Short-run and long-run determinants of the price of silver

Master Thesis

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Introduction

Silver is a material that is largely used for industrial purposes (sterling ware, photographic and electrical industries). Furthermore investors view this material as hedge against inflation. The price of silver has been showing a remarkable uptrend over the past years as well. Since the price of silver was no longer determined by the US Treasury the price has been determined by market forces. The most volatile event in the development of the silver price took place in 1979-1980, when several factors contributed to large volatility in the price of silver.

This study will research the short-term and long-term determinants of the price of silver. This is done using the Vector Error Correction model after testing for cointegration and stationarity for the 1986-2012 period. Short-term factors are determined by performing a Vector Autoregressive Model, which treats all variables as endogenous.

Main research question

The analysis in this paper will focus on the determinants of the price of silver for the long and short run, which is done by using a Vector Error Correction model and testing for cointegration between the price of silver and several macroeconomic variables. In the presence of a long-term equilibrium relationship between two or more variables, the Vector Error Correction model allows for deviations in the short run. The Vector Autoregressive model is used for variables which are not cointegrated and likely to have a relation with silver in the short run.

A lot of research has been done on the determinants of the price of gold, especially in relation to inflation hedge capabilities and investment. Although silver is a precious metal as well, surveys which try to clarify the determinants of this metal are scarce. Most of them are based on the price of silver in relation to gold; the impact of macroeconomic news or the effect of inflation on precious metals. This study takes into account macroeconomic variables, market values of investment products and prices of other commodities in order to determine the drivers of the price of silver.

Current state of research

History of price of silver

The price of silver (Figure 1) showed a remarkable uptrend over the past years with two spikes in 1980 and 2011. In the graph below the price of silver is plotted with the price of gold and both metals show a comparable pattern, but the silver price seems to be more volatile. (Dooley, Isard et al. 1995; Hilliard 1999) and (Barnhill and Powell 1981) provided a review of the history of the silver price, as well as (Silver Institute). (Barnhill and Powell 1981)

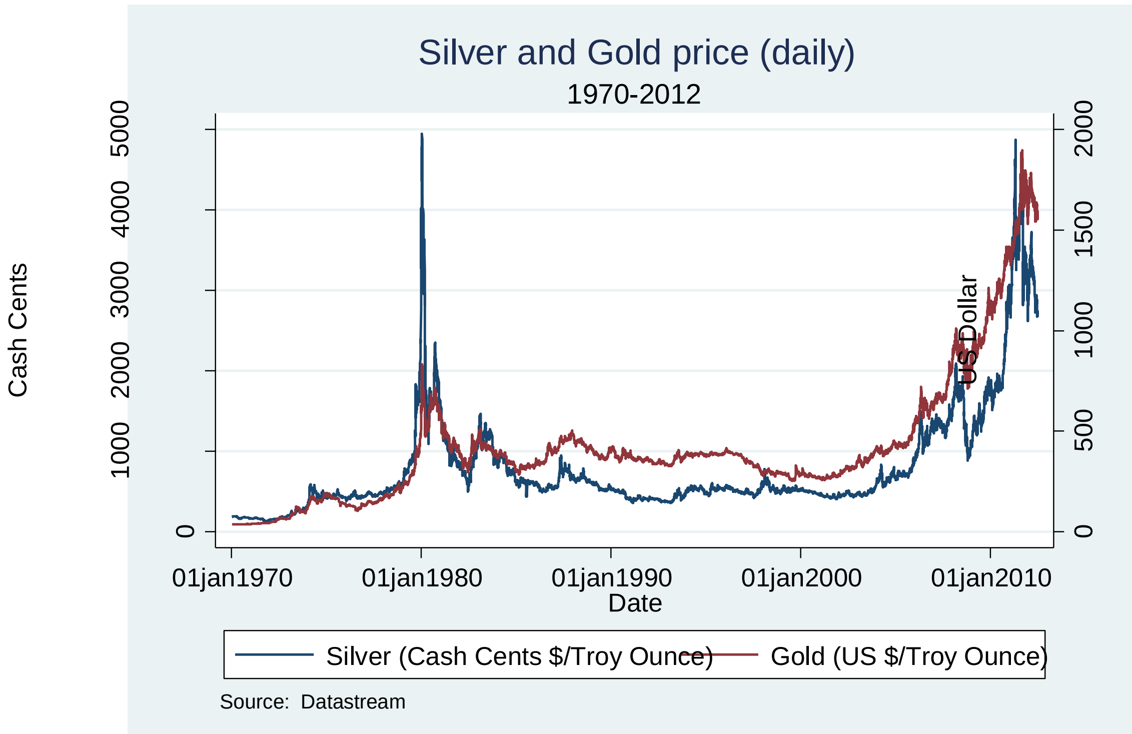

Figure 1

After World War II the fabrication demand for silver increased due to the rebuilding of Europe and Japan and the use of silver for electrical purposes, while supply was relatively constant. The price of silver remained relatively constant and this was due to selling of the U.S. Treasury in order to keep the price of silver under its monetary value of $1.29 per ounce. In 1961 the U.S. Treasury decided to phase silver out of currency by ordering $5 and $10 dollar silver certificates out of circulation. Another decision was to suspend silver bullion sales by the Treasury at the formerly fixed price of 91 cents, which led to a rise in market quotes. To keep silver prices low, the U.S. Treasury kept selling silver.

In mid-1963 the Public Law 88-36, which repealed the Silver Purchase Act of 1934 and authorized the printing of Federal Reserve Notes not redeemable in silver, was passed. This action was followed by the Coinage Act of 1965, which eliminated the use of silver in dimes and quarters and reduced the silver content of half dollars. In 1967, silver coins were withdrawn from circulation, and holders of silver certificates were given one year, until June 24, 1968, to redeem the certificates for silver.

With this development the price of silver was no longer determined by the U.S. Treasury but by industrial and investor demand, which can be spotted in the graph. After a period of declining prices due to intervention of government and an economic recession, the price went up in the period 1972-1975 due to an embargo of oil exports by OPEC and the devaluation of the dollar. During the 1976-1980 period a large spike a large spike can be spotted in the graph. Analysts explained that this exponential rise was caused by high domestic inflation rate combined with slow economic growth in the U.S, another oil crisis, a U.S. economic recession that began in 1979 and the attempt of a group of investors to influence the silver price.

(Barnhill and Powell 1981) mention four reasons in their report: (1) persistent shortfall of silver world production compared to silver world demand; (2) very large silver stock acquisitions by the Hunt family and certain other identifiable parties; (3) large investments by other investors due to unattractive real returns and a volatile politic and economic environment; (4) actions and inactions of the governments of the United States and India, which restricted access to and reallocation of 80% of above ground silver.

The Hunt brothers cornered the silver market by accumulating large amount of physical silver in the early 1970s, since gold was not allowed to be bought by citizens at that time in history. Furthermore the Hunt brothers had purchased long futures silver contracts by early 1974, which gave them the right to buy 55 million ounce of silver at a predetermined price next to their massive physical inventory they already accumulated.

A sharp rise in prices occurred due to the accumulation and large demand of silver by the Hunt brothers. The two major U.S. exchanges COMEX and CBOT were afraid that they would not be able to deliver the physical silver, which would lead to a default. The Hunt brothers were warned by the CFTC to sell some of their silver but the Hunt brothers resisted. This led the CBOT, backed by the CFTC, to raise margin requirements for silver and limit the holding of silver futures for traders to a maximum of 3 million ounces. The COMEX changed its rules as well on January 7, 1980 by limiting the maximum holding amount of silver futures to 10 million ounce; any exceeding amount had to be liquidated. However, the next trading day silver prices reached a $50 ounce record high. Prices of gold followed with a record of $850 dollar. Rules were changed by the COMEX and trading in silver was limited to liquidation orders only, which of course led to a sharp decline in the price of silver.

Beside the decline in silver acquisitions by the Hunt brothers, (Barnhill and Powell 1981) mention five other reasons for the sharp decline in the price of silver. The decline in commercial silver demand of 40% and the sharp increase in recycled silver scrap and primary production resulted in a surplus of silver. Demand from investors declined due to volatility in the price of silver, moderating oil prices and inflation rates, tightened U.S. credit supply, attractive alternative investments and the anticipation of a sharp recession in U.S. economy. The prospect of large investors repaying their collateralized loans by liquidating their cash silver holdings intensified decline in investor silver demand.

After the Hunt brothers' period, there was a long time of net disinvestment in Silver, mostly due to governments which reduced their silver stock pilings, but after 2000 there was a positive net investment demand again. Possible reasons could be the introduction of Exchange Traded funds, higher inflation and/or financial turmoil.

Supply and demand

Since supply and demand are the most important factors, driving the price of a good it is interesting to gain more insight in developments over the past years for the precious metal silver. The supply of silver to a large extent comes from mine production, which accounts for 73.19% in 2011, but recycling of silver takes a large part as well with 24.67%. Furthermore a small percentage of silver supply comes from net government sales and producer hedging. Producer hedging mainly comes from companies for which silver is a by-product. By taking a short call position or a short forward position they can lock a certain price in advance. Silver supply via net government sales mainly comes from Russia, but it is hard to find precise figures of sales, which is the case for silver stock piling as well. Thomsons Reuters conservatively estimated government stock at 97 Moz (million ounces) at end 2011.

Since 1998, the total supply of silver increased, and mine production contributed for the largest part, which can be spotted in Figure 2Figure 2. It is interesting that a large part of the 75/80% of total silver production is a byproduct of copper, gold, lead, or zinc. This would imply that the production of silver is relatively insensitive to price changes in silver. Both scrap supply and mining production increased over the past years. Mine production per country (Figure 3) remained stable while largest mine production supply comes from Mexico, Peru and China. Implied net disinvestment took a small percentage in years 1998, 1999 2000, 2002 and 2003 but in other years there was a positive investment demand. The World Silver Survey 2012 even mentioned that investment demand was the principal driver of fluctuations in the silver price in 2011. The decline in net government sales in 2011 was mainly due to a collapse in the sale of silver by Russia, which disposals dropped by 90% last year, where China was the largest supplier in 2006 and earlier.

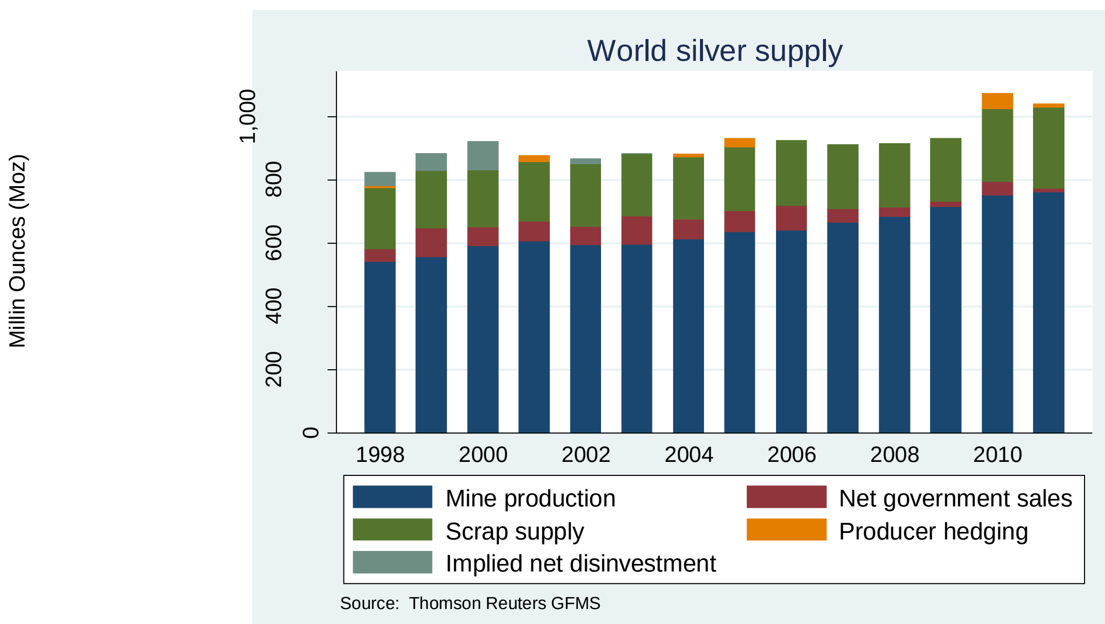

Figure 2

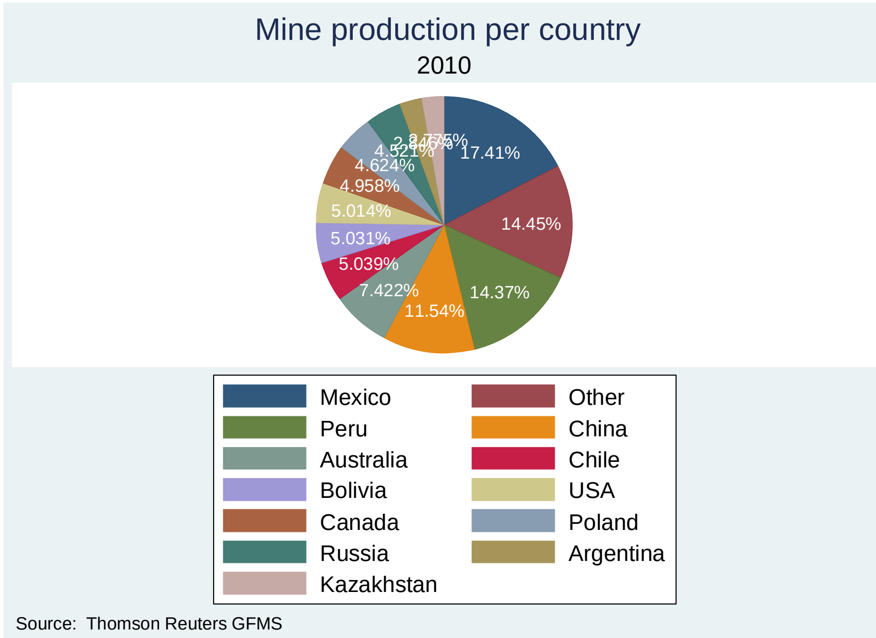

Figure 3

The demand for silver comes from a large variety of sources. Figure 4 shows that the largest demand comes from industrial use. Electronic and electrical use of silver takes the largest part of industrial use, brazing alloy and solder comes next. While in previous years there was a net implied disinvestment in silver, which can be spotted in Figure 2, in 2011 there was an implied net investment, which took a large part of the total demand. Photographic use mainly includes demand from the medical sector.

A few trends in world silver demand can be spotted over the past years. Silver is used for the largest part in industrial application and this part rised over the past years. The graph suggests that economic circumstances have an important effect on the demand of silver, since 2009 the demand for industrial application showed the largest decrease. In Figure 5 Fabrication demand per country, which includes industrial applications, photography, jewelry, silverware and coins and medals, shows that mining production matches with fabrication demand for most countries.

Since 2004 net implied investment demand has a large stake in total demand. Especially after 2008 there is a significant increase, which might be due to the financial crisis and the flight of investors to the considered safe havens of precious metals. The same pattern can be observed for coin and metal, since coins are not only used for collecting, but they serve as an investment for investors as well. The photographic demand declined a lot; a main reason for this might be the decline in consumer film sales and the increase in sales of digital cameras over the past years. However, the largest part of photographic demand comes from the medical sector and this demand was relatively stable over the past years.

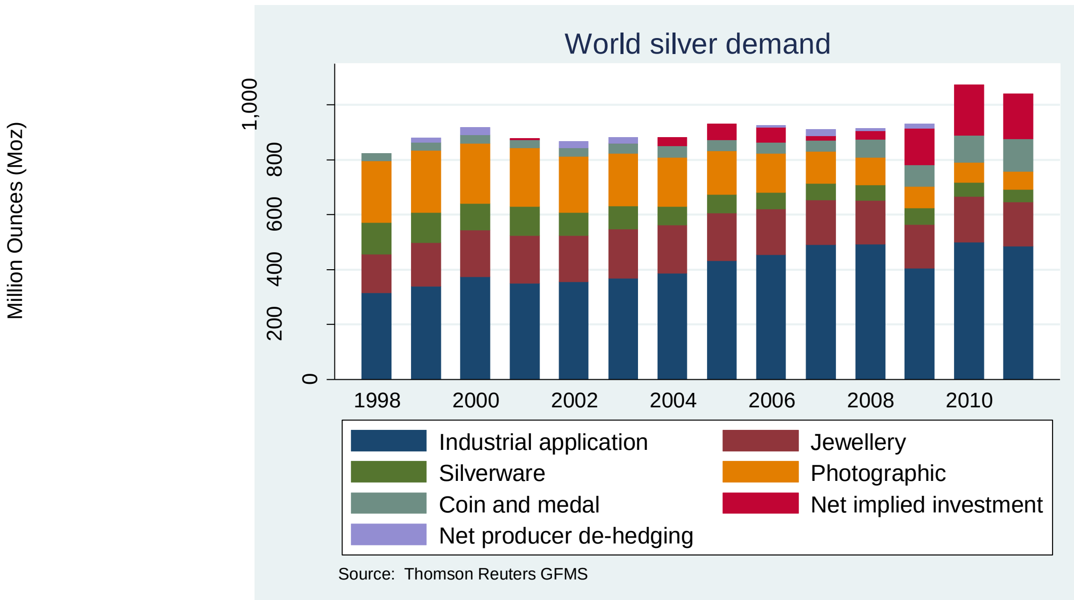

Figure 4

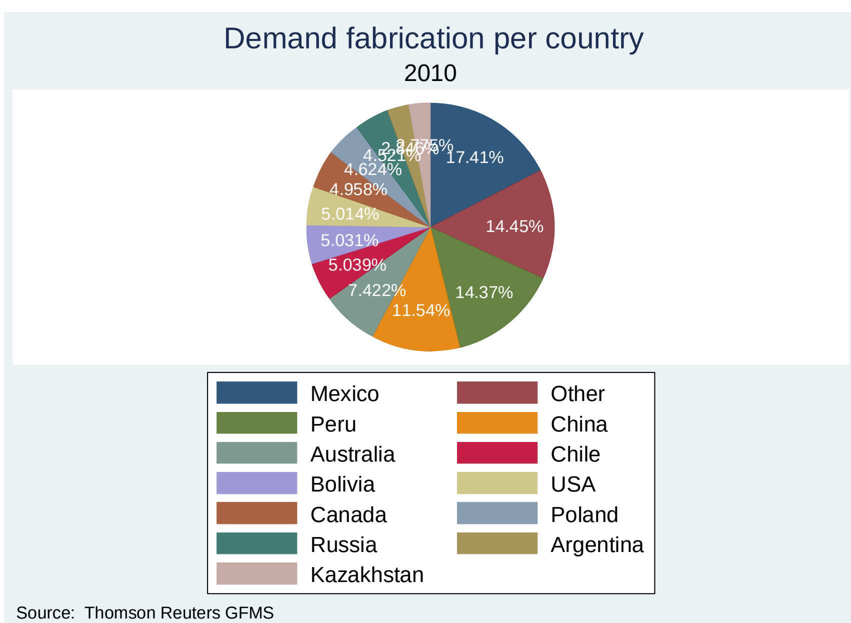

Figure 5

Using yearly world production data from U.S. Geological Survey and 1900 as a base year, the graph below (Figure 6) shows the percentage increase for gold, silver, copper, lead, zinc and platinum group. [1] Especially platinum group shows a remarkable uptrend followed by copper and zinc. World production in absolute values is smallest for the platinum group, followed by gold and silver. The trend for gold, silver and lead remains relatively stable.

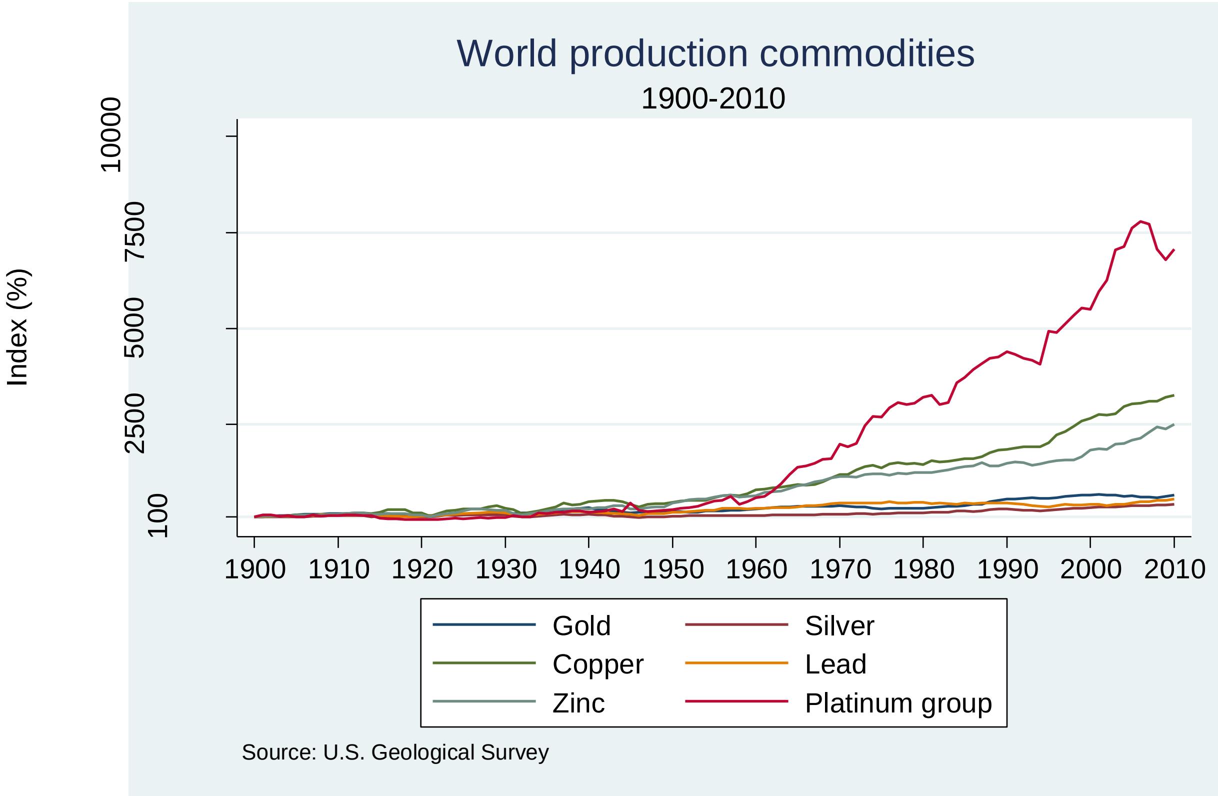

Figure 6

Efficiency of silver prices

Since movements in the price of silver seem to be more volatile compared to gold it is interesting to determine whether the silver futures market is efficient. (Booth and Kaen 1979) performed three tests (serial correlation, runs and trading rules) and results lead them to the conclusion that silver and gold markets are not information efficient. This would imply that it is possible for an investor to gain above average profits (transaction costs were not included in the analysis). These results are confirmed by a survey conducted by (Aggarwal and Sundararaghavan 1987).

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[1] http://minerals.usgs.gov/ds/2005/140/

According to (Solt and Swanson 1981), investing in silver and gold can be considered more like a speculative activity instead of an investment activity. Their results are evidence of considerable heteroskedasticity in the variance of the price changes for the metals except for the logarithmic change, nonzero and non-stationary means and positive dependence in each of the price changes. Despite of the positive dependence they mention that investors cannot, before or after transaction cost, easily generate superior returns. (Lucey and Tully 2006) provided the first evidence of daily seasonability in silver prices although the magnitude of those results is very small.

A broader study was conducted by (Hammoudeh and Yuan 2008), who took into account monetary policy and oil shocks using several conditional volatility models. An important note they make is that copper, silver and gold all have their own specifications and are not only affected by macroeconomic factors and crises, because they all have different supply and demand characteristics. Furthermore it is interesting that conditional volatility is more persistent for silver and gold compared to.

Inflation

(Levin, Montagnoli et al. 2006) found that inflation is highly correlated with the price of gold. This should make silver as precious metal sensitive to inflation as well. (Taylor 1998) concluded that during particular periods gold, silver and platinum could have been used as a short-run hedge against inflation, but it was not possible to hedge during the first oil crisis in 1973/1974 or in the period 1988-1998. Although precious metals can be used as a long-run inflation hedge, the relation between inflation and the precious metals does not move one to one over the whole period. Due to (McCown and Zimmerman 2006) gold and silver both are investment instruments to hedge inflation, although this relation is stronger for gold. This is confirmed by (Conover, Jensen et al. 2009) who found that gold relative to silver and platinum performs better as an inflation hedge.

Correlation of gold and silver prices and the expected inflation is high in a survey of (McCown and Zimmerman 2007). They measured expected inflation by using the spread between U.S. Treasury bills and Treasury Inflation Protected Securities. Correlations are slightly higher for gold and seem to increase over a longer time horizon. For silver the correlation is 0.542 over a 10 year horizon, while gold has a correlation of 0.679. This is a validation of their previous work, (McCown and Zimmerman 2006), where they concluded that both gold and silver show evidence of a useful inflation hedge over a longer time horizon using the estimates of the arbitrage pricing model. Results for the co integration model confirm their findings for the arbitrage price model.

Monetary policy

Since inflation is being monitored by Central Banks, this would imply that their monetary policy should have an impact on precious metals prices as well. A central bank lowering the discount rate is seen as an 'expansive' policy, while increasing the discount rate is seen as a 'tightening' policy. (Jensen, Mercer et al. 1996) found that stock returns are higher in periods of expansive policy compared to a tightening policy in the U.S., which is the case for foreign stock returns as well. Returns in foreign countries are even more related to U.S. monetary conditions compared to their local monetary environment.

(Conover, Jensen et al. 2009) performed a comparable study for precious metals, which included the Precious Metals Commodities index, which consists of an equally weighted average total return on gold, silver and platinum. They find that during tightening policy of the Federal Reserve, returns of precious metals are significantly higher compared to periods of expansive policy. This is in line with theory since for most central banks their task is to control inflation by increasing discount rates with high inflation and lowering discount rates with an inflation which is lower than desired. However, taking a closer look on individual results for gold and silver, the conclusion does not hold for silver as a separate commodity. The difference in annualized return between expansive and tightening periods for silver is only 0.47%, although not significant with a p-value of 0.82. Gold has a difference of 13.04% with a p-value of 0.06, which implies that monetary policy has more influence on the price of gold compared to the price of silver. Findings of (Hammoudeh, Yuan et al. 2010) confirm these results. They find that the volatility sensitivity of precious metals in relation to exchange rate volatility in the presence of monetary policy is particularly strong for silver.

Macroeconomic factors

The industrial usage of silver implies that prices should be sensitive to macroeconomic moves. (Fama and French 1988) researched whether business cycles have an impact on metals prices. They found sharp rises and declines in the prices of all metals (aluminum, copper, lead, tin, zinc, gold, platinum, and silver) around the business cycle peaks of 1973-1974 and 1979-1980. This was investigated by observing the interest-adjusted bases, which is the difference between the relative warehousing costs and the relative convenience yield. When there is higher demand, inventory levels are lower which would lead to a higher convenience yield and lower warehousing costs and thus a negative interest-adjusted base. Indeed, the interest-adjusted bases were negative for all metals but gold around the peak of 1979-1980 and for all metals but zinc around the peak of 1973-1974.

(Christie–David, Chaudhry et al. 2000) investigated the impact of macroeconomic news releases on the volatility of the gold and silver futures price. Especially interest rate futures responded substantially to the release of macroeconomic news, while metal futures responded modest. Surprisingly they found that the variance on non-announcement days is higher than on announcement days for silver. Gold and silver especially responded strong to the release of capacity utilization, while interest rates futures responded strong to the release of many of the announcements. Furthermore they found significant reactions in the price of gold for the release of the CPI, unemployment rate, GDP, and the PPI, while for silver this was only the release of the unemployment rate. Although not tested, they mention that global demand may also play a role in explaining the results and that for silver the higher non announcement variance can be interpreted as evidence of substantial speculation.

The relationship between monetary and financial variables on the volatility of the metals gold, silver, platinum and palladium is examined by (Batten, Ciner et al. 2010). Their main finding is that gold volatility is explained by monetary variables, but this is not true for silver. No significant monetary or financial variables are found as explanation for silver volatility. Finally they conclude that there is limited evidence that the same macroeconomic factors jointly influence the volatility of the four precious metals price. However, they found evidence that there is volatility feedback between the precious metals and they detect significant dependency in the conditional volatility of precious metals on their own lags.

Correlation between precious metals

Since silver has a status as precious metal like gold, one would expect that there is a correlation between both metals. This has been the case for a long period but the demonetization of both metals in a lot of countries weakened this link. As mentioned before, silver has a higher industrial demand compared to gold where gold is more being used as an instrument to hedge inflation.

(Escribano Sáez and Granger 1998) analyzed the long run relation between gold and silver prices. During the bubble period they found gold and silver prices strongly related, but the long run relationship appears to be complicated and one that varies at particular dates. Furthermore their most recent period in the data set has been the least volatile, follows models most closely agreeing with the efficient market theory. The ratio of gold to silver price of 60 (at that time of writing historically high levels) makes them suggest that some separation of the two markets is occurring.

(Escribano Sáez and Granger 1998) already suggested that separation of the two markets is occurring and this finding is confirmed by (Ciner 2001). In the paper the statistical findings indicate that the frequently cited long-term stable relationship between the prices of gold and silver has disappeared in the 1995-1998 period. This implies that silver and gold should not be considered as substitutes to hedge against similar types of risks. Both metals have got different economic uses, which result in different economic fundamentals and thus it is not possible to assume that the price of silver is dependent on the price of gold or vice versa.

(Lucey and Tully 2006) argue that, excluding for (Escribano Sáez and Granger 1998), previous research on the link between silver and gold was static and that there was no examination of whether or how the relationship between gold and silver changes over time. Their findings indicate that historically a stable relationship between gold and silver has been maintained. In general, this relationship is strong and convincing, although there are significant periods when it is weakened or broken.

(Batten, Ciner et al. 2010) found that there is limited evidence of volatility feedback between precious metals. However, (Erb and Harvey 2006) mention that every metal has its own properties and that it is not possible to consider them as the same. This becomes clear in their correlation matrix, where silver has the highest correlation of 0.66 with gold. A same conclusion comes from (Hammoudeh, Yuan et al. 2010), who found gold and silver to have the highest correlation of 0.42 except for the correlation of platinum with palladium (0.48). Their Dynamic Conditional Correlation model for silver and gold shows a stable trend over the period January 4, 1999 to November 5, 2007. The correlation varies between 0.3 and 0.5 over the period, but became stronger over the period.

Investment

Although silver is largely being used for industrial purposes it is bought as an investment as well. After 1967, when silver coins no longer had a monetary function, the price of silver was determined by the market, which made it more interesting for investors to invest in silver.

For the period 1976-2004 (Hillier, Draper et al. 2006) concluded that gold, platinum and silver have diversifying properties in investment portfolios and that they have some hedging capability. The hedging capability seems especially present during abnormal stock market volatility. (Conover, Jensen et al. 2009) carried out a comparable study about the benefits of adding precious metals to a portfolio. With a stake of 25% of precious metals in portfolio they found that the sharp ratio improves significantly. The result is an increase of 1.65% portfolio return and a drop in standard deviation of 1.86%. Furthermore an indirect investment in precious metals, which implies an investment via, for example, a mining firm, results in considerably larger benefits.

(Hood and Malik) used using daily data from November 1995 to November 2010 to investigate whether precious metals can be used as a safe haven. Coefficients are very small for silver, while gold has larger negative betas. However, the best hedge during financial crises is investing in the Volatility Index (VIX), since this index has the largest negative coefficient compared to the U.S. market. (McCown and Zimmerman 2006) confirm previous findings and find that gold and silver both have a beta statistically indifferent from zero, with a mean return of gold slightly higher than Treasury Bills, while mean return for silver is lower compared to Treasury Bills. Their conclusion is that the CAPM doesn't show any advantage of investing in silver due to higher volatility compared to gold, lower return compared to T-Bills, and a hint of a positive market beta.

With the introduction of Exchange Traded Funds it is easier for investors to invest in precious metals without holding the underlying. The study of (Ivanov 2011) researched the relation between futures, spot prices and Exchange Traded Funds of oil, silver and gold. Future prices have always been the most important factor in price discovery and by using tracking error and pricing deviations metrics this is examined. The survey has been done for the period March 1 2009 till August 31 2009. For the oil market, the price discovery still happens in the futures market but with a more important role for the ETF market. For gold and silver (Ivanov 2011) observes a shift from the futures market to the ETF market. This would imply that the ETF market dominates the information shares of the futures market and thus the spot market, which signals the important role of ETF markets nowadays. A research of (Naylor, Wongchoti et al. 2011) provides evidence of consistency between the return properties of physical silver and the SLV ETF. Furthermore the returns on ETF do not follow a random walk, which makes it possible to apply a filter trading strategy.

Margin requirements

The most volatile period happened during the Hunt brothers' period. This was not only due to supply and demand, but futures markets seemed to contribute as well. The margin hikes during that period seemed to have an important impact on the price of silver. During that time the exchange board of directors decided to put a limit on the number of futures contracts that could be held, introduced a record high margin for silver futures and authorized trading for liquidation only, which obviously had an effect on the price of silver. The significant increase in price of both silver and gold in 2011 resulted in a couple of margin hikes of the CME and the Sjanghai Gold Index, which were followed by significant price drops.

(Ma, Kao et al. 1993) investigated margin changes in the silver futures market to determine their background and their effectiveness. As suggested above, they found in speculative market period and normal market period significant changes due to changes in margin requirements. Especially short-term price levels and price volatility are affected by changes in margin requirement. They conclude that margin changes mainly affect the destabilizing speculator's activities.

(Chatrath, Adrangi et al. 2001) examined the impact of margins in gold and silver future markets. This was done by making a distinction between four types of traders, which included speculators, hedgers, small-traders, and spreaders. They found open interest and trading volume relatively insensitive to margin requirements farther away from maturity. On the other hand, there is more trading activity after a margin hike when maturity comes closer. Furthermore they conclude that due to transaction cost of margins, speculators and small traders are relatively more sensitive to margin changes. Finally, margin hikes are the result of extreme jumps in volatility, but margin hikes tend to be reduced in periods of relatively stability.

The impact of market participation in silver markets is researched by (Hardouvelis and Kim 1995) and the result of margin hikes is lower market participation, but surprisingly there is no clear evidence for lower excess volatility.

Political instability

Political unrest can have a significant impact on the price of silver, since this precious metal can only be mined in a few countries. Due to a report of the U.S. Geological Survey (Metal Prices in the United States Through 1998) the increase in the price of silver on March 28, 1994 was due to political unrest in Mexico. Since Mexico is the largest supplier of silver via mining production, this could indeed be a factor. Since the largest mining countries also take the largest part of demand one would expect that political events in those countries do have the greatest influence on the price of silver.

Exchange rate

Although monetary use for gold and silver has decreased a lot, since they weren't legal tenders, both still have influence on monetary policy and exchange rates. This was confirmed by (Dooley, Isard et al. 1995) , which found that the price of gold had a substantial influence on several exchange rates in 1976-1990 period. (Hilliard 1999) states that the rise in the price of silver in the period 1972-1975 was due to a devaluation of the dollar and an embargo of oil exports by OPEC. (Sjaastad and Scacciavillani 1996) examined the relationship between the gold price and exchange rates and found that for the 1982-1990 period the gold market was dominated by the European currency bloc. Thus, real appreciations or depreciations of European currencies had significant effect on the price of gold in other currencies. Although not surprisingly they concluded that there was more instability in the price of gold due to floating exchange rates.

(Sari, Hammoudeh et al. 2010) found a strong relation in changes in prices of gold to changes in prices of other precious metals and exchange rates. A comparable study was performed by (Soytas, Sari et al. 2009) about the relationship of crude oil price volatility with respect to exchange rates and precious metals. Findings are a decreased influence of the US dollar index on precious metals prices since the 2008 crisis. Furthermore they conclude that correlation between the crude oil market and each precious metal market increased.

Price of oil

The oil market is often mentioned as a driver for inflation, since higher oil prices, result in higher prices for base materials. (Narayan, Narayan et al. 2010) performed cointegration tests between the price of gold and oil and found a cointegration for spot and futures markets up to a maturity of 10 months. Their hypothesis was that investors using the gold market as an inflation hedge after a shock in oil prices. They found a cointegrating relationship, but proposed to investigate the relationship of between the price of oil and other commodity prices as well.

Empirical analysis

Model

The analysis for silver is done for both US and OECD variables separately. The OECD variables are included since demand of silver largely comes from countries outside the U.S while price of silver is quoted in dollars. The relation of independent variables in Equation 1 will be tested with the price of silver.

$$\boldsymbol{Ag} = \boldsymbol{CPI_{US/OECD}} + \boldsymbol{\pi_{US/OECD}} + \boldsymbol{V(\pi_{US/OECD})} + \boldsymbol{GDP}_{US/OECD} + \boldsymbol{\rho_{US/OECD}} + \$_{\boldsymbol{INDEX}} + \mathbf{Au} + \mathbf{Oil} + \boldsymbol{\beta_{Ag}} + \boldsymbol{DS} + \boldsymbol{r_{real}} + \boldsymbol{VXO} + \boldsymbol{F_{Ag}} + \boldsymbol{ETF_{Ag}}$$

Equation 1

Where:

$\boldsymbol{Ag}$ $is\ silver\ fix\ London\ Bullion\ Market\ price\ measured\ in\ US\$/troy\ ounce$

$\boldsymbol{Ag_{H\&H}}$ $is\ Handy\ \&\ Harman\ price\ measured\ in\ US\$/troy\ ounce$

$\boldsymbol{CPI_{US}}$ $is\ U.S.Consumer\ Price\ Index$

$\boldsymbol{\pi_{US}}$ $is\ monthly\ U.S.inflation\ rate$

$V(\pi_{US})$ *is volatility of U.S. inflation rate*

GDP_{US} *is U.S. Gross Domestic Product*

ρ_{US} *is monthly U.S. industrial production*

CPI_{OECD} *is Consumer Price Index of OECD countries*

π_{OECD} *is monthly OECD inflation rate*

$V(\pi_{OECD})$ *is the volatility of OECD inflation rate*

GDP_{OECD} *is Gross Domestic Product of world countries*

ρ_{OECD} *is world industrial production*

$\$_{INDEX}$ *is 10 country average index price of the dollar*

Au *is gold bullion London Bullion Market measured in \$US/troy ounce*

$Au_{H\&H}$ *is Handy & Harman price measured in US\$/troy ounce*

Cu *is the nominal price of copper*

Pb *is the nominal price of lead*

Zn *is the nominal price of zinc*

Pt *is the nominal price of platinum*

Pd *is the nominal price of palladium*

Oil *is the nominal price of oil*

β_{Ag} *is the beta of silver*

DS *is the default spread*

r_{real} *is the real interest rate*

VXO *is the volatililty index*

F_{Ag} *is estimated net long silver futures position*

ETF_{Ag} *is the volume of silver ETF trackers*

Description of variables

The data being collected for examining this study comes from several sources. The paper of (Levin, Montagnoli et al. 2006) was an important source for those variables. Their study is based on the determinants of the price of gold. Furthermore, extra variables are added which seem to have an impact on the price of silver. In appendix A each variable and the mnemonic can be found.

Ag is the monthly spot London Bullion Market silver fix (dealer market). $Ag_{H\&H}$ is the monthly Handy and Harman price (auction market), which is available from 1979 and onwards. The price quoted by Handy and Harman is a dealer price instead of an auction price. Since the Handy and Harman price is based on real silver supply and demand, one would expect that there is less volatility in the Handy and Harman price due to more stable prices. This can be seen in Figure 7 and Figure 8 below which represents the difference between the LBM daily silver spot price and the Handy and Harman price for both silver and gold.

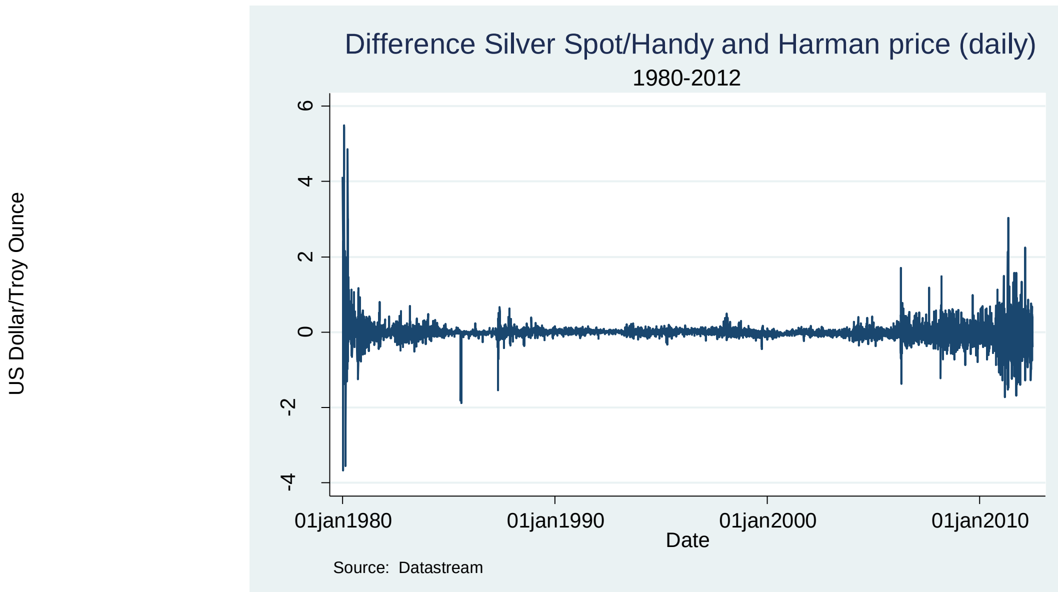

Figure 7

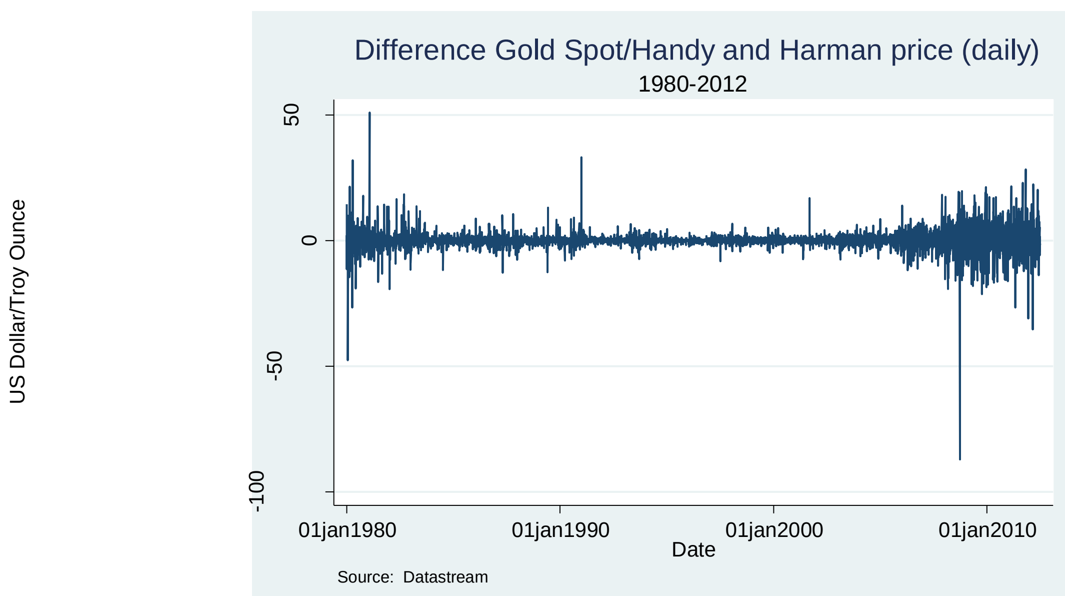

Figure 8

Especially during the Hunt brothers period and recent years there is a large difference. In 1980, movements in futures prices became more important, since the Hunt brothers took a considerable long futures position. A possible explanation for the discrepancy in recent years could be the growth in exchange traded fund and the margin calls in futures positions due to the explosion of the silver price. The graph for gold shows a comparable pattern, although it seems to be less extreme. The smaller market of silver compared to gold could be a reason. Since it is expected that investment demand has significant impact on the price of silver the monthly spot London Bullion Market silver fix is used in the tests.

Silver is still be seen as a precious metal and thus should be have some inflation hedging capacities, therefore $\boldsymbol{CPI_{USA}}$ and $\boldsymbol{CPI_{OECD}}$ are included. The OECD CPI is included because investment demand not only comes from the U.S. but from investors outside the US as well. However, no single measure takes into account each investor investment preferences. This would only be possible with an exchange corrected silver price and a country specific inflation rate. Change in the inflation rate for U.S. $\boldsymbol{\pi_{USA}}$, OECD $(\boldsymbol{\pi_{WORLD}})$, U.S. inflation volatility $\mathbf{V}(\boldsymbol{\pi_{USA}})$ and OECD inflation volatility $\mathbf{V}(\boldsymbol{\pi_{WORLD}})$ are included since the assumption is that a higher inflation rate would result in a higher demand for silver and thus leads to a higher price. A higher volatility in the change of inflation would imply more uncertainty and thus a higher rate is expected to have a positive beta with the price of silver.

$\boldsymbol{GDP}_{OECD}$ represents the gross domestic product of all countries in the OECD. An increase in OECD income is likely to result in a higher demand for jewelry and investment demand. Thus this variable is included as a control to avoid bias in the relationship between the CPI and the price of silver. $\boldsymbol{GDP}_{US}$ is included as well for US regression.

Around 50% of total silver demand comes from industrial production. Thus the hypothesis is that there is a relationship between the price of silver and industrial production. The indicator $\boldsymbol{\rho_{US/OECD}}$ is the volume index of industrial production for both the US and OECD, which comes from International Financial Statistics.

Commodity prices tend to move with each other and thus correlations of monthly log returns of silver, gold, copper, lead, zinc, platinum, palladium and oil are provided for the 1994-2012 period. Correlations are investigated in order to determine whether some relationship exists. Silver is a byproduct of gold mining and for copper, lead and zinc. Copper, lead and zinc are mainly used for industrial purposes, which is applicable for silver. Platinum and palladium are included because they have a comparable demand structure; the largest part from industrial and a small part for investment purposes, jewelry and coin.

The trade weighted U.S. dollar index $\$_{\boldsymbol{INDEX}}$, obtained from Federal Reserve Bank of St. Louis, is the weighted average of the foreign exchange value of the U.S. dollar against a subset of the broad index currencies. This variable is included since a weak dollar makes it more interesting for outside countries to buy silver. The countries included are the Euro area, Canada, Japan, United Kingdom, Switzerland, Australia and Sweden. The weighted average is determined taking into account the share of U.S. imports and exports of each country. Although relative silver demand is likely to differ from those figures, this dollar index provides a good estimate.

The variables $\boldsymbol{Au}$ and $\boldsymbol{Oil}$ are included in tests for cointegration as well. Gold is included since the gold/silver ratio still seems to be an important indicator for a lot of investors whether silver is undervalued or overvalued. Furthermore, since gold is being seen as an inflation protector, the price of silver should move with gold as well. Finally the price of WTI Crude oil is included as a variable that captures economic activity and uncertainty. Furthermore, the price of oil has an effect on the rate of inflation and a cointegrating relation between the price of gold and oil was already found.

Silver and especially gold are being used as an investment instrument due to their inflation hedging capability, but for their diversification properties as well. The beta of silver is thus to be expected negative when monthly returns of the price of silver are regressed on the Standard and Poor 500 Index. This is done using information of the previous 36 months and results in the silver beta $\boldsymbol{\beta_{Ag}}$.

The default spread $\boldsymbol{DS}$ (Figure 9) is another variable that captures financial uncertainty. This variable is calculated by subtracting the 10 year Moody's Baa corporate bond yield from the 10 year U.S. Treasury notes yield. A higher default spread implies a higher possibility of bankruptcy for weaker firms and thus more financial uncertainty.

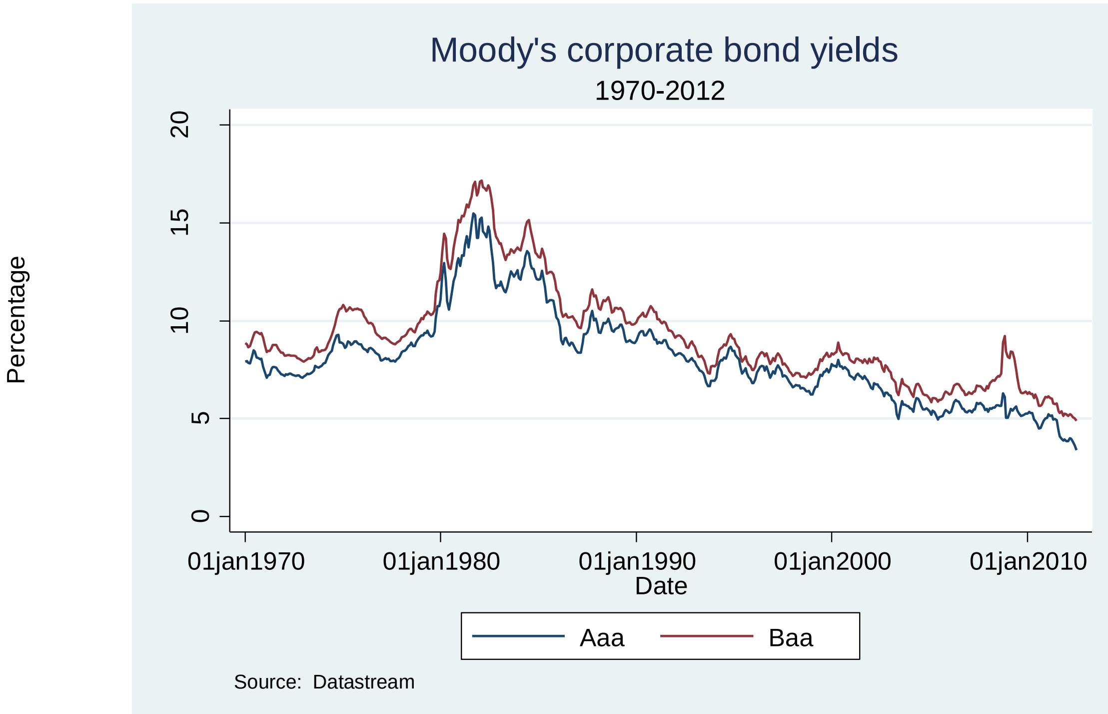

Figure 9

The inflation rate is supposed to have an impact on the price of silver, but as an investor the real interest rate is more important compared to the inflation rate. This real interest rate is computed subtracting the monthly 90-day U.S. Treasury Bill interest rate from the monthly U.S. inflation rate. A negative real interest rate makes it more interesting to invest in precious metals, while a positive real interest results in a shift of investors to invest in Treasury Bills.

During financial crises and economic uncertainty, precious metals are perceived to be a safe haven. Financial turmoil can be measures by the volatility index **VXO**. This index measures volatility using the implied volatility from S&P 500 options. The volatility index measures market expectations of 30-day volatility using a wider range of strike prices rather than just at – the money series. Although there is some discussion about the capability of the VXO to track volatility, due to the focus on at the money options instead of out of the money options, this indicator provides a quite reliable substitute for uncertainty on the stock exchange.

Since the price of silver was not longer fixed due to monetary purposes, silver became more interesting for investors and since 2000 an increase in net investment demand can be spotted in the graphs. The open interest of silver futures should thus have an impact on the price of silver. Where open interest for long COMEX silver futures $\boldsymbol{Flong_{Ag}}$ and $\boldsymbol{Fshort_{Ag}}$ for open interest of short COMEX silver futures is being used.

The introduction of Exchange Traded Funds made it easier for individual investors to invest in underlying commodities with smaller amounts of money without risking margin calls and physical delivery. The indicator $\boldsymbol{ETF_{Ag}}$ presents the summed market values of all available silver exchange traded funds provided by Datastream.[2]

Statistical methods

Stationarity

In order to test for a relationship between the price of silver and several other variables, data must be stationary. Stationary time series are defined having a constant mean, constant variance and a constant auto covariance and (Brooks 2008) gives three examples in which way stationary or non-stationary data can influence the behavior and properties of time series. The price graph of silver implies quite volatile price series with a lot of shocks. With stationary data, the impact of the shock will gradually fade away, with a smaller impact in $t + 1$ and further, while with non stationary data, the persistence of the shock will be infinite, which implies that the shock will not gradually, become smaller over time.

A second implication of non-stationary data is the trend, which is present in the variables GDP and CPI. Those variables show an uptrend over the sample period. The graph with the price of silver shows two big spikes, but an uptrend can be spotted as well. Since the price of silver and for example the variable CPI are trending over time, it is very likely that a standard OLS regression will lead to high R-squares en significant coefficient estimates.

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[2] Blackrock Silver Bullion Trust, ETFS Metal Securities Australia Physical Silver, Horizons BetaPro COMEX Silver Bullion, Ishares Silver Trust, Japan Physical Silver ETF, PowerShares DB Silver, ProShares Ultra Silver, Silver Bullion Trust, Silver Trust ETF, Societe Generale ETN Silver, Sprott Physical Silver

The third problem of non-stationary data is that T-statistics become useless, since the t-ratios and F-ratios are not following their distribution anymore. (Brooks 2008) clarifies this with an example with non-stationary data where t-ratio is bigger than two 98% of the time, while this should be between ±2 95% of the time. Non-stationary data thus results in too high T-statistic and give no possibility to draw conclusions using those values.

The two types of non-stationary are the random walk with drift

$$y_t = \mu + y_{t-1} + \mu_t$$

Equation 2

and the trend-stationary process

$$y_t = \alpha + \beta_t + \mu_t$$

Equation 3

Since the trend of the variables in the graphs is more common to the random walk or the random walk with drift, the method for this trend is being used. (Brooks 2008) mentions as well that this trend is more common in finance and economics compared to the white noise process and the deterministic trend process (equation 3). In order to make the series stationary, the series must be differenced d times.

Stationary of data is tested using the Augmented Dickey Fuller (1979) and Dickey-Fuller Generalized Least Squares test proposed by (Elliott, Rothenberg et al. 1992). Those test for the null hypothesis of unit root stationary, versus the alternate hypothesis of stationary. The Dickey Fuller GLS test proposes to transform time series by a generalized least squares regression before performing the test. This method has been proving more explanatory power compared to the augmented Dickey Fuller test. Both tests are performed in order to compare their test statistics. This is done for two types of regressions: with a constant and a time trend and a regression only containing a constant.

The (Phillips and Perron 1988) test is asymptotically the same as the augmented Dickey Fuller test, but statistics have been made robust to serial correlation by using the (Newey and West 1987) heteroskedasticity- and autocorrelation-consistent covariance matrix estimator. Although the Philip Perron test has been proved less powerful compared to the Dickey Fuller GLS test, it provides an extra check for level data. (Levin, Lin et al. 2002) mention that especially in finite samples those two unit root tests are known to have limited power against alternative hypotheses. Their solution is not to consider separate time series, but use pooling cross-section time series data. Since time series being used in regression contain over 300 monthly observations, the regular procedure is done on individual time series.

Determining the lag length for both the Dickey Fuller and Dickey Fuller GLS test, the Akaike's information criterion (AIC) has more weight compared to the Schwarz Bayesian information criterion (SBIC) and the Hannan and Quinn information criterion (HQIC). For monthly data (Ivanov and Kilian 2001) found that the AIC lag criterion resulted in the best lag selection in the case of conflicting results. Due to the use of monthly data this criteria is used in this paper when performing stationarity and cointegration tests.

Cointegration

Two or more variables are cointegrated if they are sharing common trend(s). Cointegrated variables may drift apart in the short-run, but in the long-run they are pressed back to their equilibrium paths. In order to have cointegration between variables, they must integrated at the same order (more than zero) or series contain a deterministic trend (Granger 1986).

Cointegration is tested by performing the two step (Engle and Granger 1987) method. The first step of the method is to run a regression with $\boldsymbol{lnAg}$ as a dependent variable, a stationary variable, which is integrated of the same order and a trend. Residuals of those regressions are tested using the augmented Dickey Fuller test without a time trend and constant, since the residuals are centered on zero and can have no time trend. It is not possible to use the standard critical values for the Augmented Dickey Fuller test, since tests are performed on the residuals. (Phillips and Ouliaris 1990) solved this by providing critical values for the Engle-Granger cointegration test.

The test developed by (Johansen 1988) is perceived to be stronger compared to the (Engle and

Granger 1987) due to some some drawbacks in the Engle Granger test. The inability to pick more than one cointegrating vector is the most important drawback. Furthermore, Johansens vector error correction model results in more efficient estimators of cointegrating vectors.

The Johansen test is based on a maximum likelihood and two statistics, which are the Johansen trace test and the maximum Eigenvalue test. The latter tests the null hypothesis of r cointegrating relation against the alternative of r+1 cointegrating relations, where the trace test has het null hypothesis of r cointegrating relations against the alternative of n cointegrating relations, where n is the number of variables in the equation.

The Johansen test allows for cointegration testing in one step, without specifying a variable to be normalized, which is the case for the two step Engle-Granger method. An advantage of this method is that it prevents from carrying over errors from the first step into the second. Furthermore implementing the model, no assumptions about endogenity or exogenity of variables have to be made. For more information about the Johansen method, see (Johansen 1991), (Johansen 1992) and (Johansen and Juselius 1990). First a univariate test is done using the Johansen method and afterwards a multivariate analysis is performed.

Vector error correction model

Presence of cointegration between variables makes it possible to analyze the time series with a Vector Error Correction model. This model can be used for non-stationary (unit root at the level) and cointegrated data and provides a short-run adjustment parameter and a long run component. The VEC model is applied to logged variables and as before, lag selection is based on the Aikake Information Criteria. The model is described below very briefly, since derivation of the VEC is not in the scope of this paper.

The VEC model captures both long- and short run dynamics and can be derived from the Vector Autoregressive Model, which is described below. A standard regression does not offer the possibility of short term correction in the model, which makes an equilibrium state not possible. The error correction term of the VECM defines the speed of adjustment for each variable to turn back to the long run equilibrium after a shock in the system.

Vector autoregressive model

Cointegration cannot be present with variables stationary at the level, I(0), and thus the Vector Autoregressive model is used to determine the relationship between those variables and the price of silver. A requirement for using variables in a VAR model is that variables should be selected according to economic theory and all included variables have to be integrated at the same level. Furthermore the error-term for each variable has to contain non-autocorrelated white-noise disturbances.

The number of lags is determined by using the lowest AIC value. An advantage of the VAR model is that it can be used when there is uncertainty about the exogeneity of a variable; all variables in a VAR model are endogenous. The dependent variable can be affected by its own past realizations and by current and past realizations of other variables included in the model. With a VAR model it is possible to test causality relationships. When current and past values of Y_t do not have an impact on the value of X_t, then $X_t$is perceived as an exogenous variable.

Trends in explanatory variables

In order to identify trends in the data and relations between the price of silver and other independent variables, graphs in appendix B provide an overview before going into the data. Data being used is for period 1986-2012 with monthly observations. The trends of CPI for both US and OECD are rising over time and exhibit a comparable pattern. Contrary to the US stabile inflation rates, the OECD shows a declining trend in the inflation rate, but for volatility of inflation the graphs trends are comparable.

It is interesting to see that for an US investor, the inflation hedge price was lower than the nominal price of silver. For the 'OECD' investor the inflation hedge price and nominal price are following the same path after 2000. Before that period it was less interesting to invest in silver, since the nominal price was lower than the inflation hedge price. Although the OECD inflation rate cannot be applied for a single investor, it provides a deeper knowledge about the hedging relationship of silver and inflation. It must be noted that the nominal price is not corrected for the exchange rate, since there is none for the OECD, which makes it not possible to determine whether an US or 'OECD' investor was more profitable in holding silver as an investment.

During the 1986-2012 period te variable GDP is varying a lot for both US and OECD, where the industrial production shows a unward trend for both. The declining dollar index over the past 10 shows a negative relationship with the price of silver, which is contrary, since a declining dollar index results in a stronger dollar and thus makes it more expensive for an investor outside the US to invest in silver.

The strong relationship between with gold was already noticed in previous graphs, but over the past 25 years, this relation seems to be even stronger. Oil exhibits a comparable pattern but deviations are larger compared to gold. The S&P500 and MSCI World index do not show a negative or positive relation with silver. Although beta is varying a lot over time, an upward trend can be spotted in the graph, which implies that the argument of holding silver in portfolio as a protection does make less sense.

Finally, the investment demand for silver in futures and exchange traded funds has a clear positive relation with the price of silver. Especially the ETF market value for silver does track the price of silver very closely.

Descriptive statistics

Compared to gold, silver had a lower monthly return over the time period 1994-2012 with more volatility (Table I). A shorter time period is being used since data before 1994 is not available for all variables. Furthermore it is interesting to see that returns for Handy and Harman price, both for gold and silver are lower compared to spot prices, although volatility is higher for Handy and Harman log returns.

The minimum return of -28.93% for silver was realized in October 2011, which was probably caused margins raised for silver contracts by the Shanghai Gold Exchange. Negative returns were even higher in the Hunt Brothers period in April 1980 with a percentage of -70.58%, where the positive return of 26.64% was realized in June 2009, which was due to an increasing demand for silver coins and medals; the U.S. Silver Eagle bullion coin reached record highs with over 28 million Eagles sold.[3]

[3] http://www.silverinstitute.org/site/silver-price/silver-price-history/2000-2010/

Table I

Descriptive statistics log returns

The sample consists of monthly log returns over 1994-2012 period of time for commodity variables, volatility index, S&P500, MSCI World index and the Dollar index. The table presents the variables mean, standard deviation, skewness, kurtosis and number of observations. Variable definitions are provided in the Appendix A

	Mean	SD	Skewness	Kurtosis	Min	Max	Count
Silver	.0082	.0845	-.3552	4.6257	-.2894	.2665	222
Silver H&H	.0083	.0866	-.4070	4.3556	-.3038	.2346	222
Gold	.0066	.0461	.0382	4.9698	-.1878	.1895	222
Gold H&H	.0066	.0468	-.0215	4.9065	-.1876	.1884	222
Copper	.0068	.0811	-.7046	6.5731	-.4125	.2312	222
Lead	.0067	.0900	-.2744	4.0704	-.3104	.2873	222
Zinc	.0031	.0803	-.3628	5.1718	-.3690	.2383	222
Platinum	.0061	.0656	-1.073	8.0475	-.3560	.2141	222
Palladium	.0072	.1088	-.4022	5.0461	-.4004	.3591	222
Crude Oil	.0076	.0972	-.5156	4.5325	-.4294	.3044	222
Volatility Index	.0031	.1960	.2864	4.1526	-.6187	.6951	222
S&P 500	.0046	.0482	-.7587	4.8011	-.1836	.1461	222
MSCI World Index	.0031	.0491	-.7560	4.9827	-.2084	.1357	222
Dollar Index	-.0009	.0169	-.0381	3.6670	-.0478	.0647	222

The correlation matrix in Table II, based on the monthly log returns of all commodities and indexes does not result in unaccountable figures. Not surprisingly there is a high correlation between the spot prices and Handy and Harman prices of both gold and silver. It is interesting to see that gold has a positive correlation with the volatility index, although other metals do have a negative correlation. This would imply that gold would be more like a safe haven in volatile periods on the stock exchange. Furthermore return of silver has the highest correlation with gold returns. The higher percentage industrial use of silver compared to gold could be a reason for higher correlation with base metals like copper, lead and zinc.

The positive correlation of all metals with both S&P500 and MSCI world index implies that the volatility index provides a better hedge in case of low stock returns. In line with theory, there is a negative relation with metals and oil and the dollar index; a weakening dollar makes commodities less expensive for investors and producers outside the US and thus would result in higher dollar denominated commodity prices.

Table II

Correlation log returns

The sample consists of monthly log returns over 1994-2012 period of time for commodity variables, volatility index, S&P500, MSCI World index and the Dollar index. The table presents correlations between those variables. Variable definitions are provided in the Appendix A

	Silver	Silver H&H	Gold	Gold H&H	Copper	Lead	Zinc	Platinum	Palladium	Crude Oil (WTI)	Volatility Index	S&P 500	MSCI World Index	Dollar Index
Silver	1													
Silver H&H	0.968	1												
Gold	0.687	0.700	1											
Gold H&H	0.687	0.698	0.992	1										
Copper	0.353	0.365	0.302	0.289	1									
Lead	0.313	0.316	0.186	0.181	0.480	1								
Zinc	0.327	0.353	0.279	0.272	0.648	0.581	1							
Platinum	0.565	0.563	0.530	0.517	0.480	0.290	0.384	1						
Palladium	0.382	0.403	0.274	0.268	0.349	0.270	0.329	0.610	1					
Crude Oil	0.252	0.265	0.227	0.226	0.407	0.235	0.271	0.307	0.268	1				
VXO Index	-0.102	-0.130	0.0332	0.030	-0.240	-0.226	-0.191	-0.219	-0.186	-0.244	1			
S&P 500	0.180	0.214	0.030	0.025	0.371	0.347	0.367	0.251	0.253	0.308	-0.686	1		
MSCI World Index	0.245	0.280	0.122	0.114	0.426	0.395	0.421	0.317	0.302	0.385	-0.673	0.959	1	
Dollar Index	-0.200	-0.216	-0.284	-0.270	-0.308	-0.198	-0.202	-0.265	-0.119	-0.247	0.0678	-0.122	-0.232	1

Although (Hendry and Juselius 2000) found that with presence of cointegration between series in log levels, there would also be cointegration in levels, the variables $\boldsymbol{Ag}$; $\boldsymbol{CPI_{US/OECD}}$; $\boldsymbol{GDP_{US/OECD}}$; $\boldsymbol{\rho_{US/OECD}}$; $\$_{\boldsymbol{INDEX}}$; **Au**; **Oil**; $\boldsymbol{VXO}$; $\boldsymbol{F_{Ag}}$ ***and*** $\boldsymbol{ETF_{Ag}}$ are being logged, since this leads to more stable data. Those logged variables are used in next sections.

For level data in Table III the mean of silver beta is positive and higher in relation with the MSCI compared to the S&P500 index. One would expect a negative beta for silver when viewed as a precious metal, which offers security in volatile environment, although the correlation matrix already showed a positive relationship between silver and index returns of S&P 500 and the MSCI World Index. Since data for silver futures is only provided for April 1995 and onwards and silver Exchange Traded Funds are a recent phenomenon, there are fewer observations for those two variables.

Table III

Descriptive statistics (log) level

The sample consists of all variables used in regressions over period 1986-2012. The table presents the variables mean, standard deviation, skewness, kurtosis, min, max and number of observations for variables in (log)level. Variable definitions are provided in the Appendix A

	Mean	SD	Skewness	Kurtosis	Min	Max	Count
Silver (ln)	1.949	.590	1.382	3.973	1.276	3.886	313
CPI US (ln)	5.110	.207	-.249	2.037	4.696	5.438	313
CPI OECD (ln)	4.357	.306	-.545	2.125	3.678	4.768	313
Inflation US	2.867	3.863	-1.201	10.247	-22.983	14.664	313
Inflation OECD	4.204	3.238	-.084	5.087	-11.017	17.746	313
Inflation Volatility US	3.301	1.896	1.993	7.890	1.035	11.144	313
Inflation Volatility OECD	2.462	.837	1.920	8.581	1.204	6.300	313
GDP US (ln)	4.605	.011	-.225	2.805	4.574	4.628	313
GDP OECD (ln)	4.606	.010	-.115	4.407	4.572	4.632	313
Industrial Production US (ln)	4.369	.187	-.437	1.627	4.005	4.613	313
Industrial Production OECD (ln)	4.453	.156	-.275	1.755	4.140	4.693	313
Dollar Index (ln)	4.482	.115	-.163	2.458	4.235	4.720	313
Gold (ln)	6.127	.488	1.307	3.706	5.537	7.510	313
Crude Oil (ln)	3.421	.635	.692	2.140	2.422	4.949	313
Beta S&P 500	.1403	.694	.452	3.989	-1.749	2.545	313
Beta MSCI	.3201	.779	.275	4.246	-2.487	2.741	313
Default Spread	.9859	.405	2.993	15.513	.550	3.38	313
Real Interest Rate US	2.815	3.945	.352	7.519	-10.464	26.513	313
Volatility Index (ln)	2.986	.361	.417	3.131	2.299	4.294	313
Silver long futures (ln)	11.402	.316	.203	1.947	10.867	12.178	207
Silver ETF (ln)	8.985	1.026	-1.370	8.547	4.016	10.558	74

Although variables are not stationary in the correlation matrix in Table IV, it provides a check for theory. Correlations between US and OECD variables are high, representing the integration of economic variables for several countries. Especially correlations for Consumer Price Index and Industrial Production are high between US and OECD, where correlation for inflation, inflation volatility and GDP is positive and high as well. The positive relationship between beta and silver is not in line with theory, which states that demand for silver to reduce portfolio volatility should be high for periods with a negative beta. This would imply a negative correlation. More uncertainty should lead to a higher price of silver. Uncertainty and higher risk is caught by the default spread, the price of oil and the volatility index. All three indicators show a positive relationship with silver. It is interesting to see a very high correlation for silver in relation with the price of gold and market value of futures and exchange traded funds, although correlation between those two types of market value is positive, the number of 0.36 is not high.

For macroeconomic variables, CPI seems to have the most significant impact on the price of silver followed by the variable industrial production. This is not strange, since silver is both a precious and industrial metal.

Table IV

Correlation matrix (log) level

The sample consists of all variables used in regressions over period 1986-2012 in logs and levels. Variable definitions are provided in the Appendix A

	Silver (ln)	CPI US (ln)	CPI OECD (ln)	Inflation US	Inflation OECD	Inflation Volatility US	Inflation Volatility OECD	GDP US (ln)	GDP OECD (ln)	Industrial Production US (ln)	Industrial Production OECD (ln)	Dollar Index (ln)
Silver (ln)	1											
CPI US (ln)	0.673	1										
CPI OECD (ln)	0.589	0.991	1									
Inflation US	-0.0124	-0.155	-0.166	1								
Inflation OECD	-0.243	-0.566	-0.577	0.716	1							
Inflation Volatility US	0.424	0.527	0.486	-0.142	-0.380	1						
Inflation Volatility OECD	0.293	0.213	0.162	-0.095	-0.201	0.855	1					
GDP US (ln)	0.124	-0.0658	-0.070	0.180	0.146	-0.190	-0.185	1				
GDP OECD (ln)	0.101	-0.024	-0.033	0.176	0.148	-0.211	-0.181	0.876	1			
Industrial Production US (ln)	0.507	0.928	0.955	-0.134	-0.532	0.428	0.0854	0.134	0.133	1		
Industrial Production OECD (ln)	0.592	0.957	0.967	-0.125	-0.535	0.464	0.135	0.132	0.175	0.985	1	
Dollar Index (ln)	-0.777	-0.558	-0.472	-0.008	0.189	-0.312	-0.286	0.011	-0.068	-0.317	-0.431	1

	Silver (ln)	Gold (ln)	Crude Oil (ln)	Beta S&P 500	Beta MSCI	Default Spread	Real Interest Rate US	Volatility Index (ln)	Silver long utures (ln)	Silver ETF (ln)
Silver (ln)	1									
Gold (ln)	0.956	1								
Crude Oil (ln)	0.840	0.816	1							
Beta S&P 500	0.422	0.339	0.404	1						
Beta MSCI	0.372	0.314	0.348	0.785	1					
Default Spread	0.322	0.412	0.308	-0.025	-0.083	1				
Real Interest Rate US	-0.289	-0.239	-0.324	-0.124	-0.121	0.070	1			
Volatility Index (ln)	0.053	0.043	-0.007	-0.080	-0.239	0.557	0.144	1		
Silver long futures (ln)	0.852	0.839	0.813	0.226	0.287	0.245	-0.194	-0.243	1	
Silver ETF (ln)	0.816	0.879	0.410	-0.106	-0.209	-0.0285	-0.176	0.219	0.364	1

Results

Unit root tests

The model being used for explaining the long run relationship, of the silver price with independent variables, runs over the 1986-2012 period with monthly observations. A majority of the graphs clearly show non-stationary data. This is tested by performing the augmented Dickey-Fuller, Philip Perron and Dickey Fuller GLS tests, which can be found in Table V.

Test statistics for variables $\boldsymbol{\pi_{US/OECD}}$, $\boldsymbol{V(\pi_{US/OECD})}$, $\mathbf{ln}\boldsymbol{GDP_{US/OECD}}$, $\boldsymbol{\beta_{S\&P500/MSCI}}$, $\boldsymbol{default}$, $\boldsymbol{r_{real}}$ $\boldsymbol{and}$ $\mathbf{ln}\boldsymbol{VXO}$ indicate stationarity for level time series. For variables $\mathbf{ln}\boldsymbol{F_{Ag}}$ and $\mathbf{ln}\boldsymbol{ETF_{Ag}}$ test statistics for the trend coefficient are significant as well as the test statistics for the augmented Dickey Fuller and Philip Perron using a trend component. However, performing a Dickey Fuller GLS including trend component the null hypothesis cannot be rejected. Since there is no certainty about the presence of a unit root for those series, they are not included in tests for cointegration between variables.

Differencing the variables results in I(1) stationary data for remaining variables since the null hypothesis is rejected, which is stated in Table VI. Not surprisingly, test statistics for trend coefficients are insignificant for most variables, although not for gold and CPI of United States and OECD.

Table V

Unit root tests level

The sample consists of all variables used in regressions over period 1986-2012. The table presents the test statistics for unit root tests using the augmented Dickey Fuller, Philip Perron and Dickey Fuller Generalized Least Squares test. Optimal lag used for conducting the test was based on Aikaike Information Criteria. Presented for levels of the three tests: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Augmented Dickey Fuller					Philip Perron					Dickey Fuller GLS		
Variables Levels	Lag_{AIC}	$\propto$	$T(trend)$	$Z(t_{trend})$	$Z(t)$	$T(trend)$	$Z(rho_{trend})$	$Z(t_{trend})$	$Z(rho)$	$Z(t)$	Lag_{MAIC}	$Z(t_{trend})$	$Z(t)$
Silver (ln)	2	Yes	1.89**	-1.136	0.309	2.01**	-4.281	-1.363	0.205	0.094	1	-1.016	0.585
CPI US (ln)	15	Yes	2.44***	-2.700	-2.405	1.92*	-5.601	-2.243	-0.807	-2.868*	14	-0.709	1.254
CPI OECD (ln)	14	Yes	1.03	-2.617	-4.132***	0.97	-2.253	-3.161*	-1.602	-10.986***	13	-0.573	0.676
Inflation US	14	Yes	-2.15**	-4.337***	-3.74***	-1.67*	-111.137***	-9.837***	-121.658***	-9.846***	15	-2.695*	-0.945
Inflation OECD	13	Yes	-3.32***	-4.014***	-2.278	-6.02***	-130.972***	-9.852***	-143.927***	-9.088***	11	-3.296**	-0.686
Inflation volatility US	13	Yes	1.88**	-2.753	-2.007	1.49	-23.559**	-3.474**	-15.993**	-2.830*	12	-2.175	-2.037**
Inflation Volatility OECD	13	Yes	0.72	-2.640	-2.549	0.81	-25.484**	-3.604**	-23.890***	-3.481***	13	-2.537	2.508**
GDP US (ln)	13	Yes	0.11	-3.642**	-3.69***	1.22	-17.919	-2.930	-18.105**	-2.960**	8	-3.285**	-3.052***
GDP OECD (ln)	7	Yes	-0.23	-3.991***	-4.00***	0.33	-16.7	-2.867	-16.707**	-2.872*	5	-3.161**	-3.117***
Industrial production US (ln)	8	Yes	1.17	-1.635	-1.412	-0.37	-3.342	-1.243	-1.843	-1.746	7	-1.465	0.759
Industrial Production OECD (ln)	4	Yes	2.41***	-2.812	-1.691	0.37	-6.381	-1.735	-1.898	-1.679	3	-2.378	0.529
Dollar Index (ln)	3	Yes	-1.14	-2.176	-1.858	-0.72	-8.389	-2.114	-6.231	-1.897	2	-1.786	-0.143
Gold (ln)	3	Yes	2.34***	0.065	1.872	1.82*	0.048	0.028	2.241	1.606	2	0.082	2.691
Crude Oil (ln)	8	Yes	2.29**	-2.318	-0.651	2.40**	-14.507	-2.718	-2.954	-1.129	7	-2.156	0.403
Beta S&P 500	13	Yes	2.43***	-3.856**	-2.987**	2.33**	-60.687***	-5.790***	-46.657***	-5.106***	12	-2.808*	-0.662
Beta MSCI	13	Yes	2.00**	-4.050***	-3.506***	1.30	-45.146***	-5.159***	-39.741***	-4.948***	12	-1.986	-0.391
Default Spread	2	Yes	1.63*	-3.867**	-3.558***	1.17	-20.015*	-3.203*	-18.204**	-3.001**	2	-3.29**	-3.141***
Real interest Rate US	14	Yes	-3.99***	-4.852***	2.708*	-3.32***	-105.749***	-10.082***	-139.952***	-10.005***	15	-2.135	-2.046**
Volatility Index (ln)	1	Yes	0.47	-4.203***	-4.183***	0.53	-39.724***	-4.593***	-39.280***	-4.568***	7	-2.534	-2.444**
Silver long futures (ln)	4	Yes	2.94***	-3.313*	-1.587	3.91***	-31.769***	-4.491***	-10.207	-2.232	3	-1.660	-1.478
Silver ETF (ln)	1	Yes	1.68**	-2.001	-1.460	12.1***	-59.060***	-12.191***	-18.238**	-5.911***	1	-1.449	1.780

Table VI

Unit root tests first difference

The sample consists of all variables used in regressions over period 1986-2012. The table presents the test statistics for unit root tests using the augmented Dickey Fuller and Dickey Fuller Generalized Least Squares test. Optimal lag used for conducting the test was based on Aikaike Information Criteria. Presented for Dickey Fuller GLS: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Augmented Dickey Fuller					Dickey Fuller GLS		
Variables First Differences	Lag_{AIC}	$\propto$	$T(trend)$	$Z(t_{trend})$	$Z(t)$	$Lag_{MAICAIC}$	$Z(t_{trend})$	$Z(t)$
Δ Silver (ln)	1	Yes	1.55	-14.062	-13.947	15	-3.281**	-2.479**
Δ CPI US (ln)	14	Yes	-2.11	-4.351	-3.784	15	-2.461	-1.774*
Δ CPI OECD (ln)	13	Yes	-3.33	-4.075	-2.382	11	-2.443	-2.259**
Δ Inflation US	13	Yes	0.04	-8.340	-8.353	14	-2.013	-0.414
Δ Inflation OECD	11	Yes	0.43	-8.808	-8.810	14	-1.974	-0.516
Δ Inflation Volatility US	12	Yes	-0.10	-7.391	-7.408	6	-5.529***	-5.499***
Δ Inflation Volatility OECD	12	Yes	-0.20	-7.961	-7.979	1	-10.060***	-9.719***
Δ GDP US (ln)	8	Yes	0.46	-4.676	-4.663	5	-3.650***	-2.985*
Δ GDP OECD (ln)	6	Yes	0.22	-4.661	-4.668	6	-4.279***	-3.283***
Δ Industrial Production US (ln)	7	Yes	-0.84	-4.524	-4.454	5	-3.985***	-2.976***
Δ Industrial Production OECD (ln)	3	Yes	-0.88	-5.376	-5.307	2	-5.423***	-4.700***
Δ Dollar Index (ln)	2	Yes	0.08	-9.023	-9.037	14	-2.013	-0.714
Δ Gold (ln)	2	Yes	3.01	-11.195	-10.645	15	-2.829**	-3.074***
Δ Crude Oil (ln)	7	Yes	0.55	-7.516	-7.504	10	-2.590*	-1.426
Δ Beta S&P 500	12	Yes	0.36	-5.644	-5.643	1	-15-289***	-15.393***
Δ Beta MSCI	12	Yes	0.14	-6.464	-6.476	5	-6.575***	-6.131***
Δ Default Spread	2	Yes	0.43	-9.011	-9.013	4	-5.850***	-4.743***
Δ Real Interest Rate US	13	Yes	-0.35	-8.496	-8.502	14	-1.886	-0.356
Δ Volatility Index (ln)	7	Yes	0.23	-8.444	-8.455	15	-1.384	-3.873***
Δ Silver long futures (ln)	3	Yes	-0.27	-8.167	-8.167	7	-4.306***	-3.355***
Δ Silver ETF (ln)	0	Yes	-0.97	-27.681	-28.227	1	-1.532	0.052

Engle Granger and Johansen test for cointegration

In order to have cointegrated variables, they must be stationary at the same level. For silver, variables should be I(1) to perform tests for cointegration. After performing the unit root tests the following variables are I(1) stationary: $\mathbf{ln}\boldsymbol{Ag}$; $\mathbf{ln}\boldsymbol{CPI_{US/OECD}}$; $\mathbf{ln}\boldsymbol{\rho_{US/OECD}}$; $\mathbf{ln}\boldsymbol{\$_{INDEX}}$; $\mathbf{ln}\boldsymbol{Au}$; $\mathbf{ln}\boldsymbol{Oil}$. Cointegration is tested by performing both the Engle-Granger two step and an univariate Johansen test with results (Table VII).

Results suggest a cointegrated relationship between $\mathbf{ln}\boldsymbol{Ag}$ and $\mathbf{ln}\boldsymbol{CPI_{OECD}}$ for both the Engle-Granger two-step method and the Johansen cointegration test. Only for Engle-Granger test $\mathbf{ln}\boldsymbol{Au}$ exhibits a strong cointegrating relation with silver. Since silver is a byproduct of copper, gold, lead and zinc, the Engle-Granger test was performed for the other metals as well, but except for gold none of them resulted in significant test statistics. Variables $\mathbf{ln}\boldsymbol{CPI_{US}}$; $\mathbf{ln}\boldsymbol{\$_{INDEX}}$ $\boldsymbol{and}$ $\mathbf{ln}\boldsymbol{Oil}$ result in high test statistics, but it is not possible to reject the null hypothesis of stationary residuals for the Engle-Granger test. Furthermore, the trace statistic for the Johansen test rejects the restriction that the rank of the cointegrating space is one or lager than one and accepts the hypothesis that the rank is zero. Both maximum eigenvalue and trace statistic yield same results, but in case of contradictory results, the trace statistic proved to have more power according to (Alexander 2001).

Table VII

Univariate cointegration tests

The two step Engle and Granger and Johansen test is conducted on variables which are I(1) stationary. For Engle-Granger test this is done by regressing log of silver on the variable including a trend term and performs an Augmented Dickey Fuller test on the residuals. The Augmented Dickey Fuller test does not include a constant and a trend. The number of lags used in the test is based on the Aikaike Information Criteria. Critical values are 3.02, 3.37 and 4.00 for 10%, 5% and 1% level respectively. The univariate Johansen test is performed on the logged variable silver and the I(1) variable. For maximum eigenvalue critical value at 95% level is 14.07 for maximum rank 0 and 3.76 for maximum rank 1. 5% critical value for trace statistic is 15.41 for maximum rank 0 and 3.76 for maximum rank 1.

	Engle-Granger	Maximum eigenvalue		Johansen Trace Statistic	
	Test Statistic	Maximum rank 0	Maximum rank 1	Maximum rank 0	Maximum rank 1
CPI US (ln)	-2.359	13.387	0.075	13.463*	0.076
CPI OECD (ln)	-3.516**	68.698	0.07	68.77	0.070*
Industrial Production US (ln)	-2.773	6.002	0.184	6.1858*	0.184
Industrial Production OECD (ln)	-2.625	7.543	0.290	7.8325*	0.290
Dollar Index (ln)	-2.308	10.530	0.007	10.5373*	0.007
Gold (ln)	-3.446**	9.356	1.280	10.6358*	1.280
Crude Oil (ln)	-2.290	10.225	0.005	10.23*	0.005

In order to determine the rank of the cointegrating vectors a multivariate Johansen test is performed on the eight variables (Table VIII). Due to high correlations between US and OECD variables, this is done for US and OECD variables CPI and industrial production separately adding variables $\boldsymbol{ln\$_{INDEX}}$; $\boldsymbol{lnAu}$; $\boldsymbol{lnOi}$.

Both the US and OECD cointegration tests result in a rank of 2, which is used in the VEC model. For OECD the trace statistic is higher, where maximum eigen value for US variables is higher at rank 2. From the graphs, which plotted the price of silver against all variables, structural breaks in several variables could be noted. Although the Johansen test does not account for those structural breaks, this method is being used, since not all variables exhibit those trends.

Table VIII

Multivariate Johansen cointegration test

The multivariate Johansen test is performed on the logged variable silver and the I(1) variables for both US and OECD variables. The number of lags used in the test is based on the Aikaike Information Criteria and is 3 for both US and OECD Johansen test. The maximum eigenvalue test statistic is indicated by Λ and critical values at the 5% level for both Trace and maximum eigen values are provided in the last two columns. ** indicates rejection at the 95% level.

Vector		US		OECD		Critical Values (95%)	
H0	H1	Λ	Trace	Λ	Trace	Λ	Trace
r = 0	r > 0	41.101	114.575	74.97	157.423	39.37	94.15
r ≤ 1	r > 1	32.987	73.474	40.69	82.454	33.46	68.52
r ≤ 2	r > 2	22.823**	40.487**	20.38**	41.769**	27.07	47.21
r ≤ 3	r > 3	13.710	17.665	15.10	21.384	20.97	29.68
r ≤ 4	r > 4	3.055	3.955	5.58	6.281	14.07	15.41
r ≤ 5	r > 5	0.900	0.900	0.70	0.702	3.76	3.76

Vector Error Correction Model

The long-term determinants for the price of silver are investigated by using the Vector Error Correction Model. This is done using a rank of two for both US and OECD model (Table IX and Table X). The fit of the model was tested by predicting cointegrating equations and graphing them over time. Including a linear trend in the cointegrating equations and a quadratic trend in the undifferenced data resulted in the best fit. The model without the trend resulted in unstable cointegrating equations plotted in a graph and autocorrelation in residuals of the model was present for both US and OECD.

The cointegrating vectors are indicated by β and define the parameters for the long-run equilibrium relationship. The error correction term α indicates the speed of adjustment for each variable to return to long-run equilibrium. The error correction terms are significant for the variables silver, gold and oil, where oil has a higher adjustment coefficient compared to gold. Surprisingly the error correction term for CPI result in significant coefficients only for OECD model.

Table IX

Vector Error Correction model US

The Vector Error Correction model is performed on the logged variable silver and the I(1) variables. The number of lags used in the test is based on the Aikaike Information Criteria and is 3. From multivariate Johansen cointegration test a rank of 2 is used. Finally, a linear trend in the cointegrating equiations and a quadratic trend in the undifferenced data is included in the VEC model. T-statistics are included in parentheses. *** indicates significance at the 1% level and * at the 10% level.

	β_1	β_2	α_1	α_2
Silver (ln)	1	Omitted	-0.192	0.115
	-	-	(-1.92)**	(1.46)*
Gold Spot (ln)	0.000	1	0.064	-0.112
	-	-	(2.47)***	(-2.61)***
CPI US (ln)	23.021	14.158	-0.001	0.001
	(4.84)***	(4.75)***	(-0.53)	(0.31)
Industrial Production US (ln)	2.370	3.148	0.004	-0.011
	(1.33)*	(2.82)***	(1.09)	(-1.69)**
Dollar Index (ln)	4.688	3.253	0.008	-0.012
	(2.90)***	(3.21)***	(0.79)	(-0.71)
Crude Oil (ln)	2.008	1.160	0.011	-0.076
	(4.72)***	(4.35)***	(0.19)	(-0.81)
Trend	-0.074	-0.048		
Constant	-145.983	-103.017		

Table X

Vector Error Correction model OECD

The Vector Error Correction model is performed on the logged variable silver and the I(1) variables. The number of lags used in the test is based on the Aikaike Information Criteria and is 3. From multivariate Johansen cointegration test a rank of 2 is used. Finally, a linear trend in the cointegrating equiations and a quadratic trend in the undifferenced data is included in the VEC model. T-statistics are included in parentheses. *** indicates significance at the 1% level and * at the 10% level.

	β_1	β_2	α_1	α_2
Silver (ln)	1	Omitted	-0.078	-0.006
	-	-	(-2.19)**	(-0.09)
Gold Spot (ln)	0.000	1	0.039	-0.130
	-	-	(2.05)**	(-3.58)***
CPI OECD (ln)	8.337	4.204	-0.002	0.003
	(8.61)***	(7.10)***	(-1.81)**	(1.89)**
Industrial Production OECD (ln)	-1.584	1.868	-0.002	-0.005
	(-1.59)*	(3.07)***	(-0.92)	(-1.03)
Dollar Index (ln)	2.001	1.381	0.009	-0.003
	(3.97)***	(4.48)***	(1.16)	(-0.18)
Crude Oil (ln)	1.083	0.252	-0.122	0.051
	(5.68)***	(2.16)**	(-2.89)***	(0.64)
Trend	-0.036	-0.022		
Constant	-38.143	-36.381		

In order to compare coefficients the vectors in the matrix are normalized by setting one element of each row equal to 1. By dividing each row by the chosen element, the results are obtained and thus coefficients differ by the element chosen for normalization. Coefficients can be interpreted as long-term elasticities, since a double logarithmic is used in the equitation. Normalizing the coefficients for $\boldsymbol{lnAg}$ for the first cointegrating vector results in highly significant coefficients for all variables except for $\boldsymbol{\rho_{US/OECD}}$. The long run relationship between the price of silver and the five variables is displayed below. This is done for the first eigenvector, which is based on the largest eigenvalue and thus is supposed to be the most useful.

$$\mathbf{ln}\boldsymbol{Ag} = \mathbf{23.021} * \boldsymbol{CPI_{US}} + \mathbf{2.370} * \boldsymbol{\rho_{US}} + \mathbf{4.688} * \$_{\boldsymbol{INDEX}} + \mathbf{2.008} * \mathbf{Oil} - \mathbf{0.074} * \boldsymbol{Trend} - \mathbf{145.983}$$

Equation 4

$$\mathbf{ln}\boldsymbol{Ag} = \mathbf{8.337} * \boldsymbol{CPI_{OECD}} - \mathbf{1.584} * \boldsymbol{\rho_{OECD}} + \mathbf{2.001} * \$_{\boldsymbol{INDEX}} + \mathbf{1.083} * \mathbf{Oil} - \mathbf{0.036} * \boldsymbol{Trend} - \mathbf{38.143}$$

Equation 5

All coefficients are in line with theory since as a precious metal silver is expected to capture inflation or to hold some inflation hedging properties resulting in a positive relation. The industrial use of silver does indeed respond to changes in figures for industrial production, although results are not highly significant and the OECD regression displays a negative beta for the first eigenvector.

The positive relation with the dollar index can be explained by countries holding currencies other than the US dollar. A higher dollar index should make it more interesting for an outside investor to buy silver, due to the depreciation of the US dollar. The positive coefficients are in line with theory, although it is interesting to see a large difference between the US and OECD coefficient. A possible reason for the lower coefficient for $\boldsymbol{CPI_{OECD}}$ could be the inclusion of all OECD consumer price indexes, which smoothes the time series. Finally, since oil captures both inflation and is an indicator for economic activity due to the use of oil for several base materials, production and as fuel for transport, the non-negative number can be understood from previous literature as well.

Looking at the second vector, where gold is normalized to factor 1, coefficients are identical to silver, which is surprising since both materials serve different purposes. Coefficients for CPI are relatively smaller compared to the first eigenvector, where silver is the normalized variable. The coefficient for industrial production on gold is highly significant contrary to the first eigenvector. This result is in contrast with theory, since silver use for industrial purposes is higher compared to gold.

Graphs for impulse response functions (Appendix C and D) show a positive correction in gold oil and silver to a shock in $\boldsymbol{CPI_{US/OECD}}$. The stronger effect of silver compared to gold is probably due to the relatively smaller and more volatile market. A shock in inflation has the highest impact on the price of oil. The three commodities demonstrate a similar pattern in the graphs; after three months a negative correction takes place, which implies that inflation is not perfectly captured by the price of commodities in the short run. This finding is in line with theory of previous papers for the price of gold and its inflation hedging capabilities. The price of oil gradually increases to a shock in $\boldsymbol{\rho_{OECD}}$, and does not return to zero. Reckon, that largest demand for oil comes from industrial firms, the relatively smooth correction is possibly due to the amount of oil companies have in stock after a recession.

Eigenvalues of both models are tested on stability after fitting the VECM models. It turns out that both models are not stable with 4 eigenvalues having modulus of one. This is visualized in the graphs, where eigenvalues are not in the unit circle. Results of stability tests can be found in appendix E and appendix F. VEC models with the logged silver price and one I(1) variable are estimated as a check, but all models turn out to be instable.

Vector Autoregressive Model

Variables which are stationary at the level are $\boldsymbol{\pi_{US/OECD}}$, $\boldsymbol{V(\pi_{US/OECD})}$, $\boldsymbol{\ln GDP_{US/OECD}}$, $\boldsymbol{\beta_{S\&P500/MSCI}}$, $\boldsymbol{default}$, $\boldsymbol{r_{real}}$, $\boldsymbol{\ln VXO}$, $\boldsymbol{\ln F_{Ag}}$ and $\boldsymbol{\ln ETF_{Ag}}$. Performing a VAR model to gain insight in which variables granger cause, it is essential that all variables included in the VAR are stationary at the same level. The I(1) stationary of silver seems to be problematic compared with the other I(0) variables. Proponents of the VAR approach do not recommend differencing the time series (Brooks 2008). Their argument is that differencing makes it harder to recognize a long-run relation between time series. 11 of 13 VAR model with undifferenced $\boldsymbol{\ln Ag}$ are unstable due to eigenvalues of one. Shorter time series for $\boldsymbol{\ln F_{Ag}}$ and $\boldsymbol{\ln ETF_{Ag}}$ are probably the reason for stability.

Results for all univarite VARs are reported in Table XI. The VAR model treats all variables as endogenous and thus silver is both dependent and independent variable at the same time. Absolute coefficients do not have a real meaning, since each variable is logged. However, it is interesting to see which variables have a significant relation with the price of silver and granger causality. Granger causality Wald test is performed in table XII to test causality of variables in the VAR model.

In the VEC model CPI was the most important driver in variables having a cointegrating relationship with silver, and the significance of inflation is not surprisingly. Silver seems to granger cause US inflation and this is confirmed with granger causality test, although for OECD both silver and inflation granger cause each other. Although real interest rate is more important for investors one would expect positive coefficients due to the inflation hedging capabilities of precious metals.

Both VAR models are performed with a lag of three, which is relatively large, since the market is expected to react immediately on macroeconomic figures. The lag structure results in a positive significant coefficient for inflation, both US and OECD for the first lag. Coefficient for silver as independent variable is not significant. The null hypothesis that the price of silver does not granger cause US inflation cannot be rejected. A possible reason for this finding is that markets anticipate on macroeconomic news. For OECD inflation no granger causality can be spotted, which is probably due to the combination of different inflation rates in one rate. Furthermore the silver price is quoted in dollars and that could be a reason that there is a stronger relation with US inflation rates.

Inflation volatility results in positive coefficients but after performing the granger causality Wald test, no causality is present. The positive value is in line with theory; more volatility in inflation rates results in an increased uncertainty for investors and since precious metals can be viewed as a safe haven, the price will rise. The volatility index as dependent variable has a positive coefficient but with small significance. However, it seems to granger cause the price of silver, which can be explained by market uncertainty as well.

It is likely that higher Gross Domestic Product results in increasing investment and jewelry demand. This is confirmed by granger causality test and the positive coefficient of GDP on silver as independent variable. A negative relation between the beta of silver on the S&P500/MSCI and the price of silver is expected, but coefficients are highly significant and positive. In the plotted graphs an ambiguous relation could be spotted. This means it is really hard for investors to buy silver in order to reduce portfolio volatility.

Default spread and the real interest rate granger cause the price of silver and both coefficients are in line with theory. A higher default spread implies higher risk in financial markets and thus makes silver more interesting as a safe haven. US T-bills are supposed to be risk free and with higher real interest rates more interesting for investors compared to the volatility of silver. Higher demand for T-Bills is likely to have a negative impact on silver demand by investors, which is confirmed by the negative coefficient.

Table XI

Univariate Vector Autoregressive model

The Vector Autoregressive Model is performed on the logged variable silver and the I(0) variables. The number of lags used in the test is based on the Aikaike Information Criteria. T-statistics are included in parentheses. *** indicates significance at the 1% level and * at the 10% level.

	Silver (ln) dependent variable	Silver (ln) independent variable	Stable/Unstable model	Lags
Inflation US	-0.005	-0.454	Unstable	3
	(-2.78)***	(-1.20)*		
Inflation OECD	-0.025	-0.931	Unstable	12
	(-6.19)***	(-3.07)***		
Inflation Volatility US	0.446	1.820	Unstable	14
	(5.72)***	(8.20)***		
Inflation Volatility OECD	0.037	0.794	Unstable	13
	(2.19)**	(8.58)***		7
GDP US (ln)	-0.047	0.195	Unstable	
	(-5.11)***	(2.28)**		
GDP OECD (ln)	-0.065	0.145	Unstable	7
	(-6.73)***	(1.76)**		
Beta S&P 500	0.046	0.235	Unstable	4
	(3.63)***	(4.28)***		
Beta MSCI	0.018	0.122	Unstable	2
	(2.21)**	(2.61)***		
Default Spread	0.032	0.080	Unstable	3
	(1.74)**	(3.42)***		
Real Interest Rate US	-0.001	-1.566	Unstable	2
	(-0.40)	(-4.00)***		
Volatility Index (ln)	-0.017	0.036	Unstable	3
	(-0.86)	(1.40)*		
Silver long futures (ln)	0.047	0.126	Stable	2
	(0.99)	(4.29)***		
Silver ETF (ln)	0.031	0.936	Stable	1
	(1.46)*	(7.91)***		

Figure 4, which graphed increasing investment demand from 2000 and onwards is present in coefficients as well. Although silver long futures and silver ETF market values estimated over a shorter period, they seem to have become more important in world silver demand. Both variables granger cause silver and their coefficients are positive. Silver ETF market value has a higher significance and larger coefficients compared to silver futures market value, although it must be noted that silver futures are based on Comex 500 market value and silver ETF market value is based on the summed value of silver ETF market values available from Reuters.

Table XII

Granger Causality

The Granger causality Wald tests are based on the VAR tests in Table XI. Values in the table are p-values, with H0: excluded variable does not Granger cause variable in equation.

Excluded variables	Equitation: Silver (ln)	Equation	Excluded: Silver (ln)
Inflation US	0.005	Inflation US	0.231
Inflation OECD	0.000	Inflation OECD	0.002
Inflation Volatility US	0.000	Inflation Volatility US	0.000
Inflation Volatility OECD	0.028	Inflation Volatility OECD	0.000
GDP US (ln)	0.000	GDP US (ln)	0.023
GDP OECD (ln)	0.000	GDP OECD (ln)	0.078
Beta S&P 500	0.000	Beta S&P 500	0.000
Beta MSCI	0.027	Beta MSCI	0.009
Default Spread	0.082	Default Spread	0.000
Real Interest Rate US	0.687	Real Interest Rate US	0.000
Volatility Index (ln)	0.39	Volatility Index (ln)	0.16
Silver long futures (ln)	0.324	Silver long futures (ln)	0.000
Silver ETF (ln)	0.145	Silver ETF (ln)	0.000

Conclusion

Using the Vector Error Correction model in order to obtain long-term equilibrium relationships, the consumer price index has the biggest impact on the price of silver. This finding is in line with previous research, although gold is supposed to be a commodity with the best inflation hedging properties in all surveys. Coefficient for industrial use is larger compared to investment demand, but this variable only has a positive coefficient for US. The distinction between US and OECD variables leads to the tentative conclusion that US macroeconomic variables do have a larger impact on the price of silver.

The dollar index and the price of oil included in the Vector Error Correction model resulted in positive and significant coefficients. The depreciation of the dollar is likely to increase demand from countries not having US Dollar as major currency. The relation of oil with both industrial use and inflation probably explains the positive cointegration with silver. Both silver and gold seems to share comparable properties, although the market for gold is less volatile and has a stronger relation with Consumer Price Index.

Figures for supply and demand already exposed the increasing investment demand for silver, which is confirmed when performing Vector Autoregressive Test for short-term determinants. Market values for both silver futures and Exchange Traded Funds granger cause the price of silver and have high significant coefficients. Not surprisingly the real interest rate has a negative and larger effect compared to inflation rates.

Two major issues remain unresolved. The first one is the use of values for OECD countries instead of individual countries outside the United States. The Consumer Price Index and Industrial Production for OECD countries smooth out the shocks in time series of individual countries. This makes the series less informative in a Vector Error Correction model, which includes an error term and returns to equilibrium state.

Furthermore the dollar index proved to be an important factor in silver demand from countries not having the US Dollar as major currency. It would be interesting to use individual exchange rates instead of a uniform dollar index and see which countries benefit from depreciation of the dollar compared to their own currency. The second issue is the instability of the VEC and VAR models. An ARMA-GARCH model might be a better alternative providing a stable model.

Finally the inclusion of a margin hike variable, which is a short-term determinant of the price of silver might be interesting for future research. During the Hunt brothers' period, the use of margin hikes was already common, but since 2000 this instrument has been used by exchanges more frequently due to the firm uptrend in the value of silver.

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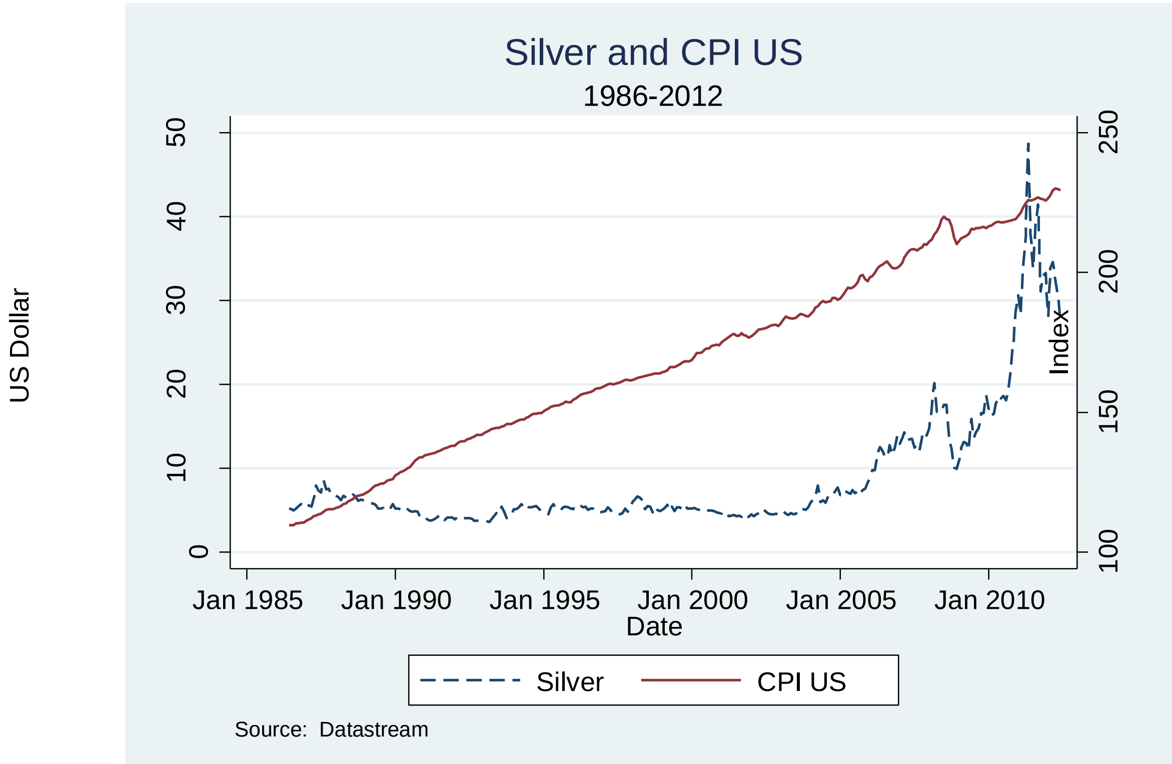
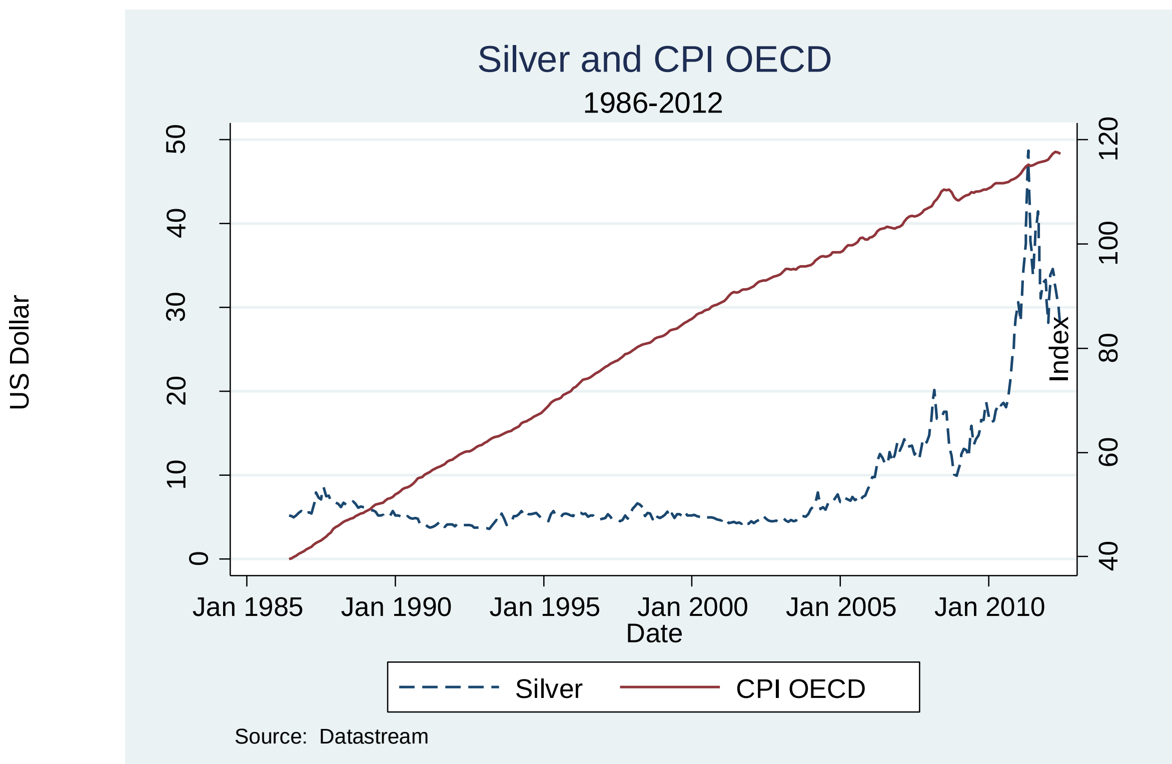
Appendix A: Variables

Variable	Mnemonic	Source	Unit
Price of silver	Ag_{spot}	London Bullion Market	US $ Cash Cents/Troy Oz
Price of silver	$Ag_{H\&H}$	Handy and Harman	US $ Cash Cents/Troy Oz
Consumer Price Index U.S.	CPI_{US}	U.S. Bureau of Labor Statistics (BLS)	Price index, not SA
Inflation rate U.S.	π_{US}	$Change\ in\ CPI_{US}$	Monthly inflation rate
GDP U.S.	GDP_{US}	OECD Main Economic Indicators	SA
Industrial production U.S.	ρ_{US}	Federal Reserve, United States	Volume index, SA
Consumer Price Index OECD	CPI_{OECD}	OECD Main Economic Indicators	Price index, not SA
Inflation rate OECD	π_{OECD}	$Change\ in\ CPI_{OECD}$	Monthly inflation rate
GDP OECD	GDP_{OECD}	OECD Main Economic Indicators	SA
Industrial production OECD	ρ_{OECD}	OECD Main Economic Indicators	Volume index, SA
Price of gold	Au_{spot}	London Bullion Market	US $/Troy Oz
Price of gold	$Au_{H\&H}$	Handy and Harman	US $/Troy Oz
Price of copper	Cu	London Metal Exchange	US $/MT
Price of lead	Pb	London Metal Exchange	US $/MT
Price of zinc	Zn	London Metal Exchange	US $/MT
Price of platinum	Pt	London Platinum and Palladium Market	US $/Troy Oz
Price of palladium	Pd	London Platinum and Palladium Market	US $/Troy Oz
Price of oil (Crude oil WTI)	Oil	Thomson Reuters	US $/BBL
Trade Weighted U.S. Dollar Index	$\$_{INDEX}$	Federal Reserve	US $
Standard and Poor 500 index	β_{Ag}	Datastream	US $
Volatility index	VIX	Datastream	US $
Alternative volatility index	$SKEW$	Datastream	US $
Comex Silver 5000 Long Futures	$Flong_{Ag}$	Commitments of Traders	Open interest
Comex Silver 5000 Short Futures	$Fshort_{Ag}$	Commitments of Traders	Open interest
Market Value silver ETF	ETF_{Ag}	Datastream	US $
10 year U.S. Treasury bill	$r_{nominal}$	Thomson Reuters	Monthly interest rate
Real interest rate U.S.	r_{real}	$r_{nominal} - \pi_{US}$	Monthly real interest rate
10 year Moody's AAA Corporate Bond yield	Aaa	Datastream	Monthly percentage
10 year Moody's Baa Corporate Bond yield	Baa	Datastream	Monthly percentage
10 year U.S. Treasury notes yield	DS	$Aaa - Baa$	Monthly percentage

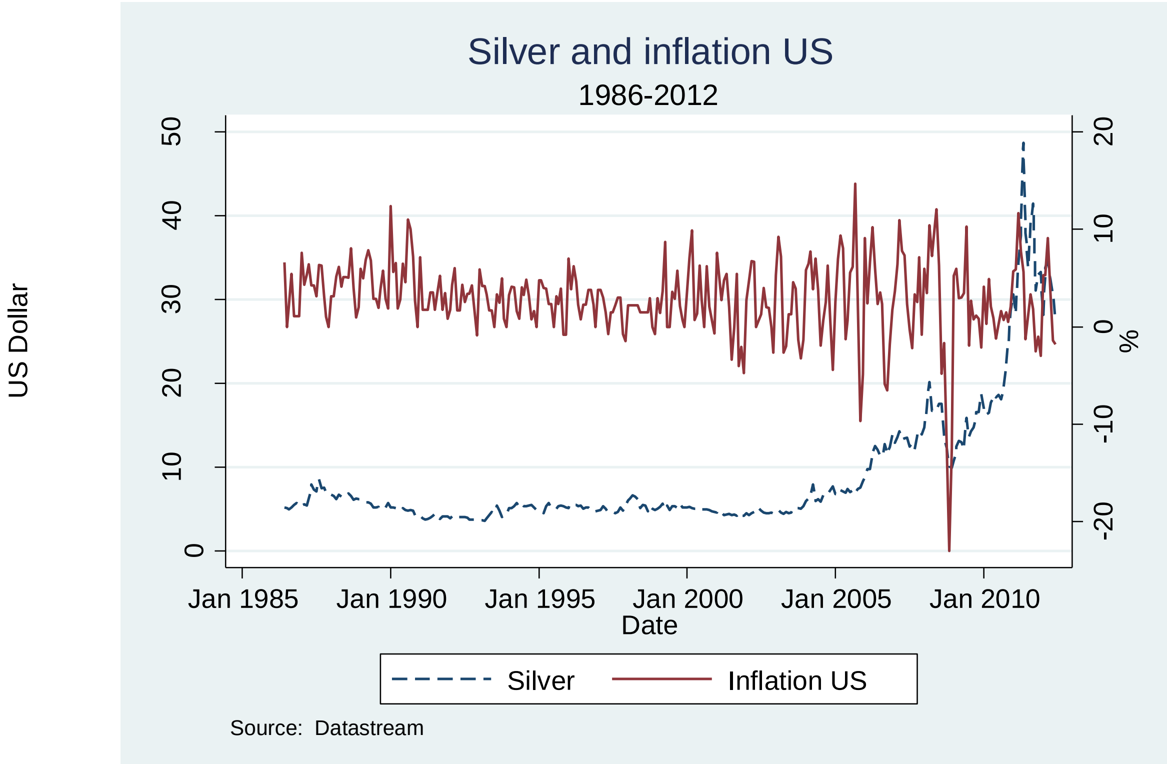
Appendix B: Trends

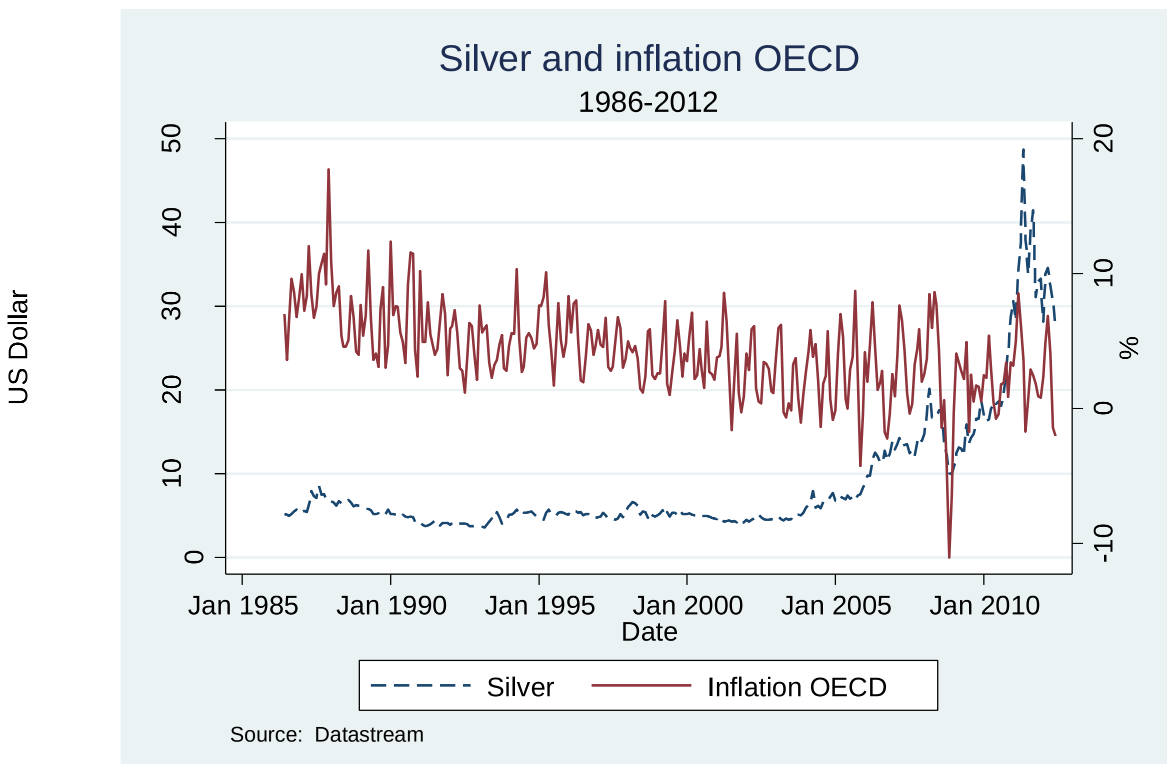
Silver and CPI



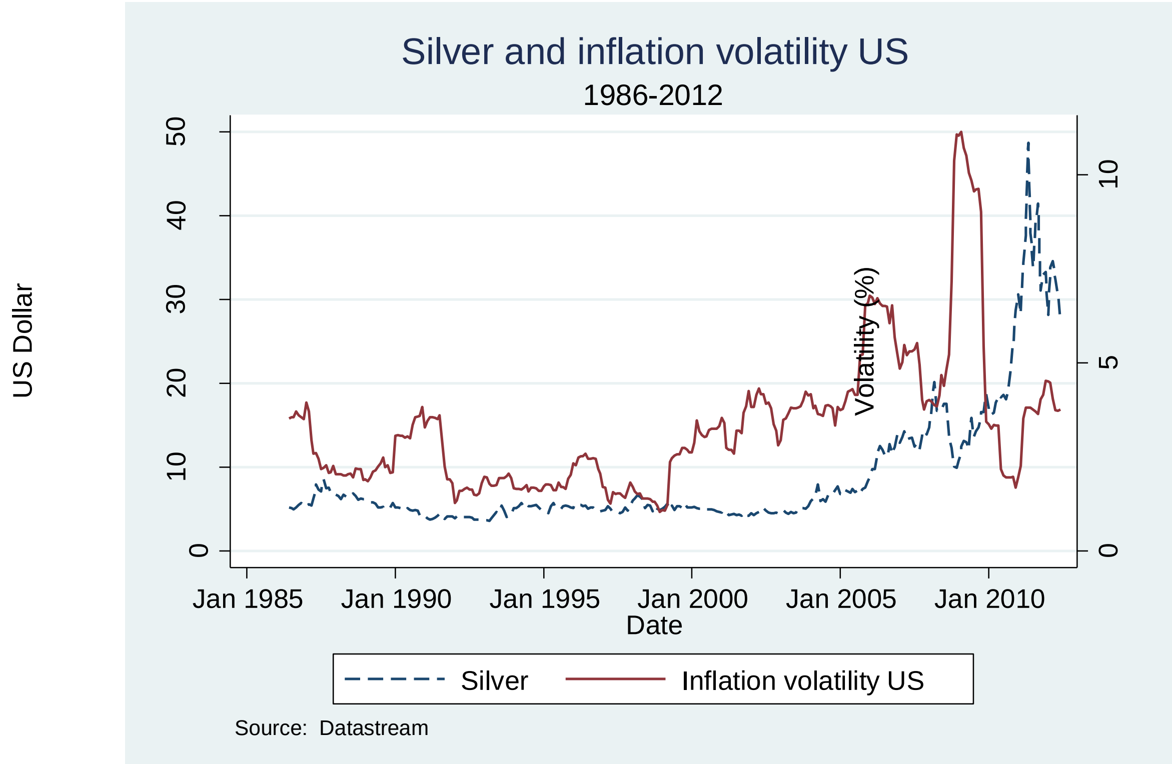


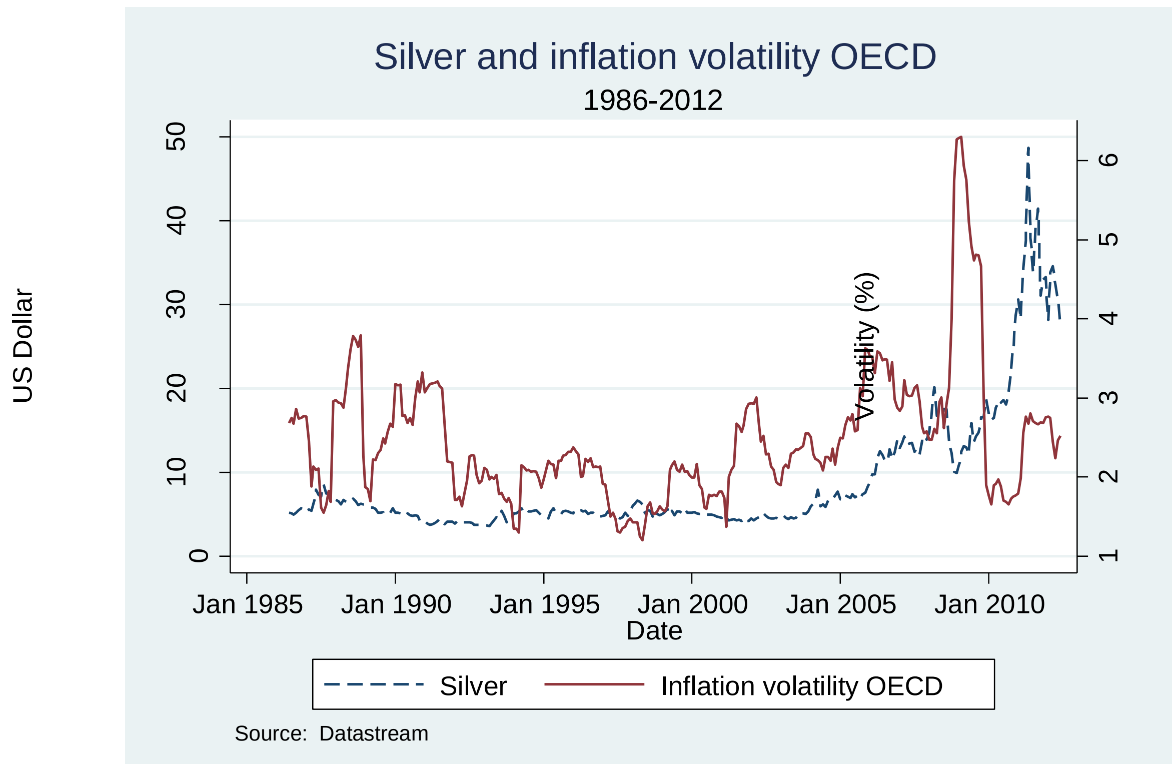
Silver and inflation



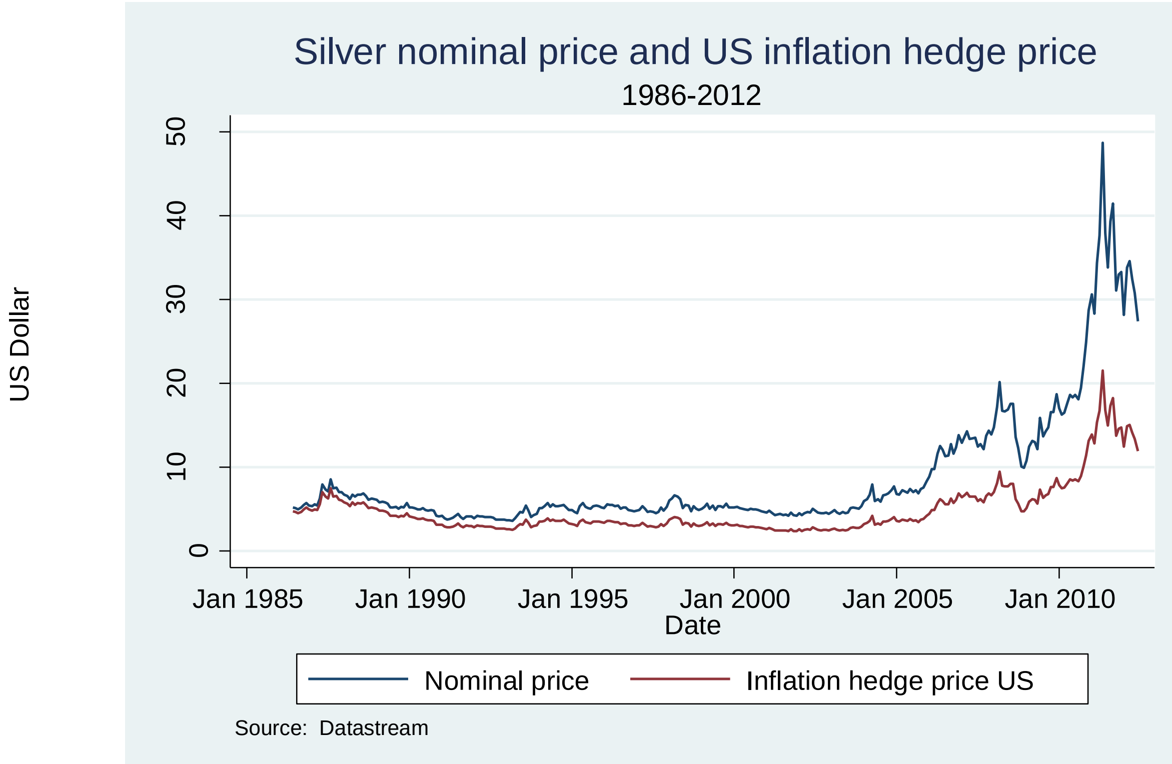


Silver and inflation volatility

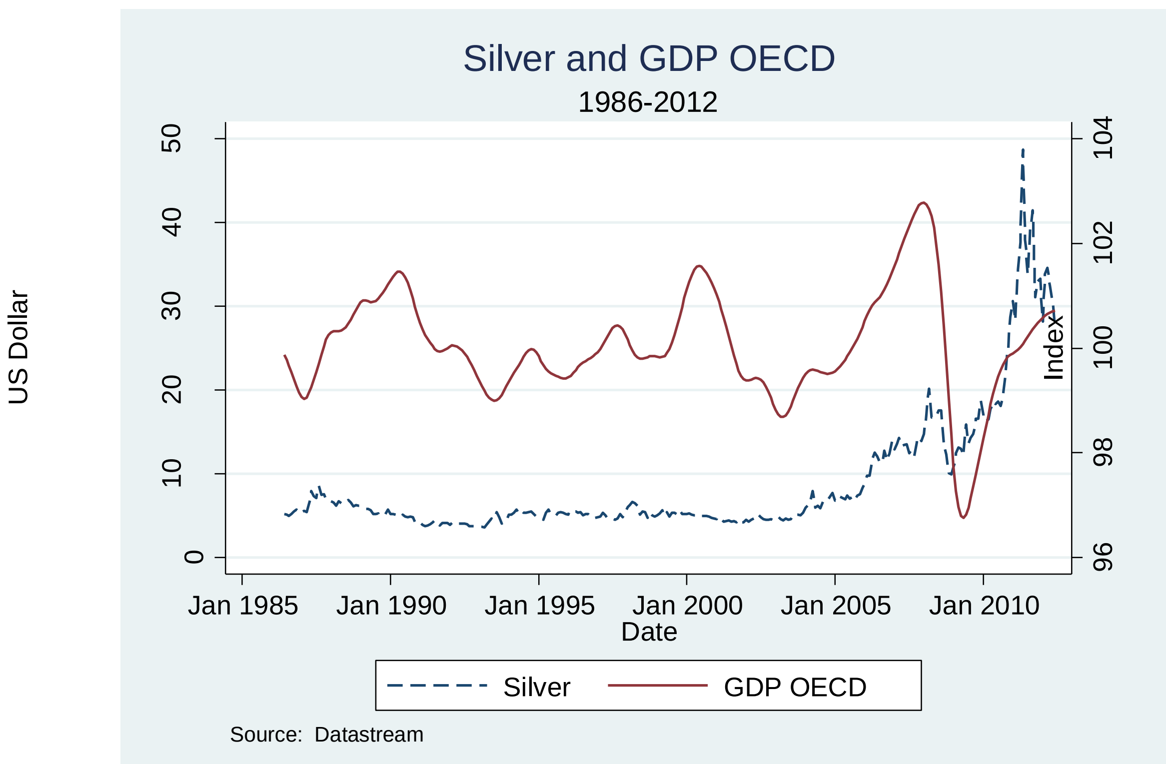




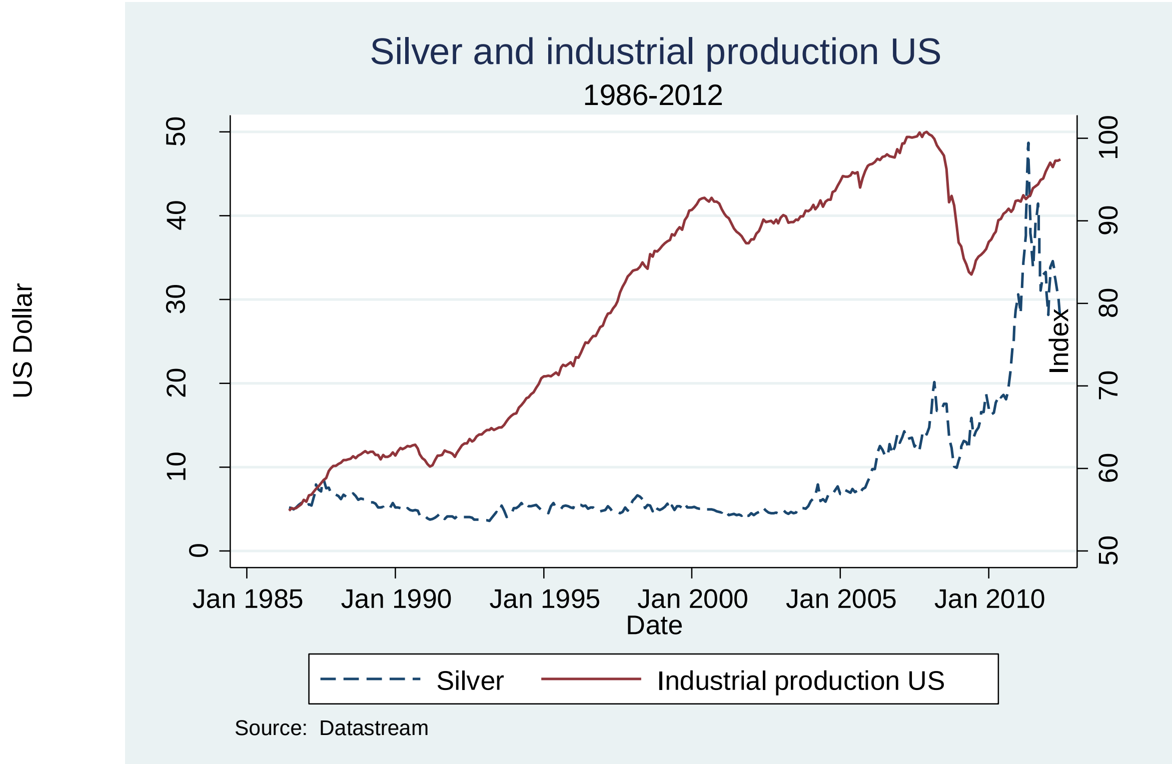
Silver inflation hedge price

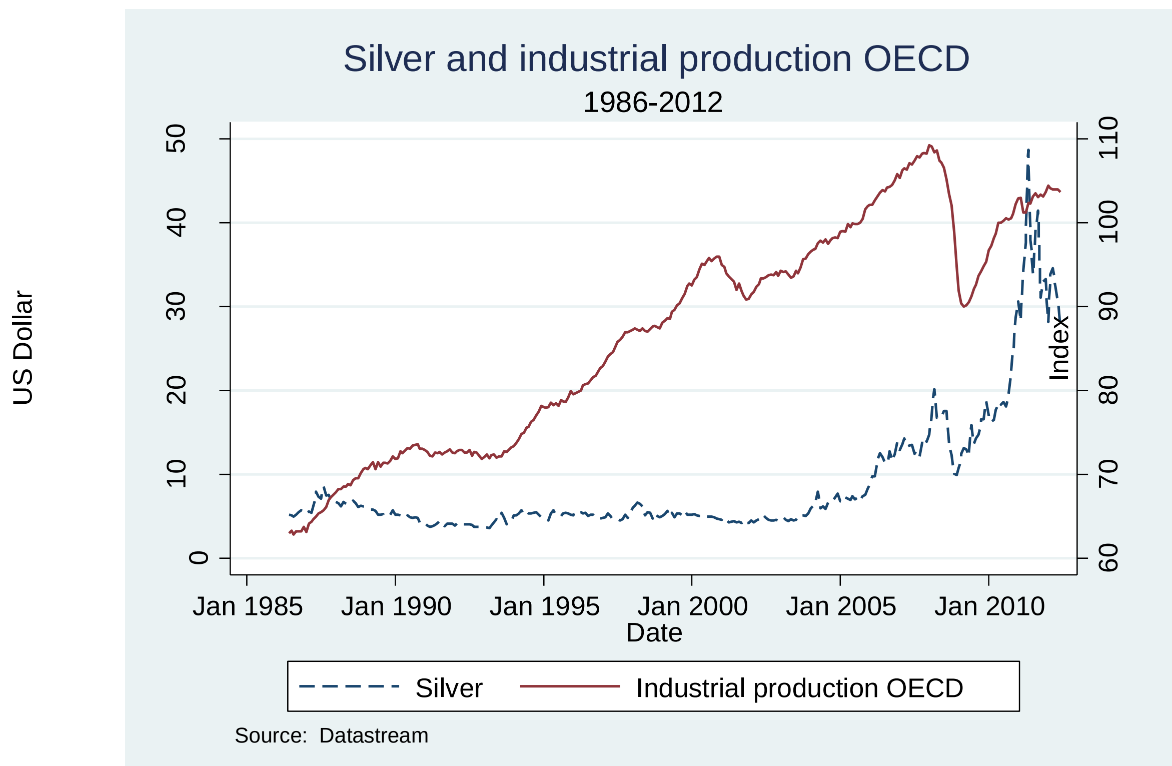


Silver and GDP

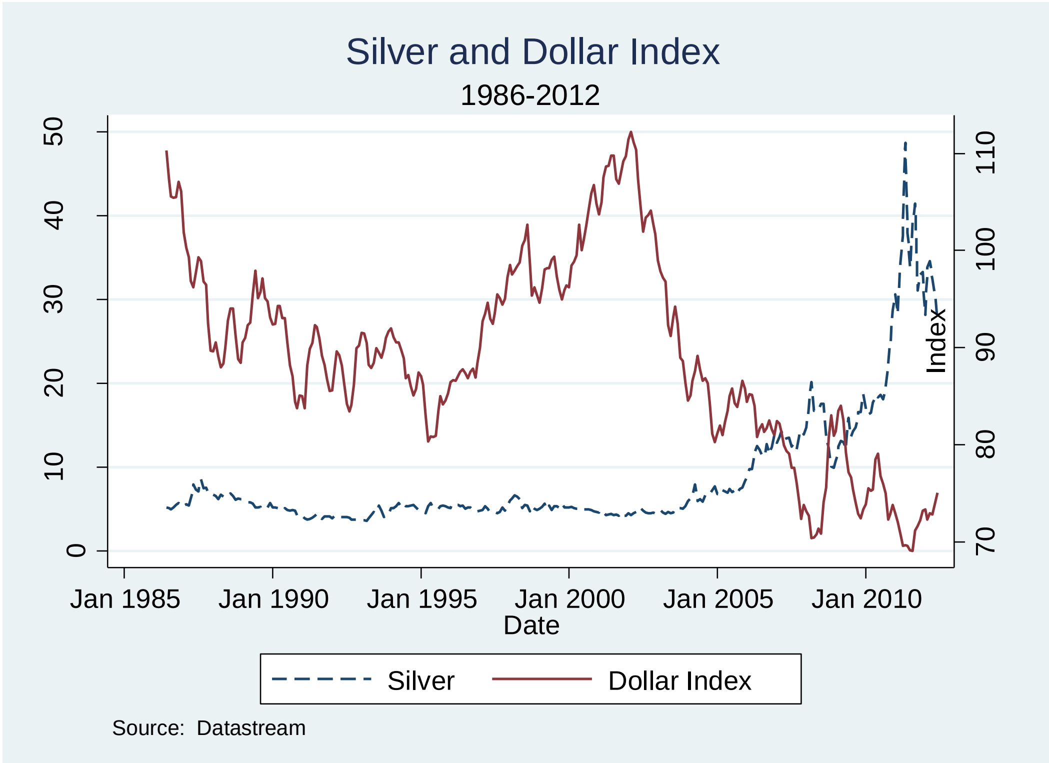


Silver and Industrial production



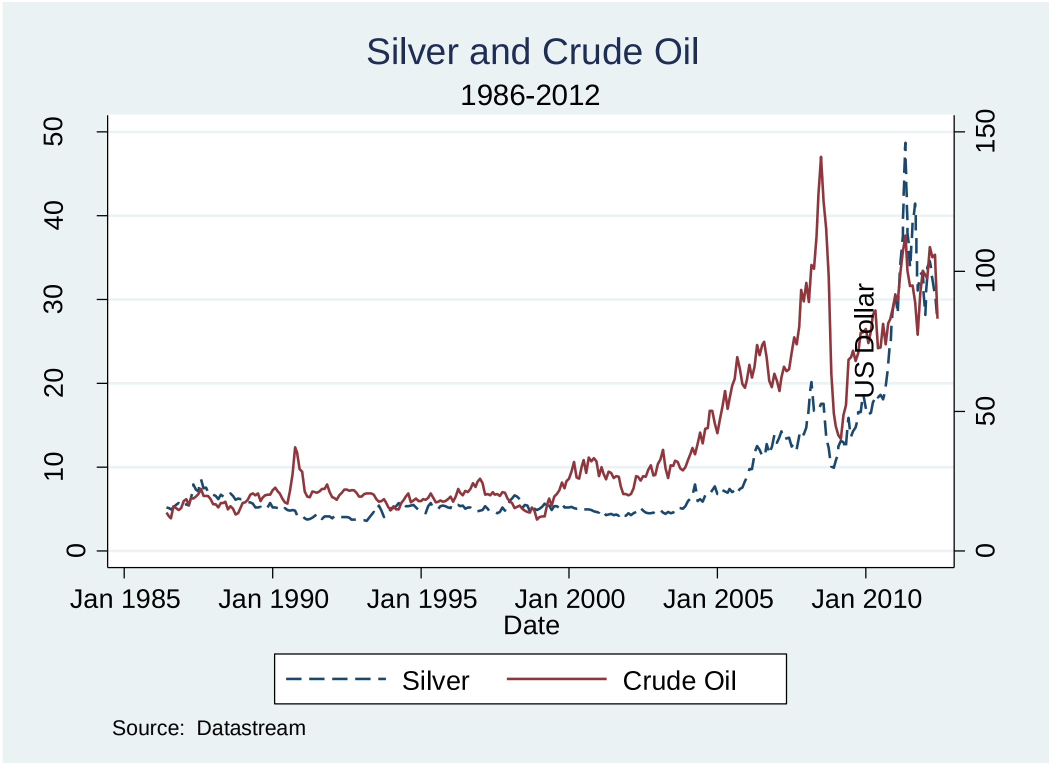


Silver and Dollar index

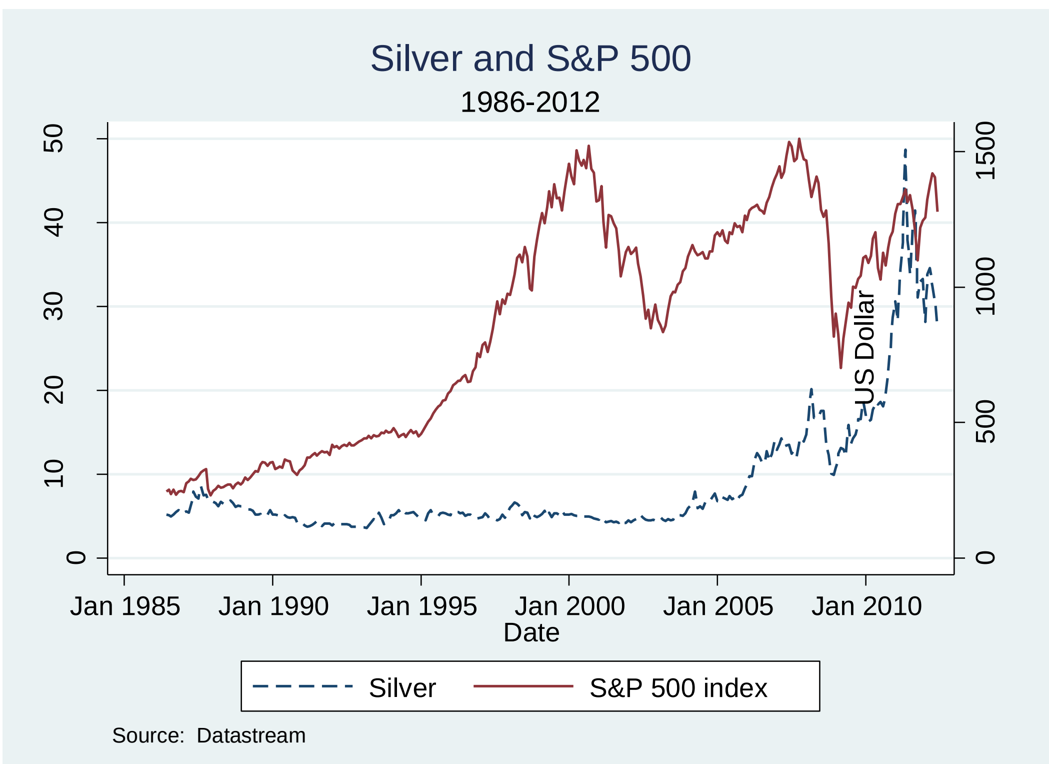


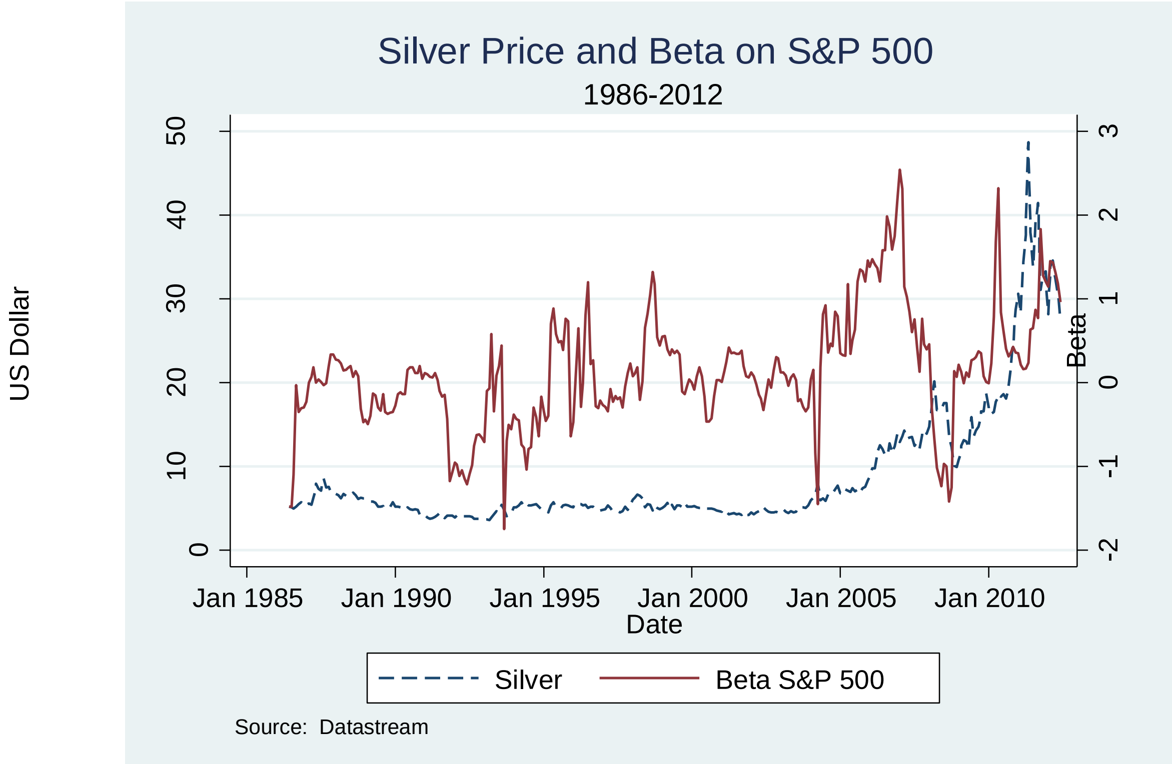
Silver and gold

Silver and oil

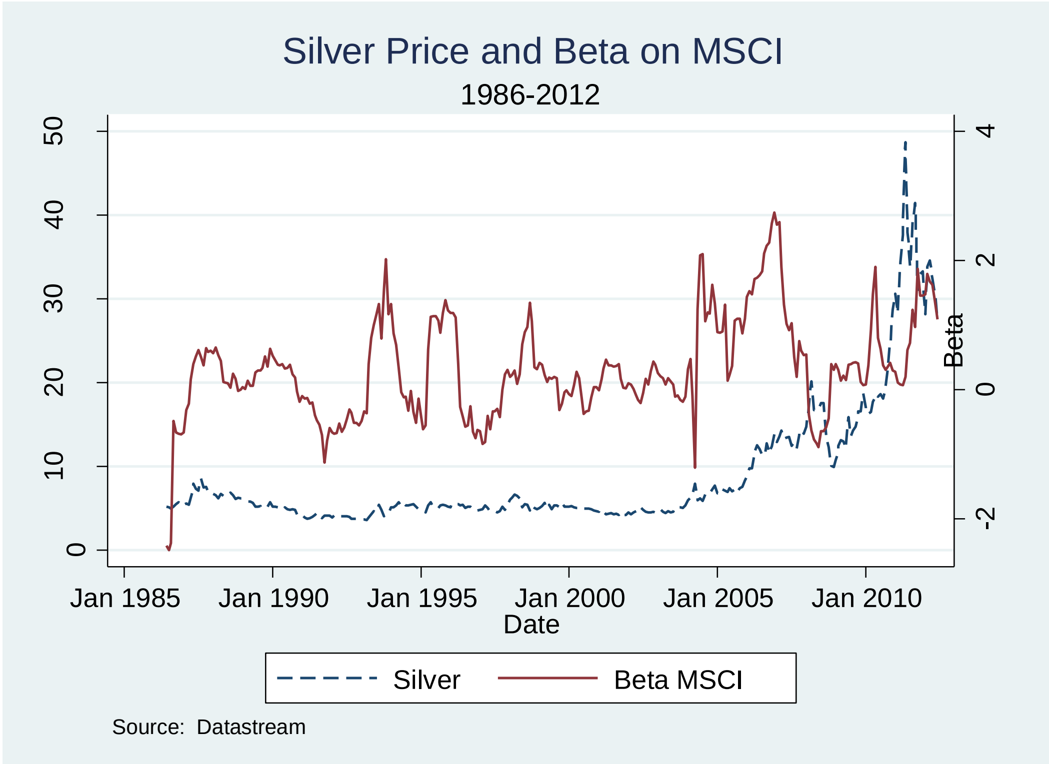


Silver and S&P 500

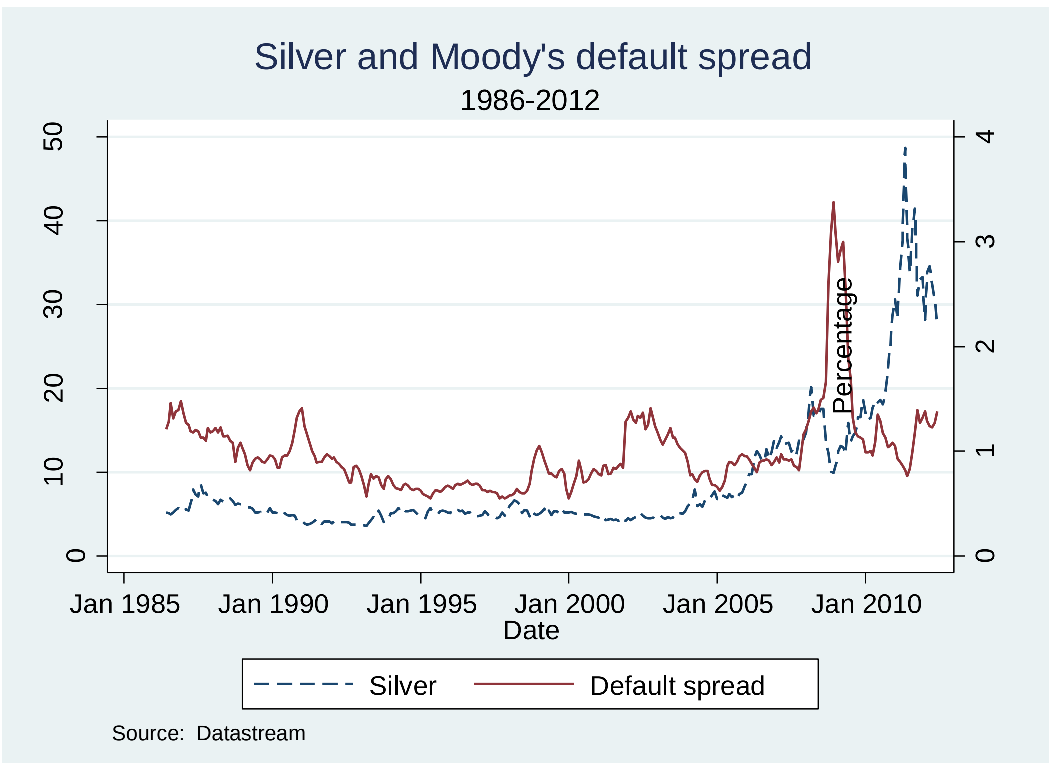




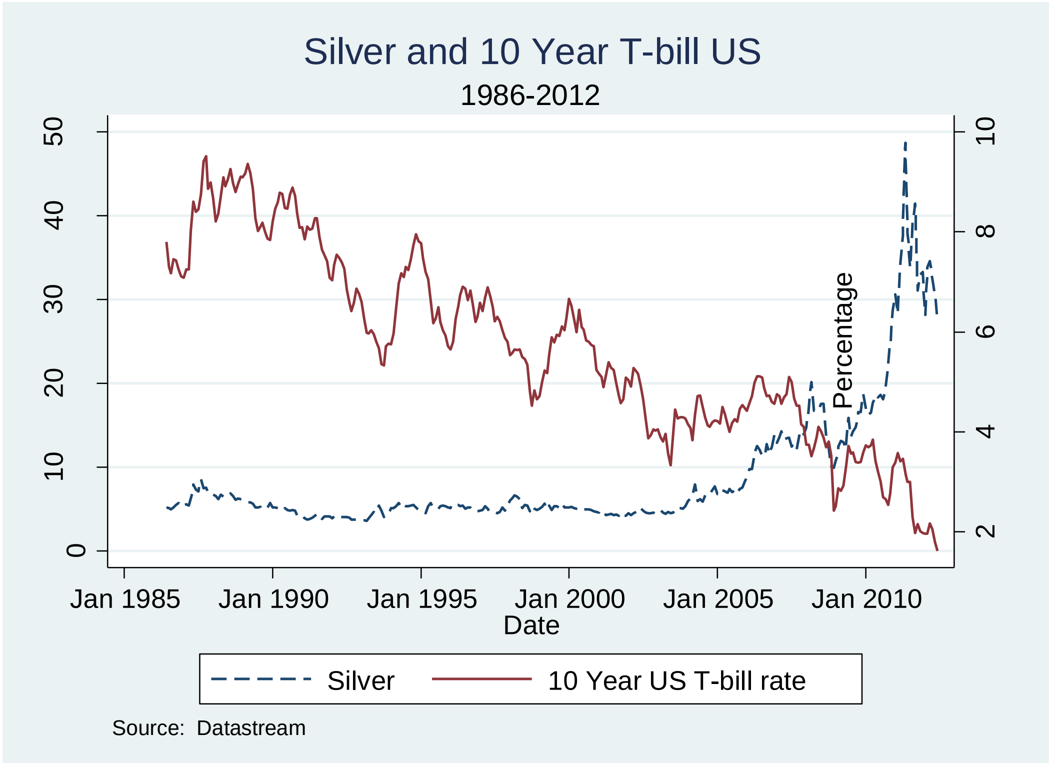
Silver and MSCI World Index



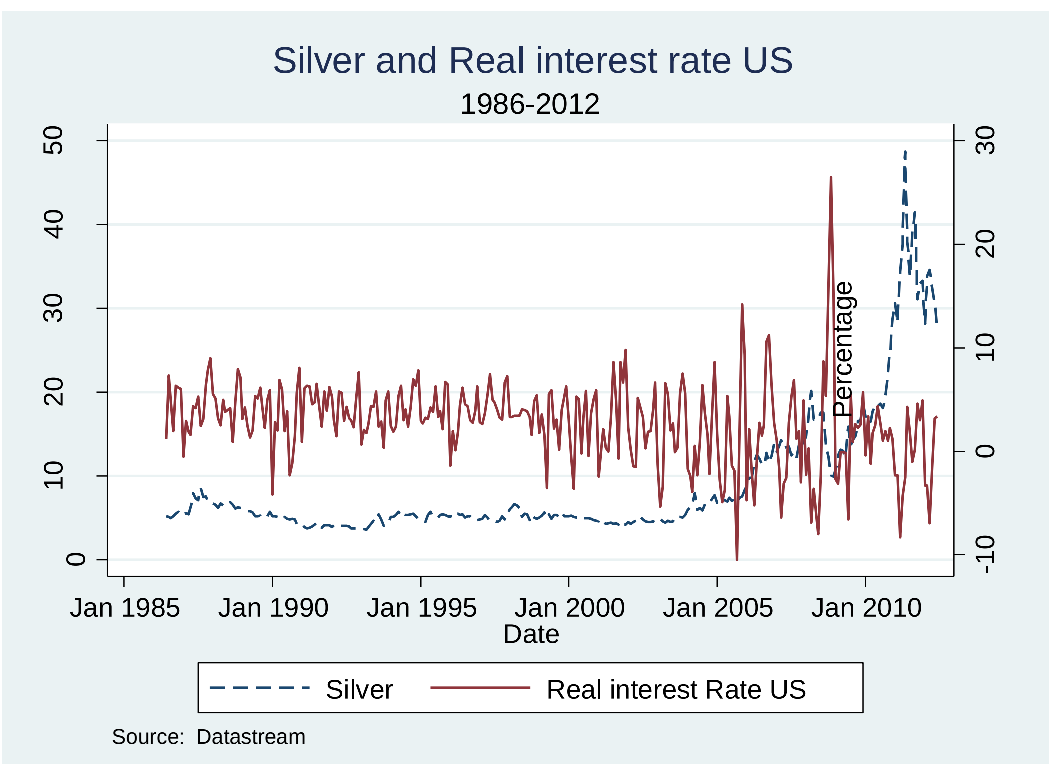
Silver and default spread



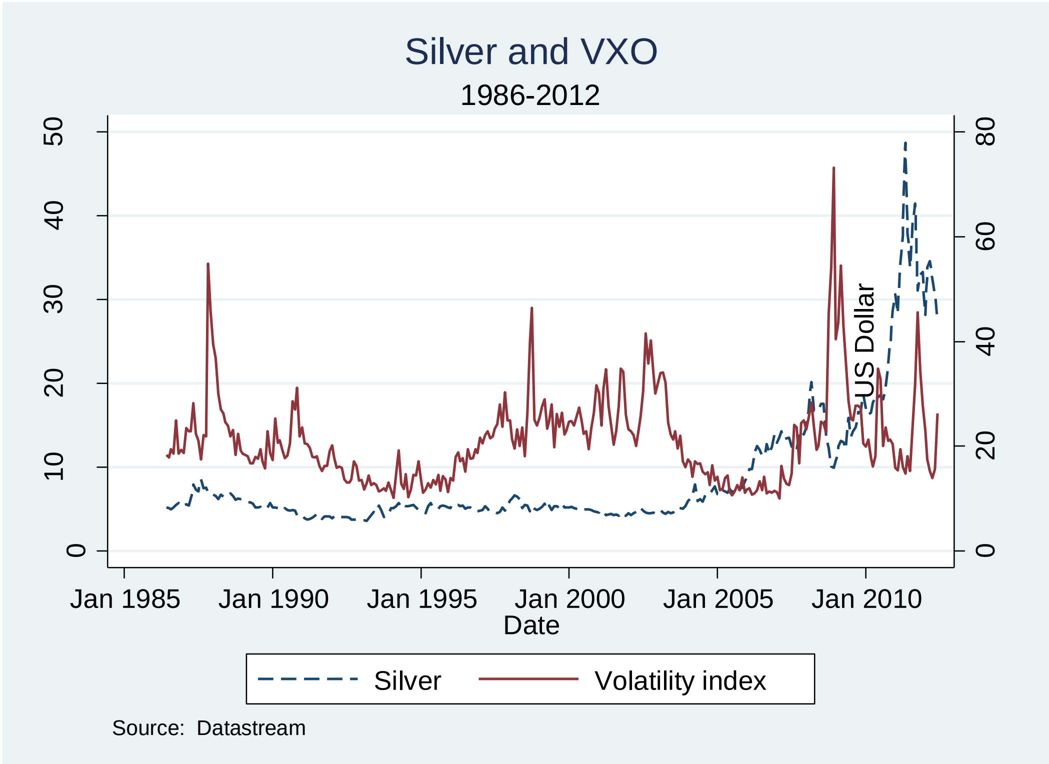
Silver and 10 year T-bill



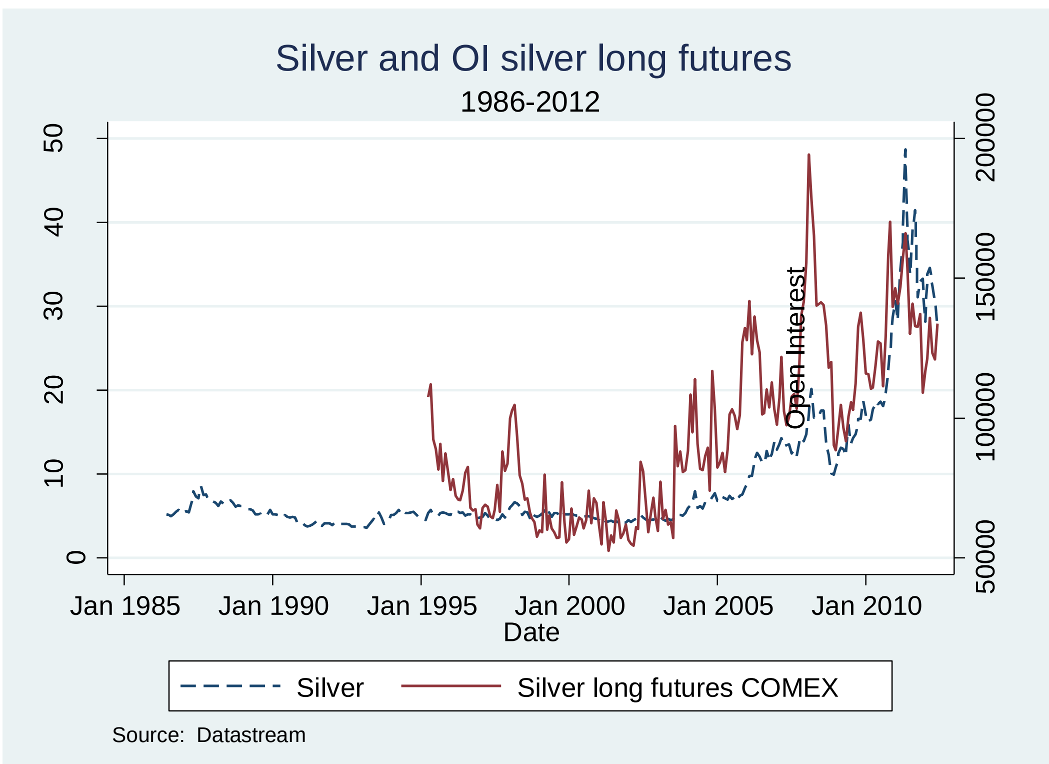
Silver and real interest rate

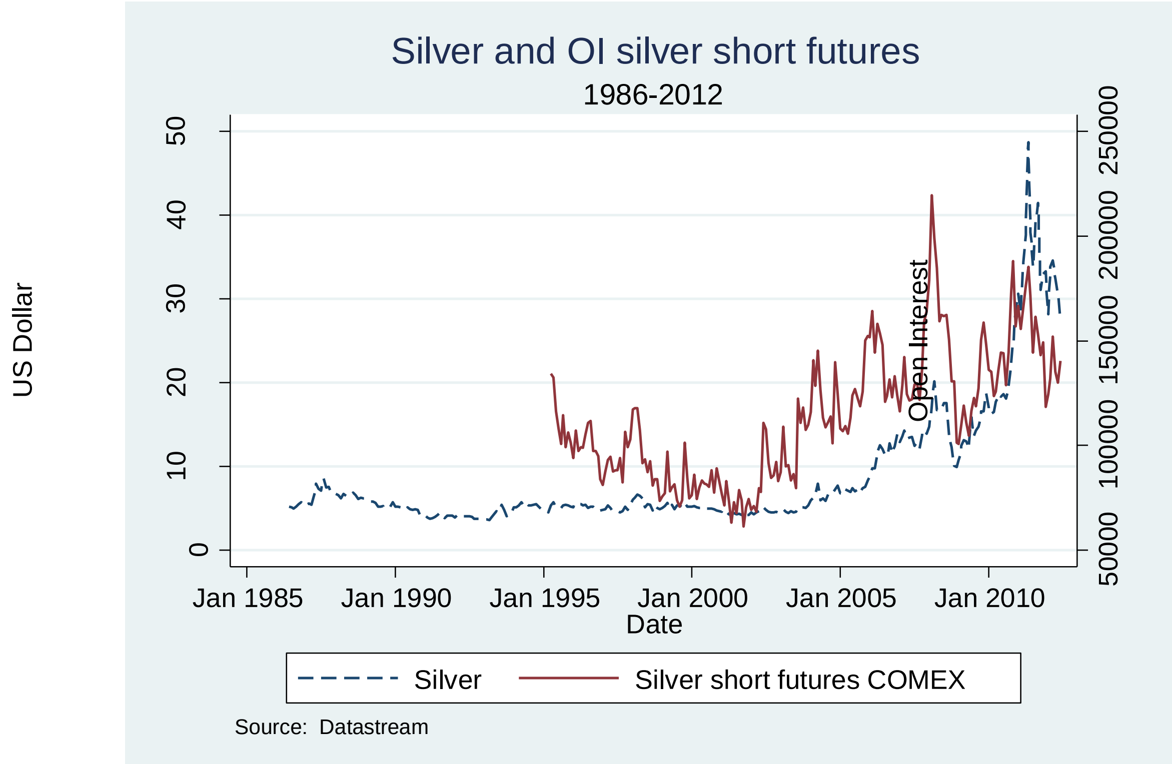


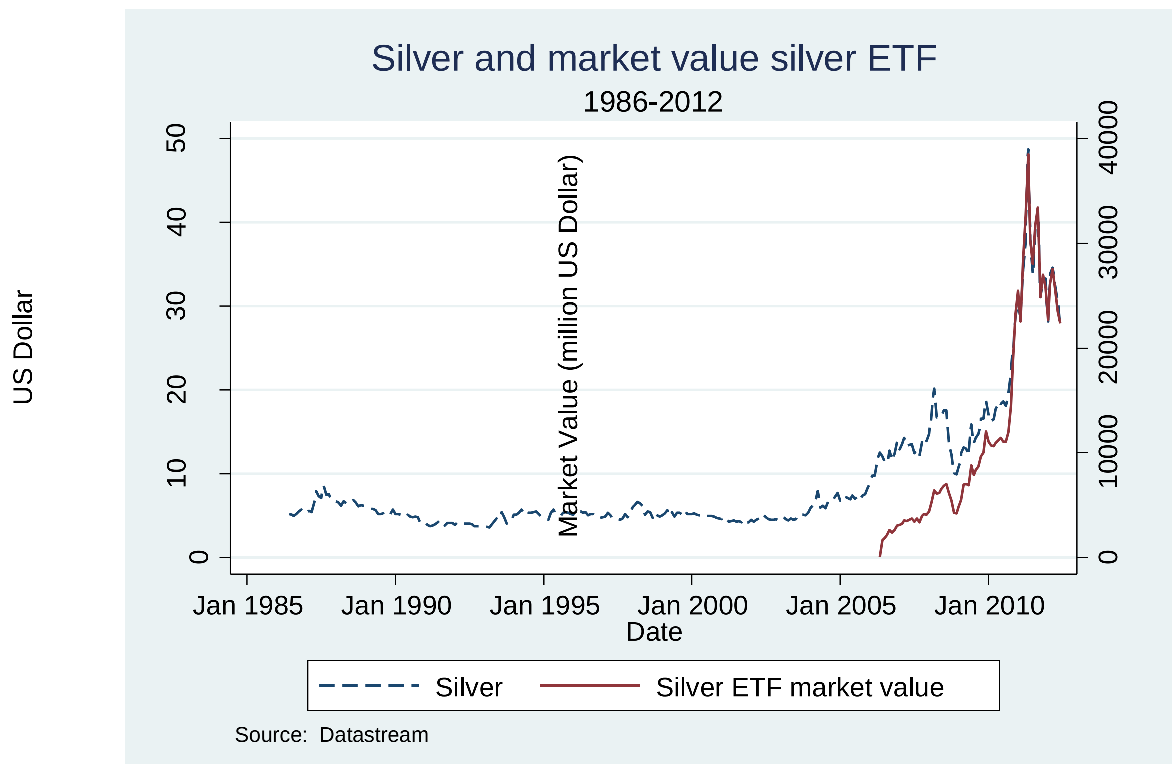
Silver and VXO



Silver and investment



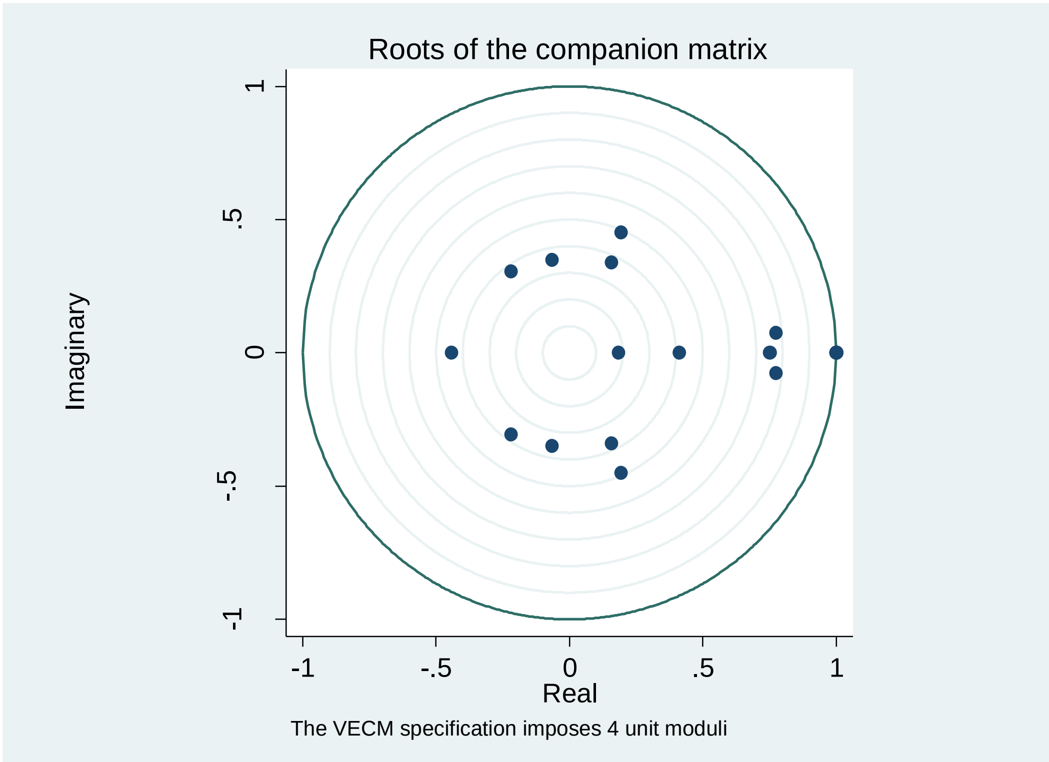

Silver and OI silver short futures
1986-2012
US Dollar
Open Interest
0
10
20
30
40
50
50000
100000
150000
200000
250000
Jan 1985
Jan 1990
Jan 1995
Jan 2000
Jan 2005
Jan 2010
Date
Silver
Silver short futures COMEX
Source: Datastream


Silver and market value silver ETF
1986-2012
US Dollar
Market Value (million US Dollar)
0
10
20
30
40
50
0
10000
20000
30000
40000
Jan 1985
Jan 1990
Jan 1995
Jan 2000
Jan 2005
Jan 2010
Date
Silver
Silver ETF market value
Source: Datastream

Appendix C: Impulse Response Functions VEC model US

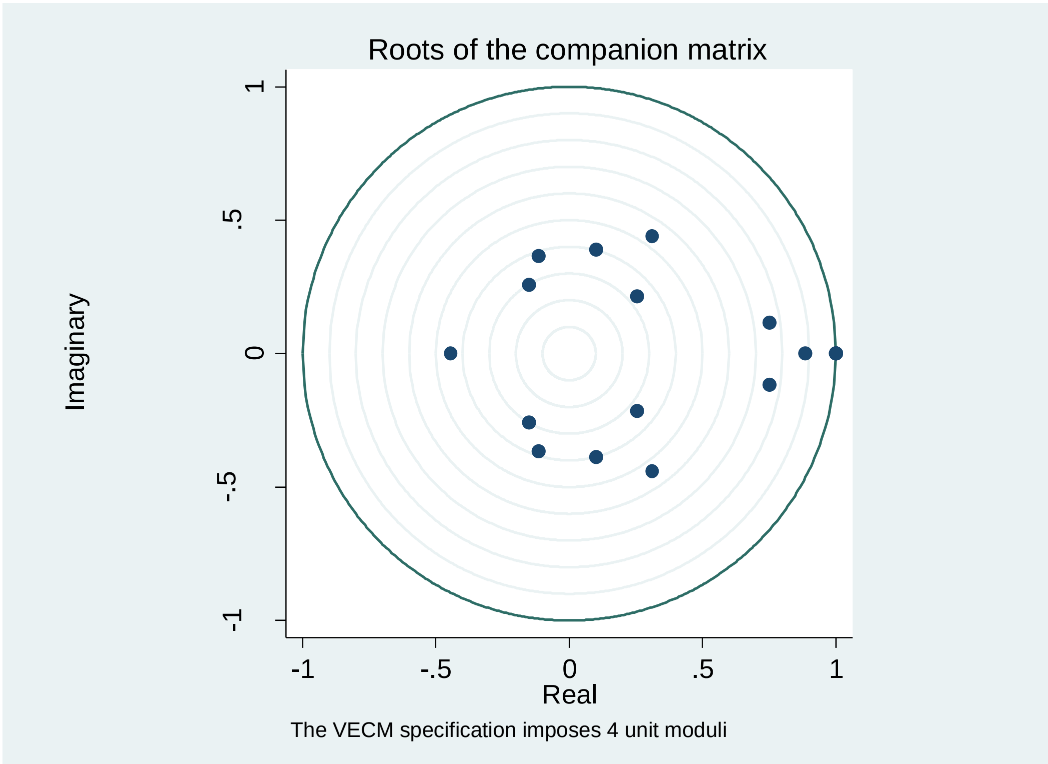
Appendix D: Impulse Response Functions VEC model OECD

Appendix E: Stability US Vector Error Correction model



Eigenvalue		Modulus
1.000		1.000
1.000		1.000
1.000		1.000
1.000		1.000
.7761682 +	.07513896i	.779797
.7761682 -	.07513896i	.779797
.750716		.750716
.1945607 +	.4510436i	.491217
.1945607 -	.4510436i	.491217
-.4402707		.440271
.4127726		.412773
-.2178497	+ .3050059i	.374816
-.2178497	- .3050059i	.374816
.1585469 +	.3394024i	.374608
.1585469 -	.3394024i	.374608
-.06344164	+ .349571i	.355281
-.06344164	- .349571i	.355281
.1859171		.185917

Appendix F: Stability OECD Vector Error Correction model



Eigenvalue		Modulus
1.000		1.000
1.000		1.000
1.000		1.000
1.000		1.000
0.886		0.886
.7503083 +	.1159665i	0.759
-0.750	.1159665i	0.759
.3111634 +	.4393261i	0.538
-0.311	.4393261i	0.538
-0.444		0.444
.1018333 +	.3883615i	0.401
-0.102	.3883615i	0.401
-.1138727 +	.3654765i	0.383
-.1138727 -	.3654765i	0.383
.2555201 +	.2155187i	0.334
-0.256	.2155187i	0.334
-.1510055 +	.2581014i	0.299
-.1510055 -	.2581014i	0.299