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An Empirical Examination of VIX Market Fluctuations

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Abstract

This study investigates the impacts of the Standard & Poor's (S&P) 500 Index, the NASDAQ Volatility Index (VXN), the spot prices of gold and silver, and the U.S. Dollar Index (DXY) on the CBOE Volatility Index (VIX). Specifically, the proposed arbitrage pricing theory (APT) model, programmed by Python, performs multi-factor regression analysis that analyzes the degree of impact measured by the beta coefficient of systematic risks on each factor. Our samples include daily transaction data from 2007 to 2018, divided into three periods to assess the VIX's impact for each sub-period. The three periods are entitled as the "Global Financial Crisis Period" (2007–2009), the "European Debt Crisis Period" (2010–2012), and the "Follow-up Period" (2013–2018). Empirical results show that the major factors are the S&P 500 index and the VXN, with the DXY being a minor factor. Moreover, both gold and silver spot prices have a significant impact on the VIX.

Keywords: VIX, Global financial crisis, European debt crisis, Systematic risk, Arbitrage pricing theory, Multi-factor regression model.

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1. Introduction

The Volatility Index (VIX), introduced by the Chicago Board Options Exchange (CBOE), measures the implied volatility of S&P 500 index options, indicates market volatility for the next 30 days, and reflects investors' sentiments (Whaley, 2000). The VIX, often referred to as the fear index, is the stock market's measure of expected volatility. When the VIX is low, investors believe that future stock market volatility will be moderate and prices will be stable. Conversely, when the VIX is high, stock prices may fluctuate significantly in the future, the uncertainty of the stock market will increase, and investors will become concerned (Fernandes et al., 2013). Therefore, the VIX indicates investors' psychological sentiment.

The 2008 Global Financial Crisis was caused by the default of a large number of subprime mortgages, after a crisis in the U.S. housing market. Immediately after the Lehman Brothers bankruptcy, the crisis spread from real estate to the credit and stock markets. Subsequently, the S&P 500 index fell from 1,463 to 893, and the VIX reached a historical high of 89.53. Meanwhile, as a hedged financial commodity, gold prices tripled and silver prices fell by 50%.

The European sovereign debt crisis occurred shortly after the Global Financial Crisis. Several Eurozone members, including Greece, Portugal, Ireland, Spain, and Italy, failed to make government debt payments and entered into technical default. Although these defaults occurred in only a few Eurozone countries, it has since become a problem for the entire region, leading to a possible split of the Eurozone. During the European sovereign debt crisis, the VIX rose to 45.45, the highest point of the past year and the U.S. Dollar Index (DXY) rose to above 80.

In this study, to illustrate the multiple factors affecting the VIX, we selected five variables from the stock, currency, and commodity markets that significantly correlate with the VIX. Our study specifically applies their relevance to the VIX for the aforementioned three periods. Empirical results show the evidences of ensuring the main impact factors for investments in the VIX market.

The remainder of this study is organized as follows: Section 2 summarizes previous studies and describes the variables; Section 3 provides the empirical model; and conclusions are presented in the final section.

2. Data

In this study, we adopted the following five assets as explanatory variables for analysis.

The source and description of the data used in the regression are as follows:

Table 1: Data

Variables	Logarithmic Return	Description	Period	Source
VIX	$\ln R_{VIX}$	CBOE S&P 500 Volatility Index	2007.01.01 to 2018.12.31	Yahoo! Finance.com
S&P500	$\ln R_{S\&P500}$	CBOE S&P 500 Index		Yahoo! Finance.com
VXN	$\ln R_{VXN}$	Nasdaq 100 Volatility Index		Yahoo! Finance.com
DXY	$\ln R_{DXY}$	U.S. Dollar Index		Investing.com
XAU	$\ln R_{XAU}$	Spot Price of Gold		Investing.com
XAG	$\ln R_{XAG}$	Spot Price of Silver		Investing.com

Note: For Table 1, lnR indicates the logarithmic return of Variable.

Standard & Poor's (S&P) 500 Index: The S&P 500 Index is a U.S. stock market index based on the market capitalizations of 500 large companies listed on the NYSE or the NASDAQ. It differs from other U.S. stock market indexes, such as the Dow Jones Industrial Average or the Nasdaq Composite Index, and is considered among the most representative indexes of the U.S. stock market. Auinger (2015) found a strong negative correlation between the VIX and the daily yield of the S&P 500 Index.

The U.S. Dollar Index (DXY): Another common indicator of investor apprehension, the DXY measures the value of the dollar relative to other foreign currencies (Nikos, 2006). It is a reference marker for the strength of the dollar. Harwood (2011) and Liao et al. (2018) showed a significant and positive correlation between the VIX and the DXY.

The NASDAQ 100 Volatility Index (VXN): The VXN, which measures the implied volatility of the NASDAQ 100 index, is comprised largely of high-tech industrial companies and does not include financial stocks. It is often used to reflect trends in the NASDAQ market or in the U.S. high-tech industry (Simon, 2003). Arak and Mijid (2006) and Schwert (2001) found that the VIX should significantly and positively correlate with the VXN.

Gold and Silver Spot Prices: The choice of two precious metal factors is based on the earlier studies. Gold and silver are inversely related to each other. Gold, a hedged commodity (Kolluri, 1981), positively correlates with the VIX, and silver, an investment commodity, negatively correlates with it; these influences were confirmed Jubinski and Lipton (2013) and Chen (2011) confirmed these correlations. Both gold and silver prices are highly sensitive to market fluctuations.

3. Methodology

The research was organized as follows. We calculated the logarithmic return of factors and then checked variance inflation factors to ensure that no multicollinearity existed. After detecting multicollinearity, we establish an APT model for regression analysis.

3.1 Unit Root Test

According to Granger and Newbold's research in 1974, it is necessary to confirm whether time series data is a stationary series before performing an analysis. Therefore, this study employs both an Augmented Dickey–Fuller test and the Phillips–Perron test to the variables' stability. The test formula is as follows:

The Augmented Dickey–Fuller Test:

$$\Delta Y_t = \alpha + \gamma Y_{t-1} + \sum_{i=2}^{n} \beta_i \Delta Y_{t-i+1} + \varepsilon_t \quad (1)$$

where ΔY_t represents the time series Y after a difference, α is the intercept term, T is the time trend, ε_t is a white noise, and i is the maximum lag order. The null hypothesis of the test is $\gamma = 0$, that is, the time series Y contains a unit root. We have used Akaike information criterion to choose the lag order.

The Phillips–Perron Test:

$$\Delta Y_t = \alpha + \rho Y_{t-1} + \varepsilon_t \quad (2)$$

The null hypothesis of the test is $\rho = 0$, that is, the time series Y contains a unit root. The alternative hypothesis is $\rho \neq 0$, meaning that the time series Y is stationary. The lag order was selected by Newey–West.

Table 2: Unit Root Test

	Level					
	$\mathbf{lnR_{VIX}}$	$\mathbf{lnR_{S\&P500}}$	$\mathbf{lnR_{DXY}}$	$\mathbf{lnR_{VXN}}$	$\mathbf{lnR_{XAU}}$	$\mathbf{lnR_{XAG}}$
ADF Statistic	−19.985 (9)*	−26.865 (4)*	−55.523 (1)*	−21.801 (8)*	−55.890 (1)*	−56.168 (1)*
PP Statistic	−59.978 (1)*	−60.582 (1)*	−55.523 (1)*	−57.821 (1)*	−55.890 (1)*	−56.168 (1)*

Note: For Table 2, * indicates a 5% significance, respectively. (.) indicates the lag order selected by Akaike information criteria.

Table 2 shows the results of the unit root test. It can be seen from the table that all the variables have reached a stationary level.

3.2 Variance Inflation Factors

Before performing regression analysis, it is necessary to confirm whether multicollinearity exists. In statistics, the variance inflation factor (VIF) quantifies the severity of multicollinearity in an ordinary least squares regression analysis.

$$VIF_i = 1/(1 - R_i^2) \tag{3}$$

where R_i^2 is the R^2-value obtained by regressing the i^{th} predictor on the remaining predictors. A VIF of 1 means there is no correlation between this independent variable and any other variables. VIFs between 1 and 10 indicate moderate correlations not severe enough to warrant corrective measures. VIFs greater than 10 represent critical levels of multicollinearity, where coefficients are poorly estimated and p-values are questionable. Table 3 shows the value of the VIFs.

Table 3: Variance Inflation Factors

Variables	VIF Factor
Intercept	1.5594
$\ln R_{DXY}$	2.9452
$\ln R_{S\&P500}$	3.3168
$\ln R_{VXN}$	1.8626
$\ln R_{XAG}$	4.4428
$\ln R_{XAU}$	5.7642

3.3 Arbitrage Pricing Model

To measure the impact of multiple factors on the VIX, we refer to the arbitrage pricing theory (APT) model of Ross (1976). An APT is more flexible than the capital asset pricing model (CAPM), because the model allows multiple risk factors to explain the assets. In this research, we established an APT model that considers the link between expected returns and *i-th* factor sensitivities. The original APT model specified by Ross is as follows:

$$R_j - R_f = \alpha + \sum_i^n \beta_i (R_i - R_f) + \varepsilon_i \tag{4}$$

where R_j represents the return of asset j and R_f is the risk-free rate (the yield on a one-year U.S. T-bill). α is the intercept term, and ε_i is a risky asset's idiosyncratic random shock, with a mean of zero. $R_i - R_f$ is the excess return of factor i, which is computing as the difference between the return and the risk-free rate. $\beta_{x,}$ indicating the sensitivity of R_{VIX} to factor *i*.

4. Estimation and Results

In this study, we established an APT model that considers the link between expected returns and the *i-th* factor sensitivities, as follows:

$$\begin{aligned} lnR_{VIX} - lnR_f = \ & \alpha + \beta_1\left(lnR_{S\&P500} - R_f\right) + \beta_2\left(lnR_{DXY} - R_f\right) \\ & + \beta_3\left(lnR_{VXN} - R_f\right) + \beta_4(lnR_{XAU} - R_f) + \beta_5(lnR_{XAG} - R_f) + \varepsilon_i \end{aligned} \quad (5)$$

where lnR_{VIX} is the logarithmic return of *VIX*, $lnR_{S\&P500}$ is the logarithmic return of the S&P 500 index, lnR_{DXY} is the logarithmic return of the DXY, lnR_{XAU} is the logarithmic return of the gold spot price, lnR_{XAG} is the logarithmic return of the silver spot price, and ε_i is the error term. α, β_1, and $\beta_2 \ldots \beta_5$ are parameters to be estimated.

4.1 Full Period (2007-2018)

Table 4: Regression Results for the Full Period

Dependent Variable: VIX			**Method: Least Squares**		
Variable	β	Std. Error	t-statistic	Prob.	
Constant	−0.0008	0.001	−1.174	0.241	
$lnR_{S\&P500}$	−0.8109	0.055	−14.783	0.000	
lnR_{DXY}	0.5434	0.067	8.163	0.000	
lnR_{VXN}	0.9535	0.011	84.878	0.000	
lnR_{XAU}	0.3850	0.077	5.022	0.000	
lnR_{XAG}	−0.1579	0.049	−3.228	0.001	
R-squared:	0.851	F-statistic:	3418	Akaike Info. Criterion:	−12,470
Adj. R-squared:	0.851	Prob. (F-statistic):	0.00	Schwartz Criterion:	−12,430

Table 4 shows that all explanatory variables have a significant impact on the returns of the *VIX*, where $lnR_{S\&P500}$ has negative effects which is significant. This is consistent with the research findings of Auinger (2015). The positive relationship of lnR_{DXY} and lnR_{VXN} with *VIX* returns also agrees with Harwood (2011), Liao et al. (2018), Mijid (2006), and Schwert (2001). The significantly positive effect of lnR_{XAU} is also consistent with previous assumptions, while lnR_{XAG}, as opposed to gold, has a significantly negative effect on the *VIX*, meaning that silver is not suitable for hedging within the full period.

4.2 Global Financial Crisis Period (2007–2009)

Table 5: Regression Results of the Global Financial Crisis Period

Dependent Variable: VIX			**Method: Least Squares**		
Variable	β	Std. Error	t-statistic	Prob.	
Constant	−0.0020	0.002	−1.229	0.219	
$\ln R_{S\&P500}$	−0.5395	0.071	−7.568	0.000	
$\ln R_{DXY}$	0.3811	0.094	4.074	0.000	
$\ln R_{VXN}$	1.0057	0.023	43.818	0.000	
$\ln R_{XAU}$	0.1115	0.111	1.044	0.316	
$\ln R_{XAG}$	−0.0579	0.074	−0.784	0.434	
R-squared:	0.867	F-statistic:	970.6	Akaike Info. Criterion:	−3,222
Adj. R-squared:	0.866	Prob. (F-statistic):	0.00	Schwartz Criterion:	−3,195

Table 5 shows that the explanatory variables during the 2008 financial crisis were significant, except for gold and silver. This means that lnR_{XAU} and lnR_{XAG} had no significant impact on the VIX during this period. We suggest that, at the time of the 2008 financial crisis, gold and silver were not perceived as the important safe haven assets by investors. When global stock markets were hit by the financial crisis, the VIX reflected U.S. stock market investors' concerns by rising above 80. Gold, meanwhile, actually appreciated.

4.3 The European Debt Crisis Period (2010–2012)

Table 6: Regression Results of the European Debt Crisis Period

Dependent Variable: VIX			**Method: Least Squares**		
Variable	β	Std. Error	t-statistic	Prob.	
Constant	−0.0023	0.001	−2.046	0.041	
$\ln R_{S\&P500}$	−1.2921	0.140	−9.249	0.000	
$\ln R_{DXY}$	0.1381	0.206	0.670	0.503	
$\ln R_{VXN}$	0.8312	0.023	35.905	0.000	
$\ln R_{XAU}$	0.3960	0.132	2.996	0.003	
$\ln R_{XAG}$	−0.1909	0.068	−2.793	0.005	
R-squared:	0.890	F-statistic:	1199	Akaike Info. Criterion:	−3,426
Adj. R-squared:	0.889	Prob. (F-statistic):	0.00	Schwartz Criterion:	−3,399

Table 6 shows that all explanatory variables have a significant effect on the VIX's returns, except for lnR_{DXY} during the European debt crisis. lnR_{XAU} has a significant positive impact and lnR_{XAG} has a significant negative impact. Gold became an ideal safe haven asset for investors after a financial crisis. The change in significance is consistent with our previous position. Meanwhile, silver opposed the aforementioned property of gold.

4.4 The Follow-Up Period (2013–2018)

Table 7: Regression Results of the Follow-Up Period

Dependent Variable: VIX				**Method: Least Squares**	
Variable	β	Std. Error		t-statistic	Prob.
Constant	−0.0011	0.001		−0.959	0.338
$\ln R_{S\&P500}$	−1.7535	0.140		−12.548	0.000
$\ln R_{DXY}$	1.2070	0.146		8.277	0.000
$\ln R_{VXN}$	0.8963	0.018		49.626	0.000
$\ln R_{XAU}$	0.7365	0.151		4.885	0.000
$\ln R_{XAG}$	−0.2823	0.102		−2.780	0.006
R-squared:	0.835	F-statistic:	1518	Akaike Info. Criterion:	−5,997
Adj. R-squared:	0.835	Prob. (F-statistic):	0.00	Schwartz Criterion:	−5,965

Table 7 shows the explanatory variables' regression results after the financial crisis. All the explanatory variables have a significant impact on the returns of VIX. $lnR_{S\&P500}$ and lnR_{XAG} have significant negative effects and lnR_{DXY}, $lnR_{VXN,}$ and lnR_{XAU} have significant positive effects. Recent regression results have a higher coefficient value, indicating a greater impact of each explanatory variable on the VIX after a global financial crisis. Among all explanatory variables, $lnR_{S\&P500}$ and lnR_{VXN} have the strongest effects on the *VIX*'s returns, while lnR_{XAG} has the weakest effects.

5. Conclusion

Using an APT model, this study aims to discover what factors impact the returns of the VIX. The selected period from 2007 to 2018 includes two major financial events: the 2008 financial crisis and the 2010 European debt crisis. We divide these two periods and one following period into three separate study models to observe which explanatory variables influence the returns of the *VIX*.

We believe that our data sources (Yahoo! Finance.com and Investing.com) are reliable. Of the APT model's five explanatory variables, the stock returns $lnR_{S\&P500}$ and lnR_{VXN} represent the capital market's impact on the returns of VIX, lnR_{DXY} represents the impact from the money market, and lnR_{XAU} and lnR_{XAG} represent the impact from the precious metals market.

The following conclusions were drawn from the empirical results.

1. The explanatory variables we selected have a significant effect on the returns of VIX.
2. From the three periods' regression results, we find that explanatory variables' effect on the VIX's returns increases gradually over time.
3. The VIX's returns primarily are affected by the explanatory variables $lnR_{S\&P500}$ and lnR_{VXN}. $lnR_{S\&P500}$ has significant negative effects and lnR_{VXN} has significant positive effects. This is consistent with our previous assumption.
4. In the 2013–2018 regression results, lnR_{DXY} has a significant positive effect on the returns of the VIX. It also shows that the DXY has gradually increased its impact on the returns of the VIX, which indicates the strong performance of the U.S. dollar in recent years.

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