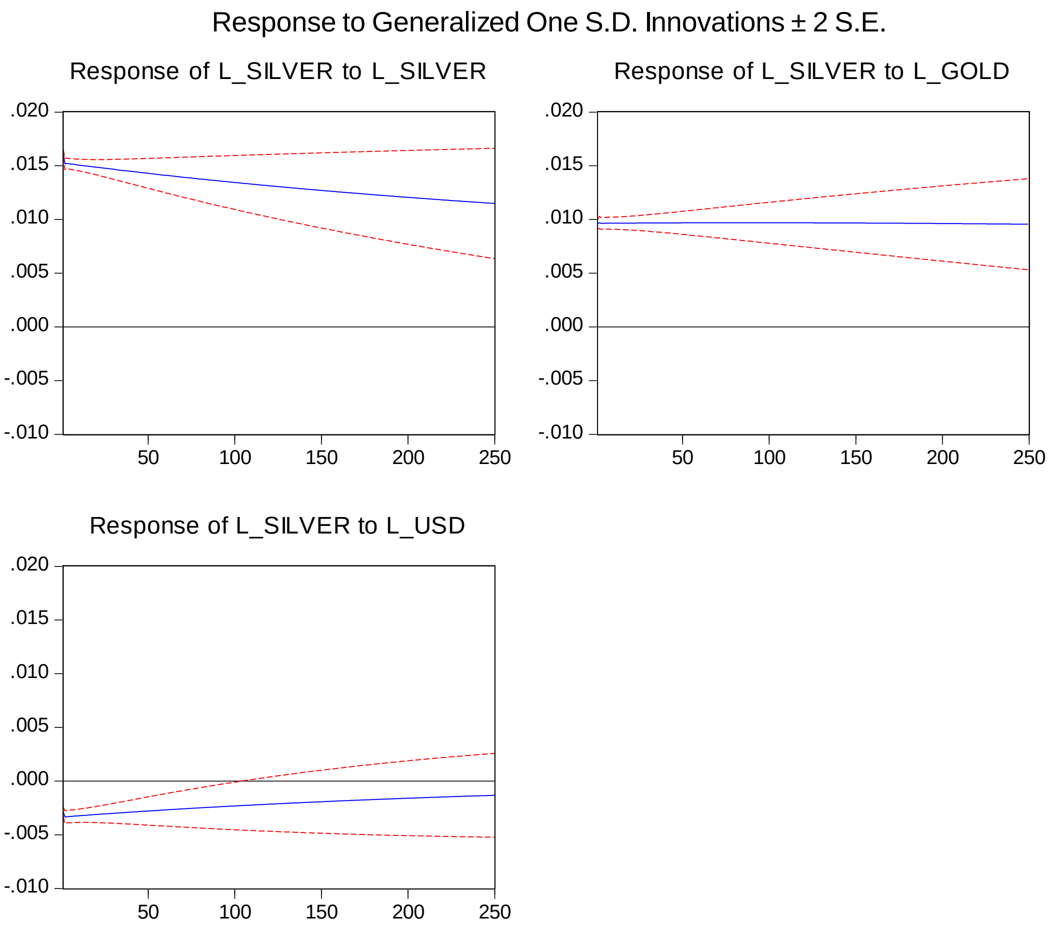
Excluded	Chi-sq	df	Prob.

L_GOLD	0.819914	1	0.3652
L_USD	0.677271	1	0.4105
All	2.137630	2	0.3434

As seen in Table 4-13, when in the pre-crisis period, all of the following three hypotheses cannot be rejected at 10% critical significance level: the gold price does not Granger caused the silver price, the U.S. dollar index does not Granger caused the silver price, and the gold price and the U.S. dollar index do not Granger caused the silver price. But in the post-crisis period as shown in Table 4-14, all of the above hypotheses at 1% critical significant level are not rejected. Therefore it appears that gold price and the U.S. dollar index are useful leading indicators in predicting silver price in the pre-crisis period, yet their predictive abilities are statistically insignificant after the U.S. subprime mortgage crisis. This demonstrates again that the relationship between the prices of gold and silver and the U.S. dollar index has weakened since the U.S. subprime mortgage crisis.

4.4 Impulse Responses in the Pre-Crisis Period

Figure 4-1 Generalized Impulse Response of the Silver Price in the Pre-Crisis Period



Impulse response (or impulse response function) reflects the reaction of endogenous variables in response to the external shocks. According the above analysis, there is a long-term relationship between the prices of silver and gold and the U.S. dollar index in the pre-crisis period, yet such relationship is unreliable and the short-term relationship of the three variables is also statistically insignificant after the U.S. subprime mortgage crisis. Hence, only the impulse responses in the pre-crisis period are presented here.

Dynamic analysis of VAR models is often carried out using the orthogonalized impulse responses, where the underlying shocks to the VAR models are orthogonalized using the traditional approach of Cholesky decomposition suggested by Sims (1980) before impulse responses and variance decomposition. But this approach is sensitive to the ordering of the variables in the VAR. Pesaran and Shin (1998) propose the generalized impulse response analysis which does not have the above shortcoming. Hence, the generalized impulse responses is used. Figure 4-1 presents the estimated impulse responses (solid line) with the corresponding standard confidence error bands (dashed line). The vertical axis shows the change of the silver price and the horizontal axis shows the dates after a temporal shock.

The impulse responses in Figure 4-1 can be summarized as follows. An exogenous increase in the silver price leads to higher silver price and the effect dies out relatively slowly and contributes to positive effect on silver price. A positive shock to the gold price has the same effect on silver price as the positive silver price shock at a relatively lower level. An appreciation of the U.S. dollar, i.e. an increase in the U.S. dollar index, leads to lower silver price immediately and thereafter the effect dies out gradually. The impulse responses are consistent with the above analysis: the silver price has a positive correlation with gold price and a negative correlation with the U.S. dollar index.

4.5 Variance Decomposition of Shocks

Variance decomposition (or forecast error variance decomposition) separates the variance of an endogenous variable into the component shocks of the VAR and provides information about the relative importance of each shock in affecting the variable. Table 4-15 shows the variance decomposition for the silver price, where the second column (labeled “S.E.”) contains the forecast error of the silver price at the given forecast horizon and the remaining columns give the percentage of the forecast variance due to each shock. It is seen that the silver price shock accounts for more than 99% of fluctuations in the first month (there are approximately 22 business days in each month). The contribution of gold price shock is larger than that of the U.S. dollar index shock, and the former increases over time while the latter increases at first seven days and then decrease gradually. Hence, the silver price is mainly driven by shocks to the silver price and the gold price, while the U.S. dollar index shock accounts form a relatively small share of silver price fluctuations.

Table 4-15 Variance Decomposition Based on the VAR(2) Model in the Pre-Crisis Period

Period	S.E.	L_SILVER	L_GOLD	L_USD
1	0.016156	100.0000	0.000000	0.000000
2	0.022191	99.81228	0.134065	0.053654
3	0.026922	99.77080	0.159495	0.069704
4	0.030926	99.74603	0.177510	0.076455
5	0.034460	99.72974	0.190536	0.079722
6	0.037655	99.71757	0.201241	0.081185
7	0.040592	99.70775	0.210623	0.081629
8	0.043323	99.69935	0.219203	0.081444
9	0.045885	99.69188	0.227272	0.080850
10	0.048306	99.68501	0.235004	0.079981
11	0.050605	99.67857	0.242513	0.078921
12	0.052798	99.67240	0.249873	0.077728
13	0.054899	99.66642	0.257137	0.076441
14	0.056916	99.66057	0.264340	0.075088
15	0.058860	99.65480	0.271511	0.073689
16	0.060737	99.64907	0.278670	0.072261
17	0.062553	99.64335	0.285831	0.070816
18	0.064313	99.63763	0.293009	0.069361
19	0.066022	99.63188	0.300210	0.067905
20	0.067683	99.62610	0.307444	0.066454
21	0.069301	99.62027	0.314715	0.065011
22	0.070878	99.61439	0.322029	0.063581

4.6 Summary of the Empirical Statistics

The empirical analysis in this chapter is based on cointegrated VAR models and Granger causality tests, and the main conclusions are as follows: In the post-crisis period from 1986 to 2006, there is a long-term relationship between silver price, gold price and the U.S. dollar index. Moreover, gold price and the U.S. dollar index can Granger-cause the silver price. However, in the post-crisis period from 2007 to January 31, 2012, the long-term equilibrium relationship and the Granger causality relationship disappear and the short-term relationship is also insignificant. These results indicate that the silver price might be largely influenced by other factors after the U.S. subprime mortgage crisis.

Chapter 5

Conclusion

This paper investigates the long-term as well as the short-term relationships between the silver price, the gold price and the U.S. dollar index before and after the U.S. subprime mortgage crisis especially focusing on the dynamics of silver price. I estimate cointegrated VAR models and test the Granger causality relationship using daily data covering the period from January 2, 1986 to January 31, 2012. The results can be summarized as follows:

1. The silver price has a positive correlation with gold price and a negative correlation with the U.S. dollar index according to the basic descriptive statistics.

2. In the pre-crisis period from 1986 to 2006, the cointegrated VAR model suggests the existence of a long-term equilibrium relationship between the above three variables. While, the Granger causality test indicates that the gold price and the U.S. dollar index can Granger cause the silver price. Furthermore, the impulse response and the variance decomposition indicate that the shocks to the silver price and the gold price account for the majority of silver price fluctuations.

3. In the post-crisis period from 2007 to January, 2012, the long-term equilibrium relationship and the Granger causality relationship disappear and

the short-term relationship is also insignificant. Hence, for silver investors, the gold price and the U.S. dollar index can be used as leading indicators during the normal economic times. But currently they should pay more attention to other factors besides the gold price and the U.S. dollar index because of the weak world economy.

Considerable work remains to be done in the area of price dynamics of silver. Possible areas of investigation include the relationship and its historical change between silver and other commodities such as platinum, aluminum, copper, etc. Greater understanding of the macroeconomic and market forces driving the dynamics of silver price is also of interest.

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