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The financial economics of white precious metals — A survey

Vigne, S. A., Lucey, B. M., O'Connor, F. A., & Yarovaya, L. (2017). The financial economics of white precious metals — A survey. *International Review of Financial Analysis*, 52, 292-308.

Published in:
International Review of Financial Analysis

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
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24 month embargo

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The Financial Economics of Silver, Platinum and Palladium - A Survey

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Abstract

This article provides a review of the academic literature on the financial economics of silver, platinum and palladium. The survey covers the findings on a wide variety of topics relation to the White Precious Metals including Market Efficiency, Forecastability, Behavioral Findings, Diversification Benefits, Volatility Drivers, Macroeconomic Determinants, and their relationships with other assets.

Keywords: Silver, Platinum, Palladium, Survey, Review

JEL Code E44; F33; G15; L72; Q31

Contents

	Page
1 Introduction	1
2 Market Efficiency	2
3 Modeling Price Data	7
4 Forecasting	10
5 Behavioural Aspects of White Precious Metals	12
6 Portfolio Diversification	14
7 Volatility and White Precious Metals	21
8 The Macroeconomic Determinants of White Precious Metal Prices	28
9 The White Precious Metals and Other Assets	35
9.1 Gold	35
9.2 Other Assets	39
10 Silver Futures and Forwards	43
11 Exchange Traded Products and White Precious Metals	45
12 Conclusion	47

1. Introduction

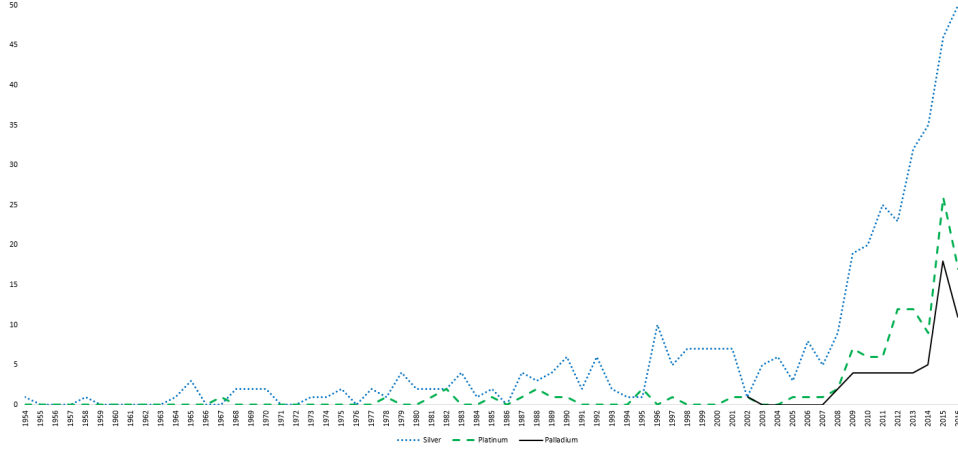
This paper will survey the empirical and theoretical research that has been carried out to date on the the financial and economic aspects of the three white precious metals: Silver, Platinum and Palladium. A previous paper by O'Connor et al. (2015) provides a similar summary for gold and this paper aims to allow researchers to see the breath of research available on the remaining precious metals with ease.

Silver is one of the oldest financial assets with it's historical role as a currency to thank for this. The advantages of using precious metals as currency lied in their rarity, divisibility and lack of corrosion. A few currencies used base metals in history, such as Byzantium which use iron coins, but these proved to be too heavy and too easily rusted to be used as an effective currency Averbury (1903). Platinum and palladium were only added to the list of precious metals more recently. Platinum was originally seen as a nuisance by Spanish gold prospectors when panning for gold in the 16th century and palladium was only discovered in 1802 by scientists who where working on improved methods of refining platinum. While they are used as investment assets their primary source of demand is industrial such as their use in the production of catalytic converters for cars McDonald and Hunt (1982).

Though as investment vehicles the white metals are generally overshadowed by gold, there is still a significant volume of academic literature published on their economic role over the past few years (Figure 1. Interestingly, the increase in academic output on the white precious metals is in line with their increased role as investment vehicles, as it can be seen for silver in Figure 2¹. The introduction of a silver ETF in April 2006 followed by platinum and palladium ETFs in 2010 heightened the attractiveness of white precious metals as investment assets by reducing the cost of investment significantly,

¹Figures obtained from the annual GFMS World Silver Surveys.

Figure 1: Academic Papers on Silver, Platinum and Palladium - Scopus



especially for smaller investors. New York is the more important market for silver, where the turnover is nearly about twice the size than the London market (Figure 3², while platinum and palladium markets are based primarily in Zurich and the importance of London as a market place was growing in recent years Gold Field Mineral Services Ltd. (2015).

2. Market Efficiency

Silver markets have been traded 24 hours a day since at least the 1930's, with London, Bombay, Shanghai, San Francisco and New York all having active markets in 1932. Today's market is not too dissimilar with London, Shanghai, COMEX, the Multi Commodity Exchange of India and TOCOM in Japan being the major silver markets today. this points to a market which should be constantly involved in price discovery and adhere closely to the Efficient Markets Hypothesis, and there are plenty of studies addressing this question.

²Figures obtained from The Silver Institute (2016).

Figure 2: Global Demand for Silver by Type in Mio. Oz

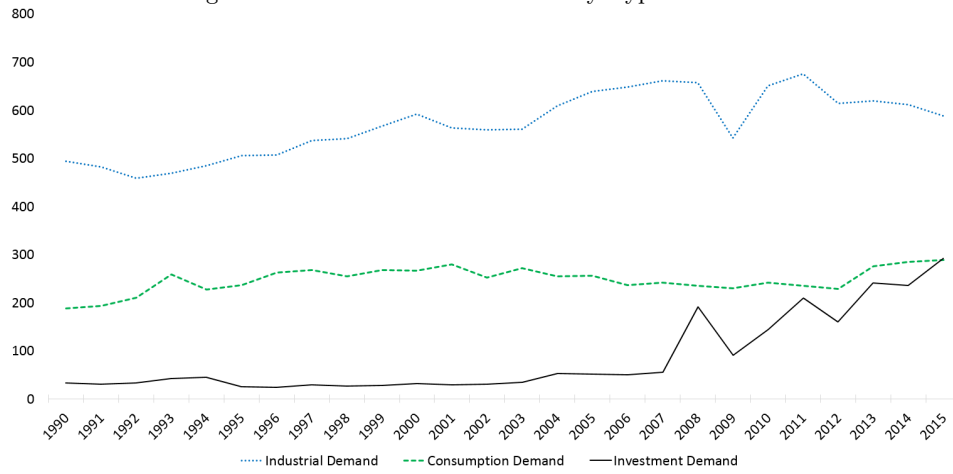
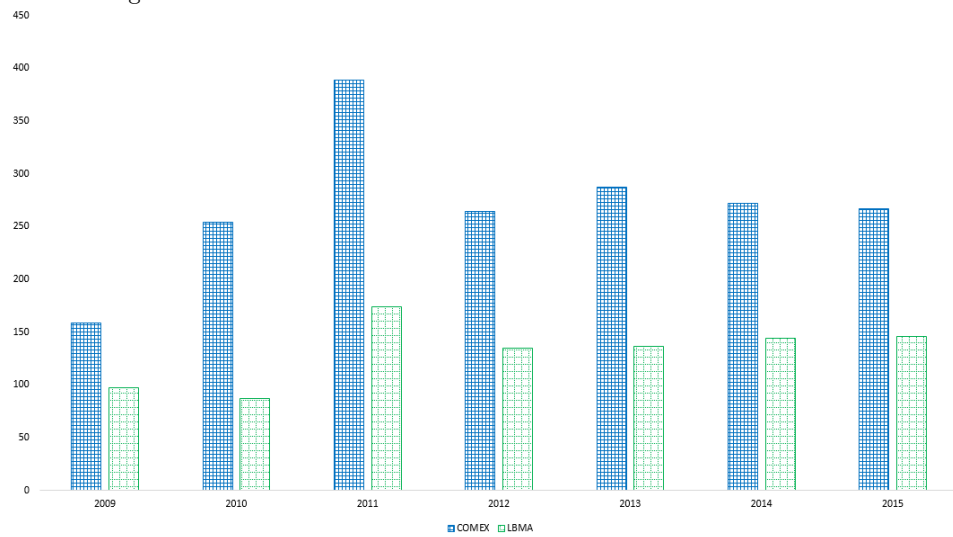


Figure 3: Annual Turnover of the COMEX and the LBMA in Mio. Oz



Solt and Swanson (1981) offers an early analysis on this question for silver up to the 1980's. The author finds strong evidence that silver prices are heteroscedastic, except for the logarithmic price series, where the mean of these price changes are nonzero, not stationary and not merely drifting. Serial dependence is also found but it is not significant enough to be profitably traded. These lead Solt and Swanson (1981) to the belief that silver markets are more speculative than a normal investment market.

Goss (1983) finds further evidence against the EMH in this time period with silver futures markets found not to be unbiased predictors of spot prices. But only very slight serial dependence in silver prices is found again indicating that it may not have been possible to profit from the inefficiencies found. Aggarwal and Sundararaghavan (1987) again test the efficiency of silver futures markets between 1980 and 1984 using a Markov chain model. Results point towards a change in behaviour of silver prices since 1981 due to the Hunt brothers attempt to corner the silver market. Considering the cycles found, traders could have earned excess returns, giving good evidence against weak-form inefficiency in the silver futures market between 1981 and 1983.

Varela (1999) examines the relationship between 15-, 30-, 45-, and 60-day silver futures and their realised cash and delivery settle prices. The period considered ranges from 1971 to 1995. Silver series are found to be stationary in levels, making it impossible to predict cash prices with futures using cointegration and Error Correction Models (ECM). However, a simple regression model indicates that closest to delivery silver futures are a good predictor of the future cash price, showing efficient links between these markets.

Mutafoglu et al. (2012) question whether open futures positions can predict platinum and silver spot prices movements. Using the Commitment of Traders (COT) reports between 1993 and 2009 they use a VAR model with two variables: spot price returns and trader positions. Mutafoglu et al.

(2012) use a generalised structural break test with unknown break points Andrews (1993) to test the stability of model parameters over the entire sample period. If structural breaks are detected the VAR analysis is repeated for each sub-sample period. Results from the entire sample show that white precious metal market returns explain trader's positions and that a major structural break happened in the early 2000's, after which the tendency of trader positions to follow returns became much stronger.

Frank and Stengos (1989) examined possible predictability of silver's rate of return. Results from daily, weekly and biweekly data between the mid 1970's and the mid 1980's for silver point to the possibility of an underlying martingale process, indicating that a nonlinear process generates observed silver returns and price of silver is an unpredictable stochastic variable.

Charles et al. (2015) brings this research up to date looking at daily spot prices for silver and platinum between 1977 and 2013. They test for weak-form efficiency using the automatic Portmanteau test Lobato et al. (2001) for the presence of conditional heteroscedasticity. They find that both markets fit the criterion of the *adaptive market hypothesis* Lo (2004), and that the markets have gradually become more efficient over the time period considered.

Batten et al. (2016) looks into possible silver price manipulation. Using 5 minute tick data between the 1st of January 2010 and the 30th of April 2015 the authors employ a cluster analysis procedure to try and detect price manipulation. Regarding silver, results point towards a large concentration of returns around the derivative expiry date, suggesting possible manipulation. Furthermore, a three component mixture model indicates abnormal market behaviour, which is also supported by a further method clustering the silver returns. However, Batten et al. (2016) warn the author in jumping to conclusions about possible manipulation of the silver market as the evidence provided is merely indicative and not a legal prove for *foul play*.

Gil-Alana et al. (2015b) address the pricing structure of silver, platinum and palladium rely on a fractional integration modelling framework in order to identify structural breaks in the monthly data of the series between January 1972 and December 2012. Results indicate evidence of long memory processes for platinum, in contrary to silver and palladium where strong evidence for mean reversion is obtained. However, taking into account the respective structural breaks identified for the three white precious metals, all series seem to be non-stationary, so that exogenous shocks will affect the long memory behaviour of the series - hence advising policy makers to adopt measures in case white precious metals drift away from their original trend.

In another paper looking at long memory behaviour of the price of silver, Gil-Alana et al. (2015a) uses annual silver prices between 1792 and 2013 and finds that real silver prices are mean reverting; indicating that no long-run memory behaviour exists between silver and inflation rate. This indicates that exogenous shocks will affect real silver prices less intensely than gold prices.

Chatrath et al. (2001b) looks at structure of both gold and silver futures markets using daily prices of between 1975 and 1995. Firstly the authors test for a correlation dimension then build on this correlation integral to test the price series for nonlinearity and deterministic chaos. Finally, a Kolmogorov entropy measures the degree at which the time series movements are predictable. Results reveal that the silver series has nonlinear dependencies, but that these are not consistent with chaos, therefore allowing for a certain degree of predictability.

Fassas (2012) argues that the price increase in precious metals between May 2007 and February 2011 was partly due to the flow of precious metals into Exchange-Traded Products (ETPs). Looking at 28 precious metal ETPs and the weekly spot returns of silver this paper finds a significant correlation between silver returns and the flows into silver Exchange-Traded Products exists. However granger causality tests indicate that there is no

causal relationship between the two, while ETP flows are a driving factor for platinum and palladium prices.

Roberts (2009) looks at longer term returns for silver and platinum using monthly data from 1947 to 2007 and rather than simple randomness cyclical phases in the prices are found to exist. A Bry and Boschan (1971) procedure is used to identify turning points in time series by adjusting for outliers to create a smoothed time series. This indicates that silver prices are not best characterised by a random walk.

Figuerola-Ferretti and McCrorie (2016) base their research on the explosive/multiple bubble technology developed by Phillips et al. (2015) to analyse the effect of the Global Financial Crisis on the price behaviour of gold, silver, platinum and palladium by looking at weekly data between 2000 and 2013. Evidence points towards short periods of mildly explosive behaviour in the prices of all precious metals, furthermore, while the Global Financial Crisis led the gold price to deviate from fundamentals, it seems that silver and palladium were rather affected by the launch of ETFs rather than the financial crisis as such.

Working with 12,187 daily observations of the price of silver between January 1968 and March 2016, alongside 6,561 daily observations of the prices of platinum and palladium between April 1990 and March 2016, Al-mudhaf and AlKulaib (2016) underline the importance of outliers for white precious metal prices by identifying that a traditional buy-and-hold strategy outperforms an attempted market timing strategy. Indeed, Al-mudhaf and AlKulaib (2016) show that large price increases of precious metals tend to be pooled around single days and that missing these individual days would come at high cost for an investor, who should rather follow a more long-term classical investment strategy.

3. Modeling Price Data

Nadarajah et al. (2015) test which GARCH specification performs better

when modeling the returns of different commodities, including silver. Using daily price returns from the March 1993 to March 2013, finding that the best fitting model for silver price returns is the Skewed Exponential Power (SEP) distribution, in line with Cheng and Hung (2011).

Another approach is to use an asymmetric GARCH (AGARCH) model Cochran et al. (2016) with a conditional skewed generalised t (SGT) distribution. Similar to Demiralay and Ulusoy (2014) the authors study the performance of VaR measures obtained from this model to results from an AGARCH model with a normal and student t distribution. For silver, an AGARCH model with the SGT distribution offers the best fit. Further findings point towards time-variation in the skewness for silver, as well as in the peakedness and tail thickness parameters of silver returns. Results from a Wald test Engle (1984) implies that higher order moments of silver returns, like skewness and kurtosis, are time-varying. An important difference between this paper, and Demiralay and Ulusoy (2014) and Nadarajah et al. (2015), is the much shorter period of time used by Cochran et al. (2016): daily spot returns of silver from 1999 to 2010.

Demiralay and Ulusoy (2014) addresses how best to model value-at-risk (VaR) for silver, platinum and palladium. Working with daily data January 1993 and 2013, the author fits the data into three different non-linear long memory volatility models (FIGARCH, FIAPARCH, HYGARCH) and finds that for all three white metals, a Fractionally Integrated Asymmetric Power ARCH (FIAPARCH) model is best suited to capture their long memory, asymmetry and fat tails, outperforming the other models in predicting one-day-ahead VaR positions.

Degiannakis and Potamia (2016) base their research on the recommendations of the Basel Committee on Banking Supervision and examine whether inter-day or intra-day model provide accurate predictions for reliable Value-at-Risk (VaR) and Expected Shortfall (ES) forecasts. Daily data for silver between the 3rd of January 2000 and the 5th of August 2015, indicates that a

GARCH-skT model, relying on inter-day data, provides better results than a HAR-RV-skT model, as it satisfies most of the conditions implied in VaR and ES forecasting, but that it overall fails to provide accurate forecasts of the risk measures implied.

Recently, Zhang and Zhang (2016) examined the Value-at-Risk (VaR) and statistical properties in the daily price returns of gold, silver, platinum and palladium between the 11th of January 2000 and September 2016. A complex two stage methodology relying on different GARCH models reveal that gold has the highest and most steady VaR values of the group while palladium has the most volatile and lowest VaR values of all four precious metals. Further results indicate that the VaR values of silver are more volatile than those of platinum, while the residuals of both metals are characterised by heavy-tail distributions. Auer (2015) also found that there was significant evidence of time-variation for both the skewness and the kurtosis of white precious metal returns.

Caporin et al. (2015) focuses on the behaviour of silver, platinum and palladium spot prices return, volatility and liquidity. A first major contribution to the field is the data used in the paper: trading quotes issued by the Electronic Brokerage Services (EBS) and provided by ICAP plc. The time frame observed ranges from December 2008 to November 2010, where 100,962,954 quotes were observed for silver, amounting to 27,638 trades and a volume of 1,173,425,000 oz of silver traded. Results from modeling the returns and volatility of the time series indicate the presence of a stochastic periodic behaviour and the possible presence of long-range dependence in the volume time series. In response to these features, Caporin et al. (2015) work with a multi-factor Generalised Autoregressive Moving Average (GARMA) model as proposed by Woodward et al. (1998) which allows for long-memory behaviour associated with specific periodic frequencies. The silver volume GARMA modeling approach of Caporin et al. (2015) can be used to forecast both volume levels and volume density if upgraded with a GARCH or

EGARCH equation. The authors conclude their work by saying that white precious metals have features comparable to those of more traditional assets and that market liquidity of silver, platinum and palladium is characterized by intra-day seasonalities and very strong commonality. More specifically, platinum is found to be the least liquid and least volatile metal of the precious metals considered. Morales and Andreosso-O’Callaghan (2011), using data between 1995 and 2010, found that the standard deviation of daily silver returns is more than twice the standard deviation of gold and if the precious metals only palladium has a higher standard deviation than silver.

4. Forecasting

A large number of papers have addressed the question of whether it is possible to forecast future prices of the white precious metals. An early study by Lashgari (1992) uses daily, weekly and monthly silver prices running from 1970 to 1989 in order to obtain optimal silver price forecasts using an exponential smoothing time series model. Using daily silver prices offers better results than weekly or monthly prices, but no trading profits could be realized.

Escribano and Granger (1998) use a battery of testing procedures, finding that non-linear forecasting models for silver perform better than random walk processes; however, this is only the case for in-sample analyses, as the predictive power vanishes for the out-of-sample period. Considering the futures market of precious metals, Narayan et al. (2013) look at whether daily futures prices of gold, silver, platinum and oil predict the spot prices of their respective market. The window considered is the longest for gold and silver, ranging from 1980 to 2011, while it is somewhat shorter for platinum, starting in 1983. Results of linear and non-linear models show that futures returns only predict spot returns in the case of silver but not in the case of platinum, leading to a potential of profit realisation in the case of silver, but not in the case of platinum. However, time-variation results indicate that

the profit potential was lowest during the Global Financial Crisis.

Urquhart (2016) analyses return predictability for gold, silver and platinum by fitting daily data between the 5th of January 1987 and the 30th of September 2014 into a battery of tests. Results indicate time-variation in the predictability potential of silver and platinum returns, where a joint-rank test indicates that silver returns could only have been predicted with confidence until April 1999, while the time frame is longer for platinum prices, which could have been predicted until March 2001. However, results are inconclusive when considering different testing procedures, leading Urquhart (2016) to work with a rolling window approach highlighting the best prediction potential for platinum and the worst prediction potential for silver.

Pierdzioch et al. (2016a) discuss the statistical and economic performance of different forecasting models in regard to the choice of the Information Criteria selected to determine the boosting algorithm. Using monthly data from January 1987 to September 2014 and using a large set of predictors to forecast the excess return of silver to 1-month LIBOR. The authors develop a trading algorithm in which an investor should buy silver if the forecasted excess return is above the historical real-time mean of excess returns. In such a scenario, the trading rule performs better under the Akaike Information Criterion (AIC) than under the Minimum Descriptive Length (MDL) proposed by Bühlmann and Hothorn (2007). Even though the forecasting model for silver performs well, Pierdzioch et al. (2016a) warn the readers that the outlined model might not survive an economic performance evaluation.

Fritsche et al. (2013) consider silver price forecasts obtained from Consensus Economics Inc. for different forecast horizons between 1995 and 2012 and rely on the market-timing approach proposed by Pesaran and Timmermann (1992, 1994) in order to test for the accuracy of silver price forecasts. Results for silver are different than those obtained for gold; indeed, it is

proven that silver price survey forecasts contain information on the subsequent price changes, in contrast to gold where forecasts are not accurate in predicting future price movements.

5. Behavioural Aspects of White Precious Metals

Yang and Brorsen (1993) focuses on futures prices arguing that past models have failed to successfully explain non-normality and dependence in speculative price changes. The authors apply a GARCH model and deterministic chaos processes to daily closing futures prices of silver, platinum and palladium between January 1979 and December 1988 in order to detect market anomalies. Building upon a GARCH model that generates data with fatter tails, their methodology (proposed by Yang and Brorsen (1993) captures day-of-the-week effects, seasonality in variance and maturity effects Milonas (1986) of silver futures prices. The GARCH model is augmented with a Residual Test in order to limit forecasting errors Brock et al. (1996). Test results indicate a strong calendar-day effect for silver since the variance of silver futures prices is larger on certain days of the week and after holidays. Concerning platinum and palladium, a calendar-day effect on the variance is observed on Tuesday and after holidays; Monday is only found to be significant for palladium. Further results point towards seasonality in the variance.

Lucey and Tully (2006a) study seasonality in daily COMEX silver cash and futures contracts between 1982 and 2002 by testing the unconditional and conditional means and variances of silver cash and futures prices. They tests for seasonality in the unconditional variance Levene (1960) while controlling for heteroscedasticity and autocorrelation White (1980) and . Results from an LGARCH model point to an increased variance on Mondays for silver cash prices in line with Yang and Brorsen (1993), and a lower variance on Wednesdays for futures. Lucey and Tully (2006a) then augment the GARCH framework by including day-of-the-week dummy variables in

both the mean and the variance and find that the seasonality in silver price returns is not due to daily variation in risk. Naylor et al. (2014) and Baur (2013) find a monthly February effect in both silver prices and silver ETFs.

Auer (2015) finds no Friday the 13th effect for silver returns. The author builds upon the findings of Kolb and Rodriguez (1987) and works with a dummy-augmented GARCH model to understand the impact that certain days have on the conditional means of silver returns. The methodology used is slightly different from Lucey and Tully (2006a) and relies upon a GARCH model with time-varying Skewness and Kurtosis (GARCHSK) Auer (2015) adds lagged returns to the mean equation in order to capture potential serial correlation and by adding two dummy variables in the mean equation according to calendar-days of interest.

Lucey (2010) finds evidence for the existence of a lunar cycle on precious metal returns. Considering daily fixing prices for silver traded in London between January 1998 and September 2007 against lunar phases, Lucey (2010) applies a battery of classical descriptive and analytic tests and finds that returns around the full moon tend to be negative in contrast to positive returns around the new moon. The existence of lunar seasonality for silver is in line with previous findings from Dichev and Janes (2003) and Yuan et al. (2006) who did similar work on stock market returns. On the other hand, the evidence for a lunar cycle on the return of platinum prices is very weak.

Recently, Lucey and O'Connor (2016) identified whether or not investors in the gold and silver markets are affected by psychological barriers in regard to prices ending in 0 and in 00. Intraday silver prices between the 2nd of March 1975 and the 30st of April 2015 are taken into account and tested for the uniformity of their distribution. While evidence is found for the existence of psychological barriers in the price of gold, no such evidence is observed for silver, whose price seems unaffected by the format.

Working with the exact same data set as Fritsche et al. (2013) mentioned

above Pierdzioch et al. (2013) model the behaviour of the authors of gold and silver price forecasts and find evidence for irrational behaviour on both markets. More specifically, results based on the asymmetric loss function proposed by Elliott et al. (2005) to test for the rationality of forecasts, indicate a herding behaviour of some forecasters, while others tend to issue more *extreme* forecasts in order to differentiate themselves from others. The authors suggest that this change in behaviour tends to occur depending on the customers of silver price forecasts, resulting in biased forecasts in order to assure a loyalty of the main group of customers.

6. Portfolio Diversification

The diversification benefits of holding gold in a portfolio of assets is well documented, see O'Connor et al. (2015) for a review. As the white metals are also classed as precious it would then seem to follow that they would be useful in portfolio construction. However all three are heavily used as industrial metals, in contrast to gold which should have little or no correlation with general economic activity as it is overwhelmingly used for investment. Jaffe (1989) is one of the first papers to address the issue empirically for silver using data from 1971 to 1987. Silver was found to have a high correlation with gold (0.744) and with Toronto Stock Exchange (TSE) gold stocks (0.589). However with common stocks a very low correlation of 0.134 showing its usefulness in a diversified portfolio.

Looking again at risk premium in the silver futures market, Kocagil and Topyan (1997) analyse the possible relationship between the risk premium, futures trading and the S&P 500. A theoretical model is used to illustrate the equilibrium relationship between cash and futures prices and fitted with daily data between 1990 and 1994. Evidence uncovers a positive relationship between risk premium and daily futures trading and to a negative relationship with the S&P 500, pointing towards silver's role as an portfolio hedge.

McCown and Zimmerman (2007) looks into the investment performance

of the metal by using multiple asset pricing models. The data used is the monthly spot price of silver and the US CPI between over a 36 year period to 2006. When looking at investment performance, they estimate the Capital Asset Pricing Model (CAPM) for silver. using 3 three different proxies for the market portfolio: the MSCI World Index, the MSCI World Index denominated in US Dollars and the MSCI World Index denominated in local currencies. The results for silver are independent of the index used as market portfolio proxy; small Betas (around 0.33) are recorded for a period of up to six months and they become negative after one year. The findings suggest that silver is a less volatile investment than the market in the short-run, and that it moves in opposite direction than the market on the long-run - arguments in support of silver's ability to be used as a hedging tool against stock markets.

Erb and Harvey (2006) uses data between December 1982 and May 2004 and shows that silver has very low correlation with other major commodities, except gold (0.66) and has had constant negative excess, spot, and roll returns. To assess silvers hedging ability against sovereign debt they apply a liability hedging technique proposed by Sharpe and Tint (1990). Silver is show to act as a hedge for Treasury Inflation Protected Securities (TIPS) and 10 Year Treasury Bonds between 1997 and 2004, but not for long term US debt between 1982 and 2004.

Investing in Miners is seen as an alternative and cheap route to get exposure to precious metals ina portfolio. Conover et al. (2009) uses daily returns for silver and platinum between the 1973 and 2006, as well as the equity performance of precious metal miners. An investment into the equity of precious metal miners proves to be much more efficient than a direct commodity investment; a 25% miner allocation in a portfolio of US equities leads to an increase in returns and a decrease in portfolio standard deviation. In addition gold is found to be a superior investment relative white precious metals, results in line with Hillier et al. (2006). Also, the investment benefits

held by precious metals varied over time and grew during the later years of the sample. Adding silver to a portfolio is found to be of greater benefit when the Fed policy is restrictive rather than expansive, findings somewhat in line with Conover et al. (2008) who advised investors to use monetary conditions as a guideline for portfolio allocation; however, Conover et al. (2009) points out the impossibility of knowing that return patterns are caused by monetary policies or some other variable.

Using monthly data from 1995 and 2010 Belousova and Dorfleitner (2012) look at the impact of adding silver to a diversified portfolio of stocks, sovereign bond and the money market instruments during bull and bear markets. Adding silver or platinum to a portfolio during bull markets reduces volatility and enhances return. During bear markets silver only reduces portfolio risk, in line with Hillier et al. (2006), but platinum loses its diversifying ability.

Bruno and Chincarini (2010) generating optimal mean-variance portfolios for more than 15 different countries between 1930 and 2009 but the only national portfolios explicitly advised to have holdings in silver were the cases of Germany, Mexico and the United States of America between 1970 and 2009. For both Germany and the US., an optimal allocation of 0.01% to silver is advised which is much lower than for gold, whereas Mexico stands out with a much higher proportion of 1.98% of silver.

Hammoudeh et al. (2013) focuses on the daily downside risk associated with gold, silver, platinum, palladium, oil and the S&P 500 Index between 1995 and 2011 within a VaR framework, a period of primarily rising precious metals prices. The VaR metrics are computed at the 99% confidence level and two Asymmetric Power Autoregressive Conditional Heteroscedasticity (APARCH) models are used to forecast results, where one follows a normal student- t distribution and the second a skewed- t distribution. Hammoudeh et al. (2013) constructs three optimal portfolios: (1) consisting only of the four precious metals, (2) consisting of all six assets under study, and (3)

consisting of gold, oil and the S&P 500. Portfolio 1 has the highest annual return, around 9%, but also a higher standard deviation than 2, containing the greatest amount of different assets, which scored an average yearly return of 8.625%. Looking at portfolio efficiency, the authors conclude that an optimal portfolio should hold a higher proportion of gold than any other asset (even though silver was the best performing asset over the time frame observed), and that overall, the pure precious metal portfolio proved to be the least efficient.

Hillier et al. (2006) looked at silver returns in the Zurich market and the London platinum price against the S&P 500, the MSCI Europe, the MSCI Australia and the MSCI Far East Index between January 1976 and 2004 and apply a GARCH(1,1) model. During this period silver had about twice the standard deviation of the S&P 500, while platinum gave the highest mean daily returns. Subsample analyses indicate a constant very small correlation with the S&P 500 of an order between -0.05 and 0.05. Looking into the diversifying properties of an investment in white precious metals, the persistent negative elasticity of silver and platinum indicates that it was a valuable diversifying asset against an S&P 500 portfolio but not so in regard to the MSCI indices. Focusing on periods of high volatility and poor returns of stock markets, silver's hedging abilities were found to be stronger than those of platinum. However, when looking at what metals to optimally hold in a portfolio, silver did not perform as well as both gold and platinum which scored higher returns over the period.

Li and Lucey (2017) looks at the safe haven characteristics of the white metals and gold across 11 countries from 1994 to 2016. All the precious metals are found to be safe havens at different times during the sample and silver is found to out perform even gold in relation to US equities with platinum second best. But no precious metal is consistently a safe haven. The paper goes on to examine if there are determinants that can explain when a metal will act as a haven. Economic policy uncertainty is the only

variable found to consistently determine whether a metal acts as a safe haven across markets.

Sarafrazi et al. (2014) focus on daily downside risk of euro-zone national equity and sovereign bond markets by classifying the countries in two distinct groups: the *PIIGS* (Portugal, Italy, Ireland, Greece and Spain) and the *Core* (Germany, France, Austria, The Netherlands and Finland). The period observed ranges from March 1999 to November 2012. Using the Sharpe ratio the optimal portfolio over the full period is composed of a surprisingly large share of commodities with 13% gold, 11% copper, 11% oil, 9% silver and 7% platinum. When looking the subperiod between July 2007 and November 2012, results show that from all the commodities observed, only gold and silver prove to contribute to diversification benefits to stock and bond portfolios by increasing the sharpe ratio.

Agyei-Ampomah et al. (2014) used data from 1993 to 2012 silver returns were on average negatively correlated with bond returns; the hedging ability is particularly strong for Austria, Belgian, German, Italian, Portuguese and UK bonds. Platinum's hedging ability is even stronger while palladium's is much weaker. In sub period analysis silver was only an effective bond hedge between 1993 and 2000, platinum was effective over that time as well as 2007 to 2012.

Chang et al. (1990) tests the theory of normal backwardation by applying the CAPM model to investigate whether silver futures between January 1964 and December 1983 carried systematic risk and if this risk was rewarded. The Dow Jones Cash Commodity Index is used as a proxy for the market portfolio and the risk-free rate used is the end-of-period return on one-month Treasury-bills. Results show that investing in silver futures yielded higher returns than investing in futures contracts of other metals, but was also linked to higher volatility. Furthermore, silver outperformed the stock market over the period observed and has a β close to 1 (later supported by Cochran et al. (2012), on the other hand, the β of platinum was of 0.848

for the same period. Chang et al. (1990) conclude by finding that based on standard deviations of returns, silver and platinum futures are riskier than common stocks but earn less return per risk unit than equity - therefore strongly challenging the attractiveness of white precious metals futures as an investment asset.

In a recent paper, Mensi et al. (2015) look at the linkages between silver and other commodities and develop implications for Saudi-Arabian investors derived from daily data between 2005 and 2013. They allow for asymmetric volatility responses to both positive and negative shocks, and long memory in the volatility dependence. Results from initial tests point towards a negative linear correlation between silver and Saudi Arabian stock returns - a finding overturned using a DCC-FIAPARCH model which showed evidence for time-varying conditional correlations between both series, disproving the capacity of silver to be used as a hedge or a safe haven against the Tadawul.

More recently, Reboredo and Uddin (2016) work with a quantile regression approach and analyse the impact of financial stress and policy uncertainty on weekly gold, silver platinum and palladium futures prices between 1994 and 2015. Results find no Granger causality between the prices of commodity futures and financial uncertainty, but that financial stress has a positive effect on gold and silver prices, in contrary to platinum and palladium.

Whether the four main precious metals acted as a safe haven against the S&P 500 and US 10 year bonds between January 1989 and July 2013 is addressed by Lucey and Li (2015). The methodology is upgraded with the approach of Ciner et al. (2013) to identify time-variation in the safe-haven property of silver, platinum and palladium and graphically depict it. Results for silver have interesting implications for investors; concerning equity, silver was only a safe haven during the last quarter of 2009 and the first quarter of 2010, the performance of gold, platinum and palladium was much better and it had safe haven properties during more quarters -

concerning bonds though, silver was a safe haven at times during which gold failed to be, but also during far more quarters than both platinum and palladium. Empirically however, gold should be considered the better safe haven investment for it acts as one more often than white precious metals.

Bredin et al. (2017) continue the investigation into the equity hedging abilities of silver and platinum by considering daily, weekly and monthly price returns between 1980 and 2014. The hedging potential is identified via a Value-at-Risk (VaR) procedure detecting the level of tail- and downside risk associated with silver and platinum investments, and measures the respective cost or benefit of such investments by considering risk-adjusted returns against an S&P 500 portfolio. Results indicate the superiority of gold to act as a hedge, while the equity risk reduction potential of silver and platinum only seems to be strong on a short time horizon but not on long time horizons.

Pierdzioch et al. (2016b) consider the ability of daily gold, silver, platinum and palladium prices between 1999 and 2015 to act as a hedge against exchange rate movements from the US Dollar, the Yen, the Canadian Dollar, the Euro, the Pound Sterling and the Australian Dollar. Results indicate that silver is the overall better exchange rate hedge than platinum and palladium. Silver is found to be an asymmetric hedge against exchange rates: it is a weak hedge in times of US Dollar appreciation, but a strong hedge, even a safe haven, during times of US Dollar depreciation. Platinum and palladium are not very effective currency hedgers except for their pronounced ability to hedge depreciation of the US Dollar against the Canadian and the Australian Dollar. An earlier study by Jaffe (1989) found that correlation coefficient is that between silver and the German Mark/US Dollar exchange rate was -0.252, the lowest of the assets addressed.

7. Volatility and White Precious Metals

The relatively high volatility of precious metals prices is other other side of their ability to diversify portfolio risk and act as safe havens. Silvers history includes the Hunt brothers cornering of the market in 1981 and the resultant crash in prices (the role of the Hunt family on the silver market can be found in Fay (1982) among others). Here we will look at the economic drivers of the white metals volatility.

Barnhill and Powell (1981) address which determinants caused the unusually high volatility of the silver price between July 1979 and April 1980 by looking into the demand and supply for silver, as well as into the relationship between the price of silver and macroeconomic indicators. This points towards multiple explanations for the sharp increase of the silver price in late 1979. First was a considerable shortfall of silver production relative to the commercial demand for silver, leading to the belief that silver was undervalued. Secondly the large acquisition of silver by the Hunts. Also rising investment demand for silver due to unattractive real returns offered by conventional investments and political actions undertaken by the government of India and the United States of America restricting both access and reallocation of a large portion of above-ground silver stocks was also highlighted. The collapse of the silver price in early 1980 is explained by a fall in industrial U.S. commercial demand by 40%, accompanied by a slow-down of cash silver acquisition by the Hunt family. On the supply side, an increase of 200% in scrap supply as well as an increase of 80% in recycled silver resulted from the unusually high prices. Finally, a growing attractiveness of alternative investments mixed with a negative investor sentiment against silver led to a very heavy drop of the price in late March 1980.

Hammoudeh and Yuan (2008) finds that Silver's volatility, between 1990 and 2004, is more persistent than the volatility of industrial metals such as copper. Silver is found to have a low sensitivity to bad news in the short run, giving it safe haven like qualities. Increases in interest rates reduce silver

price volatility. Oil price shocks have the effect of cooling precious metals volatility, making them good diversifiers in a commodity portfolio. Nowman and Wang (2001) look at the monthly price of silver between February 1970 and May 1997 with nine models designed to analyse the volatility of silver. Results show that price volatility depends strongly on the price level of silver itself, possibly driven by the 1981 peak in the silver price.

Using annual prices between 1900 and 2007 obtained from the US Geological Survey (USGS) Chen (2010) looks at precious metals in order to gain a longer run view of the price volatility of precious vs. industrial metals. The results indicate much higher volatility figures for industrial metals. Looking at within- and between-group volatility shows that volatility transmission is higher within the metal groups than between the metal groups; in other words. In a final step, Chen (2010) applies a single factor asset pricing model and finds that the importance of global macroeconomic factors in explaining silver and platinum price volatility has increased over the time period observed. Between 1900 and 1971 over 90% of the price volatility of silver can be attributed to commodity-specific risk against under 10% to be attributed to global macroeconomic risk factors; between 1972 and 2007, these numbers shifted and the global macroeconomic risk share is above 36% against nearly 62% for commodity-specific risk factors. A similar picture is observed for platinum, where the share of commodity-specific risk between 1900 and 1971 is of more than 93% against around 87% between 1972 and 2007.

Using a GARCH (1,1,) model Vivian and Wohar (2012) finds further evidence of high volatility persistence of the silver, platinum and palladium prices. Focusing on interactions between precious metals, Morales and Andreosso-O’Callaghan (2011) investigate the nature of volatility spillovers amongst daily precious metal returns between 1995 to 2010 using GARCH and an EGARCH models. Over the entire period volatility runs from gold to silver but not the other way around. Morales and Andreosso-O’Callaghan

(2014) examine volatility persistence between precious metal returns and equity indexes up until the global financial crisis of 2008 by looking at daily silver and platinum returns from 1995. GARCH and EGARCH results point toward an insignificant relationship between the white metals and the Dow Jones index, but to a significant positive relationship with both the FTSE100 and the Nikkei225. A significant positive relationship between the volatility of silver and Brent crude oil is also found.

Sari et al. (2010) look at volatility transmission between the four precious metals from 1999 and the 19th of October 2007. Impulse response functions show that over the long run gold accounts for 16% of silver's variance; in line with Lucey and Tully (2006b). Interestingly silver is found to explain 23% of gold price volatility. In the short-run, unexpected shocks to gold, platinum and palladium prices have a positive and significant impact on the price of silver and vice versa. Silver explains about 10% of the variations of both platinum and palladium prices, while platinum and palladium explain about 22% of their respective price fluctuations.

Using a longer sample from 1987 to 2012 Balcilar et al. (2015) dispute Sari et al. (2010). Using a Bayesian Markov-Switching Vector Error Correction Results it is shown that during high volatility regimes, the impact of change of the gold price on silver is about 1.25%; against an impact of about 0.07% from silver on gold. The impact of change of the gold price on both platinum and palladium is of about 0.8%, while the impact of change of silver prices is practically non-existent for both platinum and palladium prices.

Looking at weekly closing spot prices between 1990 and 2006, Choi and Hammoudeh (2010) assess issues of volatility and correlation in relation to financial and geopolitical crises. They distinguish between high- and low-variance regimes using a Markov-switching model. Low volatility regimes for silver last about 50 weeks against about 25 weeks for high volatility regimes. Though silver is generally highly volatile around the same periods as gold,

in the early 2000's silver volatility was significantly lower. Using a DCC multivariate GARCH model show that gold and silver's correlation is fairly high and remains pretty constant through time.

Arouri et al. (2012) analyse the returns and volatility of gold, silver, platinum and palladium in order to investigate both long memory properties and the potential of structural changes of the price series between 1999 and 2011 using squared daily returns as a measure of volatility. Results from an ARFIMA-FIGARCH model finds no long memory evidence for spot silver prices. They find only three structural breaks for silver spot and futures prices; these breaks found are not in line with Vivian and Wohar (2012), but the spot price breaks in 2001 and 2004 are observed by Morales and Andreosso-O'Callaghan (2014). Platinum futures returns are found to exhibit the highest long memory property in the variance equation, suggesting that platinum might not be able to function as a good hedging instrument; long memory patterns are also observed for palladium futures prices.

Cochran et al. (2012) also work with a FIGARCH model to examine the return and long memory properties of daily return volatility for copper, gold, platinum and silver between 1999 and 2009. The silver return series is modeled as a multi-index CAPM proposed by Chang et al. (1990). Results point towards a negative effect of interest rates movement on silver but not on platinum (results in line with Jaffe (1989) and Hammoudeh and Yuan (2008) and a negative relationship between exchange rates and both silver and platinum returns, proving that the law of one price holds for silver. FIGARCH results show evidence of long memory characteristics for the two white precious metals, while the metals return volatility share a positive relation with changes in the VIX. Dummy variables indicate an increase in volatility of the prices of the three precious metals since the Global Financial Crisis. Using daily data over a much shorter period (2009-2014) Bunnag (2015) examine the same issue. Results point towards a short run persistence of shocks on the dynamic conditional correlation for gold

with silver, and towards an important long run persistence of shocks on the dynamic conditional correlation for palladium with silver.

Sensoy (2013) contrasts the findings of Cochran et al. (2012) and finds that the Global Financial Crisis of 2008 has no effect on volatility levels of silver, but indeed caused an upwards shift in the volatility levels of platinum and palladium. The data taken into account are the daily gold, silver, platinum and palladium spot prices between 1999 and 2013 filtered through an ARMA(p,q) process. The results show that while 2008 had no effect on volatility levels of silver, but silver is found to have a volatility shift contagion effect on platinum and palladium. On the other hand, it is found that platinum and palladium have no volatility shift contagion effect on one another. Sensoy (2013) argues that platinum and palladium were historically not considered a store of value, creating an insensitivity in the correlation dynamics these two more industrial metals and silver.

Papadamou and Markopoulos (2014) look at volatility transmission between currency exchange rates and gold and silver prices using hourly data between January 2010 and March 2012. A BEKK-GARCH model points towards volatility transmission from gold, the EUR/USD exchange rate and the GBP/USD exchange rate to silver but note vice versa.

Antonakakis and Kizys (2015) looks at volatility spillovers using weekly data between 1987 and 2014 and using a generalised VAR framework and a Forecast Error Variance Decomposition (FEVD). On average silver returns contributes 52.78% of the FEVD to the other variables and receives an average of 50.90% from other variables. Platinum contributes 52.39% to the FEVD of other variables and receives an average of 49.61%. In contrast to the two, palladium is found to be a net receiver of return spillovers. A similar picture is observed for volatility, where silver and platinum are net transmitters, while palladium is a net receiver of volatility spillovers. Even though the Global Financial crisis of 2008 weakened the role of silver returns as a net transmitter of shocks, it strengthened the role of platinum as a net

transmitter of return shocks.

Using monthly futures closing prices for gold, silver, platinum and palladium traded on the New York Mercantile Exchange between 1984 and 2012 some of Batten et al. (2015)'s results contrast with Antonakakis and Kizys (2015). Silver is found to be a net transmitter of return spillovers, contributing 52% to gold returns, while platinum and palladium receive 49%. But here silver proves to be a net receiver of volatility spillovers, it contributes only 29% to the volatility of the other three metals and receives 31%. A time-varying approach shows that the Global Financial Crisis of 2008 increased the importance of silver as a net recipient of spillovers - somewhat in line with Antonakakis and Kizys (2015) who observe a weakening transmission of shocks for silver during that time. Conflicting results to those of Antonakakis and Kizys (2015) are also observed for platinum, which is neither a net transmitter nor a net receiver of return spillovers, but is a net receiver of volatility spillovers. Palladium is net receiver of both.

Kang et al. (2017) examine volatility spillover effects on six commodity futures, including silver. Results obtained from weekly silver futures prices between 2002 and 2016 indicate that equicorrelation between commodity futures increased during the recent Global Financial Crisis, and remained high during periods of economic and financial turmoil. Again silver was a net information transmitter to other commodity futures markets.

Bosch and Pradkhan (2015) take a different approach to volatility and examines if the position of speculators can be used to predict returns and return volatility of precious metal futures. The authors work with futures contracts traded on the COMEX between the 13th of June 2006 and the 31st of December 2013 and use a Brunetti and Buyuksahin (2009) rolling procedure to create a continuous series. The data of trading positions is obtained from Disaggregated Commitments of Traders (DCOT) and COT reports, similar to Mutafoğlu et al. (2012) who also work with Commitments of Traders reports. The relationship between the variables is detected

through a Johansen (1991, 1995) and an Engle and Granger (1987) test followed by a Vector Error Correction Model (VECM) and a VAR Model to detect short-term impacts. Results point towards a herding behaviour of traders on the silver market between October 2007 and December 2013 and on the platinum and palladium market between the entire estimation period from June 2006 to December 2013. Furthermore, evidence point towards a trend-following behaviour of non-commercial traders, a finding in line with Mutafoğlu et al. (2012).

Sarwar (2016) identifies the interaction between the VIX, and the volatility on US Treasury notes, gold and silver markets. Implied futures market volatility examined using data from August 2007 to March 2009 is chosen to reflect the equity market crisis period. Results indicate a Granger relationship between increases in stock market volatility and increases in silver prices, implying that the impulse for investors to rebalance their portfolio towards silver begins with increases in the VIX.

Charlot and Marimoutou (2014) use daily data between January 2005 and October 2012 in order to examine the volatility and correlation amongst WTI oil, gold, silver, platinum, the Euro/US Dollar exchange rate and the S&P 500. The decision tree results from a Markov Switching model indicate that the volatility of silver responds strongly to economic shocks and is linked to specific events such as the Financial Crisis of 2008, while the response of platinum is very slow.

Luo and Ye (2015) looks at predictability potential of the Shanghai silver futures market using the CBOE Silver ETF Volatility Index (VXSLV). The authors take into account 139,500 observations between 2012 and 2014 and differentiate between realised volatility and implied volatility. Realised volatility is defined as the root of the sum of squared returns using a sampling frequency of 25 minutes. Previous literature showed that option-implied volatility contains information on future volatility, Luo and Ye (2015) believe this information can be found in options on the iShares silver trust

fund. Trading volume, open interest and a momentum variable are added in the empirical model and the results show that the VXSLV has significant power in predicting daily and weekly volatility forecasts. Furthermore, adding trading volume, open interest and momentum leads to a significant improvement in forecasting the volatility of the Shanghai silver futures market.

Lyócsa and Molnár (2016) propose identifying one-day forward volatilities of gold and silver. High frequency data from January 2008 to December 2014 reveals that gold is more volatile than silver and that forecasts are less accurate in times of high market volatility. More interestingly, the GHAR type models provided above average forecasts, pointing towards the inferiority of univariate models in predicting the volatility of silver prices.

8. The Macroeconomic Determinants of White Precious Metal Prices

Precious metals have long been seen as a natural inflation hedge, as their production is limited by nature - in contrast to fiat currencies. Taylor (1998) uses data from 1914 to 1996 to assess the inflation hedging ability of white precious metals. The results for silver indicate that it was a long-run hedge over the period observed, but that it also served as a short-run hedge against the US CPI over many subperiods of the sample. A noteworthy finding is that silver was a hedge during the second *Organisation of Oil Exporting Countries (OPEC) crisis* of 1979, but not during the first *OPEC crisis* of 1973. For platinum and palladium, Johansen cointegration results indicate that the two white precious metals served as a long-run inflation hedge, while evidence also points towards the short-run hedging abilities of platinum.

Over a shorter period (1967-1999) looking only at after gold prices began to float more freely Adrangi et al. (2003) continues the investigation into the relationship between silver and US inflation. They use the Ameri-

can Industrial Production Index (IP) as well as the Consumer Price Index. this paper's first framework predicts that a rising inflation rate will lead to a reduction of both economic activity and the demand for money. The authors argue that this would on the one hand lead to a reduction of industrial demand for silver, but might lead to an increase of the investment demand side due to silver's alleged ability to act as a hedge during inflationary times. The second framework is build upon the portfolio equilibrium model of Feldstein (1980). The framework is based on the assumption that the demand for gold and bonds in a portfolio is a function of expected real after-tax returns of the two assets. However, Feldstein et al. (1977) showed that the after-tax return on gold is higher than the after-tax return of bonds as long as the capital gains tax is lower than the ordinary income tax rate; therefore, during inflationary periods, the relative price of gold rises, making it a good inflation hedge. Using cointegration and causality tests, silver is shown to be a good hedge against inflation over the time period observed. Second, the Fischer (1930) hypothesis holds, in other words: real silver returns are not adversely affected by inflation. However results do no offer support in favour of the first hypothesis. A positive relationship between silver and the CPI in the long-run and the short-run is observed.

Radetzki (1989) looked at the factors that influenced the price of silver and platinum in the medium and long term. The analysis is done by differentiating between driving forces of supply and driving forces of demand between 1972 and 1987. Mine production across countries is found to be a more important factor of supply for silver than gold, which has a very large stock relative to other commodities. On the demand side, industrial demand dominates for silver; such as photographic, electrical, and also the jewellery industry. These findings lead Radetzki (1989) to conclude that two factors drive the price of silver: demand from industry and private inventories. Oil prices and official inventories are not believed to be amongst the major driving forces of the silver price, even though they are seen here as

important in determining the price of gold. On the supply side for platinum scrap supply is not found to be a driver, though it is for silver. Industrial demand for platinum is again important for platinum prices, driven by its use in the automobile sector.

Bampinas and Panagiotidis (2015) uses a 220 year data set of annual silver and consumer prices in the United Kingdom and the United States of America to 2010 to look at the relationship in a time varying framework. Expected CPI series is derived from a Hodrick and Prescott (1997) filter and an asymmetric Christiano and Fitzgerald (2003) band-pass filter. For both the UK and the US, silver is found to share no long-run relationship with inflation; however, in a time-varying framework, a strong long-run relationship does exist between silver and UK inflation. Since even a time-varying relationship fails to exist for the US no hedging relationship exists. In all cases the long run relationship is not found to be 1:1 which is a necessary condition for silver to be an inflation hedge.

In a multiple-factor Arbitrage Pricing Theory (APT) McCown and Zimmerman (2007) finds a growing importance for inflation in driving silver prices. A high correlation between the price of silver and expected inflation is found, making it a good indicator of the latter, though gold is seen to perform better at this role than silver.

The effect of macroeconomic news announcements is first addressed by Christie-David et al. (2000) using 15 Minutes intraday data between the January 1992 and December 1995 for silver futures. Results show that silver futures prices respond strongly to the announcement of capacity utilisation and the unemployment rates. Inflation has a weak effect (a finding in line with Frankel and Hardouvelis (1985), as does hourly wages, business inventories, and construction spending. Other announcements have no measurable effect in this sample.

In the same year, Roache and Rossi (2010) re-examine the effect of macroeconomic news announcements on the price of silver futures relying

on daily data between January 1997 and December 2009 using a GARCH model. Similar to Christie-David et al. (2000), the set of macroeconomic variables under observation is quite extensive but only the German IFO survey and the US Dollar index, both lagged by one day, have an effect on the price of silver over the entire time period considered. More variables are found to be significant for platinum. Here, results point towards the FOMC interest rate decision, alongside the lagged value of changes in non-farm payrolls, existing home sales, the German IFO survey and the US Dollar index. Finally, palladium is found to be influenced by the following variables: the GPD, industrial production, the employment cost index, existing home sales, the German IFO survey and the US Dollar index.

Similar to the work from Christie-David et al. (2000), Elder et al. (2012) work with intraday data between January 2002 and December 2008 to analyse the impact of US macroeconomic news announcements on the return, volatility and trading volume of gold, silver and copper futures. Advance retail sales, changes in nonfarm payrolls, durable goods orders, business inventories, construction spending, and new home sales announcements have a statistically significant negative influence on silver futures prices; only trade balance announcements are positively associated with silver futures prices. These results are in contrast to the findings of Christie-David et al. (2000) who observe an importance for the announcements of capacity utilisation, the unemployment rate and the CPI, all of which are not found to be statistically significant in influencing the price of silver futures in the work of Elder et al. (2012); indicating time-variation in the importance of macroeconomic announcements on the price of silver.

Adrangi et al. (2015) consider the response of intraday gold, silver and copper futures prices traded on the COMEX between January 1999 and December 2008 to 18 macroeconomic variables believed to influence the behaviour of financial markets in the United States. The results are then divided into different categories: thirty-minute return responses, thirty-minute

return responses taking into account the surprise element, standardised inventory holdings and return responses, and finally, local inventory clustering and return responses. Across all different categories, capacity utilisation and industrial production have a positive significant relationship with the price of silver, results somewhat in line with Christie-David et al. (2000), but contrary to Elder et al. (2012) who find no significant relationship between either capacity utilisation nor industrial production with silver futures prices.

Thorbecke and Zhang (2009) analyse the effect of monetary policy surprises on commodity prices including silver. Chan and Mountain (1988) found that interest rates were a driver of silver prices, but did not effect interest rates. Thorbecke and Zhang (2009) first use Romer and Romer (2000) hypothesis's that a federal funds rate increase might lead to an increase in inflation by revealing the Fed's private information about inflation. The second theory, by Gürkaynak et al. (2005) predicts that an increase of the federal funds rate leads to a decrease in long-term expected inflation. Thorbecke and Zhang (2009) consider the time period between 1974 and 1979 as well as between 1989 and 2006; the period between 1980 and 1989 is omitted because the Fed abandoned fund rate targeting in 1979. Regression results differ substantially for both time periods considered. Between 1974 and 1979, an increase in the federal funds rate led to an increase in the price of silver as a reaction to an increased demand in answer to anticipated inflation. Between 1989 and 2006 however, an increase in the federal funds rate led to a decrease in the price of silver in expectation of increasing short-term real term interest rates; a finding in line with Frankel (2008). Soytas et al. (2009) results show that Turkish interest rates Granger cause silver prices.

Focusing more on explaining the price volatility of gold, silver, platinum and palladium through macroeconomic determinants, Batten et al. (2010) work with monthly data between January 1986 and May 2006 and express the expected return of silver as a function of the information available at a previous time interval while estimating the conditional standard devia-

tions with the methodology of Davidian and Carroll (1987). The following macroeconomic variables are considered in the analysis: the S&P 500 and its dividend yield, the World excluding US stock index and its dividend yield, the difference in interest rate yields between a US 10 years bond and a US 3 months Treasury bill, US M2 money supply, US industrial production, US inflation, the US Dollar index, and finally, US consumer confidence. The authors argue that these variables contribute to the effects of the business cycle, monetary environment and financial market sentiment on asset returns. Results show that neither monetary nor financial market variables are significant for silver price volatility. Instead, the volatility from the other precious metals markets has an effect on silver price volatility. These findings are in line with Sensoy (2013) concluding that the same macroeconomic factors do not jointly influence the price series of the four main precious metals. Results for platinum indicate a significant effect of stock market volatility during a part of the sample period under observation, while the effect of macroeconomic variables seems much stronger on palladium. Here, it seems that the volatility of the S&P 500 and its dividend yield significantly effect the volatility of palladium prices.

Apergis et al. (2014) look into the nature of spillovers between the prices of gold and silver, stock markets, and different macroeconomic variables of the G7 countries using monthly data between January 1981 and December 2010. The authors use the Zurich silver price in US Dollar per kilogram and consider a vast amount of variables reflecting industrial production, inflation, unemployment, exchange rates, commodity prices, interest rates, government debt, money supply, equity prices, market capitalisation, price/earnings ratios, and price to book ratios. Apergis et al. (2014) work with a Factor-Augmented Vector Autoregressive (FAVAR) approach which they argue is better suited than a standard VAR model when considering large amounts of variables. Results indicate that the price of silver responds negatively to positive shocks of industrial production and interest rates, fur-

thermore, a higher inflation and unemployment rate have a negative impact on the price of silver. The authors explain this negative relationship with inflation by saying that a higher inflation rate deteriorates the macroeconomic environment while adding to macroeconomic uncertainty, hence turning investors away from precious metal markets. On the other hand, FAVAR test results indicate that both positive money supply shocks and positive stock market shocks lead to higher silver prices.

Fernandez (2017) focuses her research on gold, silver and *Platinum-group* elements, amongst which platinum and palladium, and derives the differences in macroeconomic determinants for annual prices between 1930 and 2014 and for monthly and weekly prices between July 1992 and July 2016. On a yearly basis, a relationship between white precious metals prices and both global production and US consumption is identified. On a monthly basis, a strong relationship is identified between white precious metals and US industrial production as well as US monetary supply; the effects of South African mine production are also revealed. Finally, a very strong relationship is identified between the prices of gold and silver on a weekly basis during bullish environments, while platinum and palladium have a strong relationship with silver during bearish periods. A very interesting finding is the rise in importance of the price of white precious metals and consumer confidence and exchange rates in the United States, in line with the rise in importance of white precious metals as an investments asset.

Ciner (2017) takes a very specific approach and predicts the price of silver, platinum and palladium by looking at the level of the South African Rand in relying on daily data between October 1996 and July 2016. Results indicate a unilateral effect from exchange rates to the price of white precious metals but not the other way around, while the effect is strongest on palladium, than platinum and finally silver, in that order. Indeed, the ability of exchange rates movements of the Rand to forecast palladium prices remains significant under different model specifications, which it doesn't for both

platinum and silver.

9. The White Precious Metals and Other Assets

9.1. Gold

Gold and silver are seen as a pair, and therefore might be assumed to be close substitutes from the perspective of a financial economics. However using data between December 1979 and March 1981 Koutsoyiannis (1983) finds a very low value for the elasticity of the price of gold with respect to changes in the price of silver (0.08) suggesting the opposite is true. There are many possible reasons for this but one must be that the industrial uses of silver are far more numerous than gold.

Historically the ratio of gold and silver prices have been a long running feature of economic discussions, with many commentators focusing on their historical parity ratio of 16:1 from a monetary perspective. Ma (1985) tests if a trading strategy can be developed based on changes in a derived equilibrium parity ratio looking at daily spot gold and silver prices between 1974 and 1984. The technical trading rule developed does provide excess returns, but only before trading costs with trading being very frequent. Ma and Soenen (1988) extends this to futures prices and find that this is more profitable than spot trading, but again only before transaction costs.

Looking data between the December 1993 and December 1995, Adrangi et al. (2000) collect 15 minutes intraday data of silver futures. A bivariate GARCH model is used to examine the high frequency relationship between gold and silver futures. Results point towards a bicausal relationship between gold and silver returns where the silver contracts carry the burden for spread convergence - Adrangi et al. (2000) believe that this is due to a faster reaction of the gold market to macroeconomic factors. Also noteworthy are the strong volatility spillovers from the gold to the silver market.

In an attempt to understand the relationship between gold and silver prices, Chan and Mountain (1988) consider the price of gold and silver

traded in Toronto and the Canadian bank rate using weekly basis between March 1980 and February 1983, testing for granger causality. Results point towards a causal relationship between the price of gold and the price of silver with lags of up to four weeks. Using daily cash and futures prices between January 1982 and July 1992 Wahab et al. (1994) also find a strong correlation between gold and silver spot and futures prices. The authors use this to propose a trading strategy which generates profits but with a very level high risk.

Escribano and Granger (1998) find a long-run relationship between gold and silver spot prices using monthly data from 1971 to 1990, which is especially strong during the silver price bubble which burst in March 1980. Finally, a linear regression indicates a strong simultaneous relationship between gold and silver returns across the entire time period considered. Using daily data between 1992 and 1998 Ciner (2001) uses Johansen Cointegration tests to confirm Escribano and Granger (1998)'s contention that this long run relationship started to break down in the 1990's. Based on his findings he advises market participants not to consider gold and silver as substitutes when hedging similar risks. Lucey and Tully (2006b) reviews the findings of Ciner (2001) using weekly COMEX prices between January 1978 and November 2002 and a dynamic cointegration analysis, involving estimations of Johansen cointegration tests over various time windows. A visual application of the Hansen and Johansen (1992) method (used before by Rangvid (2001) for example) shows that the stable relationship between gold and silver prevails over time. Concidering that results indicate no cointegration between gold and silver from 1992 to 1998, Lucey and Tully (2006b) concludes that the findings of Ciner (2001) might only be driven by the choice of the time period considered and should not be regarded as empirical sound. Gerolimetto et al. (2006) also finds a dynamic long run relationship between gold and silver.

Building upon the results of Escribano and Granger (1998), Baur and

Tran (2014) enlarge the sample considered and look at monthly gold and silver prices between January 1970 and July 2011 in order to analyse their potential long-run relationship. Closely following the method proposed by Escribano and Granger (1998), results show that the price of gold drives the price of silver and therefore the long-run relationship. Time-variation is observed in the relationship, namely the disconnection of gold and silver prices in the 1990s.

Considering monthly data from 1970 to 2015, Pierdzioch et al. (2015) work with a Residual Augmented Least Squares (RALS) test for noncointegration, looking at the problem from another angle. Even though gold and silver are cointegrated during major parts of the whole sample, evidence for noncointegration is found in the mid 1990s and the early 2000s as in the earlier papers.

Zhu et al. (2016) take a quantile regression approach to the relationship between gold and silver by considering weekly data from 1968 to 2016. A Quantile Autoregressive Distributed Lag model based on the Johansen procedure detects a positive long-run relationship between gold and silver that is mainly driven by the tail quantiles outside the interquantile range. Further results indicate that prices of silver are more susceptible to contemporaneous price changes of gold, though this adjustment is stronger when silver prices are in their extremes.

Liu and Chou (2003) employ a general method of fractional cointegration analysis to study the gold-silver spread in both cash and futures markets. Results indicate slow-adjustment long-memory processes and that the futures and cash spreads between gold and silver are cointegrated. Further results point towards the ability of futures spreads to reflect information before cash spreads. Batten et al. (2013) consider daily gold and silver futures prices between January 1999 and December 2005 to look at spread returns. They detect long-term dependence by using statistical techniques proposed by Hurst (1951, 1956). Results indicate a dominant positive dependence

between the spread returns, even though negative dependence is also observed during some of the sample. An important result for investors is the proposed trading strategy derived from Hurst coefficients which indicates when to buy or sell. This outperforms both a simple buy-and-hold strategy and a moving-average strategy. Auer (2016) augments to include transaction costs. Auer (2016)'s trading strategy continues to outperform on a buy and hold basis even after transaction costs.

Kearney and Lombra (2009) is one of the few to focus on the relationship between gold and platinum prices between 1985 and 2006 focusing on the short-term shifts from positive to negative correlation. Results obtained from the hedge books of 93 gold mining companies between 1996 and 2006 uncover that forward sales are negatively related to gold prices and equilibrium errors and therefore altered the return on gold and explain the shift towards a negative relationship with platinum prices.

Morales and Andreosso-O'Callaghan (2011)'s results from a GARCH model point towards a significantly positive relationship between precious metal returns, where the prices of gold, silver, platinum and palladium tend to appreciate simultaneously and also depreciate at the same time.

Hammoudeh et al. (2010) look at conditional volatility, correlation dependency and interdependency for all four major precious metals and the US Dollar/Euro exchange rate using daily spot prices between 1999 and 2007. Results point towards high conditional correlation between gold and silver. Results for platinum and palladium indicate a high correlation amongst the return of the two white precious metals, but to a very low correlation between gold and palladium. Interestingly, the authors point towards superior portfolio diversification benefits of platinum in comparison to silver, hence advising investors to hold more platinum than silver.

Chng and Foster (2012) argue that while gold is demanded by investors as a safe haven, but that during good economic times firms stockpile silver, platinum and palladium for industrial consumption. Using daily data be-

tween 1996 and 2010, they test whether or not the implied convenience yield of precious metals affect returns, volatility and volume dynamics of other precious metals. The authors derive time series for the implied convenience yield of a precious metal taking into account the percentage storage costs of the metal (a 0.43% annual fee). A VAR model augmented with a sub-sample analysis point towards significant cross-metal interactions amongst convenience yields of precious metals, though gold and silver seem to be more influential depending on the state of the economy. Silver is more convenient to hold during positive economic times since it carries the heaviest industrial usage. Regarding the relationship between gold and silver, it seems that a long-run equilibrium relation is only observed during normal economic times. Further findings point towards the greater influence of the convenience yields of gold and silver in comparison to that of platinum and palladium.

Kucher and McCoskey (2016) consider weekly data for gold, silver and platinum prices between 1975 and 2015 in order to understand their long-run relationship. Results indicate a cointegration relationship between gold and silver prices as well as gold and platinum prices, though these relationships are time-varying: they tend to decline around business cycle peaks and increase during recessions. Finally, while Kucher and McCoskey (2016) finds that the prices of precious metals are influenced by the actual economic condition, the long-run relationship amongst them seems to be unaffected by short term macroeconomic shocks.

9.2. Other Assets

Soytas et al. (2009) examine both short-run and long-run information transmission between the Brent oil price, the Turkish interest rate, the Turkish Lira/US Dollar exchange rate, and finally, the domestic spot price of gold and silver considering daily data between March 2003 and of March 2007. Short-run dynamics are identified using generalised impulse responses in a VAR model, in order to make the ordering of the variables irrelevant. There

is evidence for unidirectional causality from gold to silver in the long-run. Concerning oil, evidence shows that price shocks have a negative impact on the price of silver, pointing to silvers' industrial importance in Turkey. On the other hand, the silver spot price quoted on the Istanbul Gold Exchange (IGE) is found to have a significant positive impact on the Brent oil price in the short-run.

A few years later, Bhar and Hammoudeh (2011) take a more global approach and look at the relationship between WTI oil, copper, gold, silver, short-run US interest rates, a trade-weighted average index of the value of the US dollar, and finally, the MSCI world equity index. Bhar and Hammoudeh (2011) fit weekly data between January 1990 and May 2006 into a regime-dependent VAR model. Results relying on different model specifications show no evidence for a significant relationship between oil prices and silver. However, a positive relationship between silver and the US Dollar exchange rate is observed, indicating that silver can't be considered a hedge against a depreciating dollar.

Jain and Ghosh (2013) conduct an analysis similar to that of Soytaş et al. (2009) focusing on India by looking at cointegration relationships and Granger causality between daily prices of Brent oil, gold, silver, platinum, and the Indian Rupee/US Dollar exchange rate between January 2009 and December 2011. Evidence points towards a strong relationship between gold and silver - also in explaining each others error variances. Granger causality is observed between oil and silver, implying that the silver price has predictive powers for international oil prices. Results also uncover a bi-directional causality between gold and platinum, indicating that platinum starts to behave like an alternative investment to gold. Finally 9.55% of the variance of oil is found to explain the variance of platinum.

Charlot and Marimoutou (2014) results indicate a low correlation between oil and silver (0.41) that increased since 2009 and a high correlation between silver and platinum/gold (0.74 and 0.83 respectively). An increase

in correlation since the Global Financial Crisis is also observed between oil and platinum (0.44), while a strong correlation also exists between platinum and gold (0.72).

Focusing more on the effect that Brent oil price shocks have on the volatility of precious metal prices, Behmiri and Manera (2015) consider daily spot prices of aluminum, copper, lead, nickel, tin, zinc, gold, silver, platinum and palladium between July 1993 and January 2014. Outliers in the GARCH model are detected via the Doornik and Ooms (2005, 2008) procedure inspired by Chen and Liu (1993) allowing to distinguish between outliers affecting the levels of the series and outliers affecting future conditional variances (a discussion on the different types of outliers and their effects on GARCH models can be found in Sakata and White (1998) and in Hotta and Tsay (2012)). This approach provides Behmiri and Manera (2015) with two sets of data: the original time series and a data set corrected for outliers. Finally, the Mork (1989) method developed for oil prices is used to differentiate between positive and negative shocks. Empirical results indicate that negative oil price shocks do not affect the volatility of silver, while positive oil price shocks decrease the volatility of silver prices. Regarding platinum, it is found that negative oil price shocks increase the volatility of platinum while positive oil price shocks decrease the volatility of platinum prices. the volatility of palladium prices is always increased, disregarding the type of oil price shock. However, considering the data set corrected for outliers, only the positive oil price shocks remain significant in affecting silver price volatility. Behmiri and Manera (2015) give two possible reasons for the fact that negative oil price shocks become insignificant when the series are corrected for outliers: first, detected outliers in the silver market are due to shocks in the oil market, and second, the volatility of both the silver and the oil price are likely to be affected by the same events.

Similar to Jain and Ghosh (2013), the paper by Bildirici and Türkmen (2015a) analyses cointegration and causality relationship between oil, gold,

silver and copper using monthly data between January 1973 and November 2012. The oil price considered is the equally weighted average of the spot price of Brent, Dubai and West Texas Intermediate (WTI) oil. A Brock et al. (1996) test indicates nonlinearity in the series, hence leading Bildirici and Türkmen (2015a) to perform a nonlinear ARDL test of cointegration: an asymmetric extension of the linear ARDL approach proposed by Pesaran et al. (2001) (examples of nonlinear ARDL tests and their applications can be found in Katrakilidis and Trachanas (2012) and Bildirici and Türkmen (2015b)). Regarding causality amongst the variables, Bildirici and Türkmen (2015a) argue that a standard linear Granger approach might not be appropriate due to the nonlinear nature of the series. The authors therefore propose to work with a Hiemstra and Jones (1994) modified Baek and Brock (1992) test to reveal information about the positive and negative nature of shocks, and a Kyrtsou and Labys (2006) test to detect response asymmetry from one variable to another. Results indicate a positive long-run relationship between oil and silver, where a 1% increase in the price of oil results in a 1.33% increase in the price of silver. However, the different causality tests indicate conflicting results about the relationship between oil and silver; Bildirici and Türkmen (2015a) therefore advice the reader to be cautious when interpreting these results.

Reboredo and Ugolini (2016) examine the impact of strong bidirectional oil price movements on ten metal prices, including silver, platinum and palladium, using weekly spot prices between January 2000 and October 2015. Results point towards an asymmetric effect of oil price spillovers, where the effects of upward price movements were larger than those of downwards price movements. Reboredo and Ugolini (2016) also take a specific look at the Global Financial Crisis and find that it did not affect the spillover effects running from oil to the three white precious metals, evidence that the relationship between oil and silver, platinum and palladium is not time-varying.

10. Silver Futures and Forwards

Garbade and Silber (1983) studies the extent to which hedgers use futures contracts to manage silver price risk. Building upon the assumption that the futures price for a commodity should be equal to the cash price plus a premium reflecting the deferred payment on the futures contract Garbade and Silber (1983) develop a pricing model that is able to assess whether or not futures contracts are good substitutes for a cash market position and detect in which market price changes first appear. Results for silver indicate that the elasticity of supply is quite high, the authors argue that this is due to the low storage costs for silver and the ability to sell short silver very easily. Another interesting finding indicates that in contrary to gold, where the spot price depends largely on the futures price, price discovery for silver is more evenly distributed amongst the spot and the futures price.

Ntungo and Boyd (1998) consider weekly silver futures and try to understand whether or not neural network models Kaastra and Boyd (1995) outperform traditional ARIMA models in predicting silver prices. Neural network procedures were designed based on the structure of the brain and consists of a collection of input units and processing units receiving the data. In contrary to other forecasting procedures, neural networks compare the results of their analysis with the desired output, adding a *machine learning* element to the procedure Hecht-Nielsen (1990). While the predictive models generated positive returns, neural network results for silver indicate that the more complex models did not perform better than the traditional ARIMA model considered; an explanation provided by the authors is that the data considered might not have been highly nonlinear.

Longin (1999) derives optimal margin levels required in silver futures contracts in the light that it should be high enough to protect brokers against insolvent customers, but also low enough to minimise the additional costs for investors. They work with observations derived from the COMEX between 1975 and 1994. Results for long investors show that optimal margins

are smaller than the historically observed margin requirements for a probability of margin violation above 10%, a similar observation is found for short investors where the optimal margin requirement is smaller than the historically observed margin requirements for a probability of margin violation above 25%.

Another paper that looks at margin levels of silver futures is that of Chatrath et al. (2001a) using daily data between 1986 and 1995. Market volatility is measured firstly based on the dispersion of prices, while the second method is based on a GARCH model. The costs imposed by futures margins are estimated with a Two Stage Least Square (2SLS) model and differentiates between different types of traders. Empirical results for silver futures reveal that open interest and trading volume are relatively insensitive to margin changes far away from the maturity date - indicating they are seen as a transaction cost and not an opportunity-cost. Also results show that small traders and speculators are more sensitive to margin changes than hedgers and spreaders.

Cifarelli and Paladino (2015) focuses on hedgers and speculators to analyse the behaviour of futures returns of silver with daily data between January 1990 and January 2010. Using a non-linear CCC-GARCH to model the reactions of hedgers and speculators to volatility shifts in the silver futures markets and a two-state Markov-switching procedure they find that individual periods of high futures return volatility are associated to specific intensified trading activities from hedgers or speculators respectively. Results indicate that the effect of hedgers on the silver futures market is far more important than the effect of speculation activities, while the behaviour of speculators is very much dependent on the level of volatility in the silver futures market.

Looking at the silver futures market in the United States and Japan, Xu and Fung (2005) analyse daily gold, silver and platinum futures data between November 1994 and March 2001 to detect across-market information

flow amongst the contracts through a bivariate asymmetric ARMA-GARCH model. Intraday information transmission is measured with a Seemingly Unrelated Regression (SUR) framework. Results show that price transmission is strong between the markets and originates in the USA. Furthermore, SUR results point towards the speed at which new information is incorporated in the market - usually not longer than a day. Aruga and Managi (2011) also look at the US and the Japanese silver futures market. Johansen test results indicate that the daily prices considered between January 2001 and June 2010 are cointegrated while a causality test indicates that American prices are dominant in driving the cointegration relationship. Furthermore, results indicate that the Law of One Price (LOP) did not hold over the entire period, hence allowing investors to realise profits through arbitrage.

Paschke and Prokopczuk (2012) consider daily data of crude oil, copper, gold and silver between January 2006 and the June 2008 in order to understand whether or not continuous time pricing models can be used to reveal mispriced commodity futures prices. A set of different models reveals that excess returns can be realised based on the pricing errors present in the silver futures market - the evidence for gold is much weaker, which the authors blame on the much bigger size of the gold market.

11. Exchange Traded Products and White Precious Metals

The iShares silver trust fund mentioned earlier is part of the study of different other papers looking at the performance of silver Exchange Traded Funds (ETFs). Naylor et al. (2011) look at daily returns of three silver ETFs traded on the NYSE between May 2006 and December 2009 to understand whether or not abnormal returns could have been realised through these securities. The methodology is based upon a CAPM and a Classic Linear Regression Model (CLRM). Building the CAPM, the market under consideration is the S&P 500 and the risk-free rate is given as the US 90 day Treasury bill rate. Results show that the behaviour of silver ETFs is very

similar to that of physical silver returns, particularly, the price movements do not follow a random walk. An important conclusion for investors is that using a filter trading rule Fama and Blume (1966), Solt and Swanson (1981), abnormal returns can be generated through ETFs, hence outperforming a passive investor.

ETFs also raise questions about how price discovery, which is traditionally seen as originating from futures markets, evolves in precious metals markets. Ivanov (2013) looks at this issue by examining at the relationship between silver ETFs, future prices and spot prices using 1 minute intradaily data between the 1st of March 2009 and the 31st of August 2009 using Hasbrock information shares. Silver ETFs largely dominate the information share against spot and futures prices with a value above 89%; indicating that the price discovery role may be being overtaken by ETFs.

A few years later, Naylor et al. (2014) investigate the microstructure of silver investment funds and look more closely at tracking ability, tracking deviation, and the impact of market panics on ETF dynamics. Daily share prices, trading volumes and assets under management of two similar ETFs starting from April 2006 and July 2009 are used, with data up to December 2011. Following Frino and Gallagher (2001), results point towards an average daily tracking error of 112 basis points for silver ETFs which is maximised in times of high market volatility.

Similar to Luo and Ye (2015) who look at the iShares Silver Trust, but looking more specifically at market contagion during the 2010 Flash Crash, MacKenzie and Lucey (2013) use 4,695 one minute intraday observations between April 2010 and May 2010. Results point towards the vulnerability of the iShares Silver Trust to contagion.

Lau et al. (2017) opens the ETF investigation to platinum and palladium and considers daily ETF prices for gold, silver, platinum, palladium, oil and global equity between the 19th of June 2006 and the 18th of June 2016. An E-GARCH procedure is used in order to ensure that the conditional variance is

strictly positive and augmented with a frequency dynamics of connectedness procedure and a hidden semi-Markov model to measure the dynamics and intensity of return spillovers as well as to analyse the return characteristics of white precious metals. Results identify a strong relationship between gold and silver ETFs, but a relatively unimportant relationship between oil and white precious metals ETFs, where oil price movements spill over on silver and platinum but not on palladium. Regarding the relationship of white precious metal ETFs with the global equity ETF, results do point towards a cointegration relationship between equity and precious metals, but the effect of equity ETFs on white precious metals ETFs are relatively unimportant.

12. Conclusion

A primary finding from this review is the relatively small amount of research available on platinum and palladium when compared with silver, and the studies on gold reviewed by O'Connor et al. (2015). This in part reflects their more primary role as industrial metals but also possibly indicates that the benefits they could provide have not been fully addressed. Additionally the research to date has focused on investment in terms of the prices of the metals, a gap remains for research on the drivers of physical demand, such as coins, and supply for the metals, such as scrap. Additionally the focus has generally been on the prices from the London and American markets but more can be done on the remaining markets whose importance is growing.

Another outcome is the clear finding that they do form a single asset class of three homogeneous and interchangeable metals. It has been shown that they have different relationships with other assets, such as oil, divergent abilities in hedging risk. Any further research cannot lump the three together without an appreciation of their differences.

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