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Tesla under International Capital Flow: An Empirical Research Based on Time-series Model

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Abstract: The announcement that the Federal Reserve may announce its eighth interest rate hike in almost a year on 23 March 2023. The trend of international capital flows to the U.S. has become more pronounced. However, this is a double-edged sword for U.S. multinationals. The entry of international capital into the U.S. may contribute to a more prosperous U.S. financial market. However, at the same time, a higher dollar exchange rate means that multinationals' revenues may fall. This paper, therefore, chooses to analyse Tesla, one of the most representative US multinationals. A VAR and an ARMA-GARCH model are used to analyse Tesla's share price movement and the U.S. dollar index futures price movement. This paper finds a correlation between the U.S. dollar index futures price and Tesla's share price. Based on the results of this paper, investors can adjust their investment decisions in Tesla stock based on the following Federal Reserve policy.

Keywords: federal reserve interest rate hike, Tesla, VAR, ARMA-GARCH

1. Introduction

On 16 March 2022, The Federal Reserve announced a 25-basis point rate hike. The first Fed rate hike since December 2018, and it followed this up with seven more rate hikes over the year [1]. This paper will focus on analysing the impact of international capital flows on the volatility of U.S. corporate share prices in the context of the Fed's interest rate hike. It will complete the study with Tesla as the main object of analysis.

Given that the U.S. is currently the world's largest economy, and the U.S. dollar still dominates the international monetary system, the adjustment of the U.S. monetary policy is bound to cause global economic and financial resonance [2]. The U.S. dollar is the most widely used currency worldwide and has the highest share of the world's settlement currencies. As such, changes in U.S. dollar interest rates can significantly impact capital markets. U.S. monetary policy can affect international capital flows [3]. For example, a study of Hong Kong's capital markets noted that U.S. monetary policy has led to capital outflows from Hong Kong's financial markets [4]. Moreover, the Federal Reserve's monetary policy can impact energy prices because of the widespread use of the U.S. dollar in international energy trade. A Fed rate hike could plunge emerging economies into recession, affecting international capital flows [5].

The Fed's decision to raise interest rates may be based on several reasons. One of the main reasons the Federal Reserve may raise interest rates is to combat inflation [6]. When the economy grows too quickly and there is too much money in circulation, inflation can rise, leading to higher prices for goods and services. As interest rates increased, the borrowing cost became higher, keeping inflation somewhat in check. The Federal Reserve also considers global economic conditions when deciding interest rates. If other countries are experiencing economic instability, the Federal Reserve may raise interest rates to prevent a flow of capital out of the United States, which could destabilise the economy. Another reason is that The Federal Reserve may raise interest rates to influence the public's expectations about future inflation. If the public expects inflation to rise, they may demand higher wages and prices, which could lead to a self-fulfilling prophecy of rising inflation. By raising interest rates, the Federal Reserve can signal to the public that it is serious about controlling inflation and may help to keep inflation expectations in check. Moreover, the ECB also announced its policy of raising interest rates after this. An ECB interest rate hike that spills over across the Atlantic is followed by an easing, not a tightening, of the U.S. financial conditions and an expansion of economic activity [7].

This paper will briefly examine the price movements of Tesla in the context of the Fed's interest rate hike and test whether its price movements are affected by the Fed's rate hike. Tesla is one of the last decade's most famous American multinational companies. From its establishment on 1 July 2003 to becoming the world's highest market capitalisation car company on 15 March 2022, Tesla has taken just under 20 years. Moreover, at the same time, Tesla's accumulated technological superiority and the market share it holds in the electric vehicle sector have made it one of the most exciting stocks for investors on the NASDAQ. The company has also significantly accelerated the transition to electric vehicles and renewable energy sources.

This paper will use the U.S. dollar index futures price and the Tesla share price as sample data and test them using VAR and ARMA-GARCHX models, respectively.

In the second part of this paper, the data sources used, the unit root tests performed on them will be given, and the VAR model settings and ARMA-GARCHX model settings will be used. In the third section, the empirical results of the VAR and ARMA-GARCHX models will be presented, and the results will be analysed accordingly. The paper's main findings are presented and discussed in the fourth and fifth sections.

2. Empirical Research Design

2.1. Data Sources

The data used in this article is sourced from investing.com [8]. Daily price data for USD Index futures from June 2021 to March 2022 and for Tesla on Nasdaq were selected. Once the data was obtained, the data was first processed to calculate the daily returns of the U.S. dollar index futures and Tesla stock, after which the prices and returns of the U.S. dollar index futures and Tesla stock were logarithmically processed separately, using the formulae ln=(1+P) and ln=(1+R) respectively.

2.2. Augmented Dickey–Fuller (ADF) Unit Root Test

According to Table 1, the original series of the Tesla share price and the U.S. dollar index is not smooth ($p>0.1$, accepting the original hypothesis that there is a unit root in both series). Therefore, they cannot be modelled.

After differencing, the log-return series of both series reject the original hypothesis (such as $p < 0.05$ or $p < 0.01$), i.e., the differenced series are smooth and can be modelled.

Table 1: ADF test.

	Variables	t-statistic	p-value
Price			
	Tesla	-2.0730	0.5610
	USD Index	-1.2850	0.8916
Yield			
	Tesla	-14.5930	0.0000***
	USD Index	-16.4830	0.0000***

2.3. Vector Autoregression (VAR) Model

A Vector Autoregression (VAR) model is a statistical model used to analyse the relationship between multiple time series variables [9]. In the basic assumptions of the VAR model, each variable is affected by its own lagged value and the lagged values of other variables. Therefore, each variable will be modelled as a linear function of its own lagged value and the lagged values of the other variables. In this paper, P is used to denote the order of the VAR model and is used as a proxy for the lagged value of each variable in the Model. Various methods can be used to estimate a VAR model, such as maximum likelihood estimation, least squares, or Bayesian estimation. Once a VAR model is estimated, various diagnostic tests can be performed to assess the Model's goodness of fit and its assumptions' validity.

There are 2 independent time variables in the VAR model in this paper, namely $x_{t,1}$,$x_{t,2}$.

$$x_{t,1} = \alpha_1 + \emptyset_{11}x_{t-1,1} + \cdots + \emptyset_{1p}\, x_{t-p,1} + \beta_{11}x_{t-1,2} + \cdots + \beta_{1p}x_{t-p,2} + e_{1t}\,. \tag{1}$$

$$x_{t,2} = \alpha_2 + \emptyset_{21}x_{t-1,1} + \cdots + \emptyset_{2p}\, x_{t-p,1} + \beta_{21}x_{t-1,2} + \cdots + \beta_{2p}x_{t-p,2} + e_{2t}\,. \tag{2}$$

$$\begin{pmatrix} x_{t,1} \\ x_{t,2} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \emptyset_{11} & \cdots & \emptyset_{1p} \\ \emptyset_{21} & \cdots & \emptyset_{2p} \end{pmatrix} \begin{pmatrix} x_{t-1,1} \\ \vdots \\ x_{t-p,1} \end{pmatrix} + \begin{pmatrix} \beta_{11} & \cdots & \beta_{1p} \\ \beta_{21} & \cdots & \beta_{2p} \end{pmatrix} \begin{pmatrix} x_{t-1,2} \\ \vdots \\ x_{t-p,2} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \end{pmatrix} \tag{3}$$

Equations (1) and (2) above represent the daily return on Tesla stock and the daily return on U.S. dollar index futures. Respectively, equation (4) is in matrix form. In equation (1), $\alpha_1 + \emptyset_{11}x_{t-1,1} + \cdots + \emptyset_{1p}\, x_{t-p,1}$ represents a linear function of past lags of Tesla stock return, while $\beta_{11}x_{t-1,2} + \cdots + \beta_{1p}x_{t-p,2}$ represent past lags of USD index futures daily yield, e_{1t} is the error term.

2.4. ARMA-GARCH Model

The ARMA-GARCHX Model is a statistical model that combines two popular models: Autoregressive Moving Average (ARMA) and Generalized Autoregressive Conditional Heteroskedasticity (GARCH), to analyse and forecast time series data [10]. The ARMA model is used to model the mean or expected value of a time series, while the GARCH model is used to model the volatility or the conditional variance of the time series. The X in ARMA-GARCHX refers to including exogenous variables, which are external factors that may influence the time series being analysed. The ARMA-GARCHX Model is typically used in finance and economics to Model financial time series that exhibit volatility clustering. The estimation method for the Model is the maximum likelihood estimation method. The parameters used are based on minimising the sum of squared errors between the actual and predicted values. Once the Model has been estimated, the Model can be used to predict the future values of the time series and to be able to estimate the associated risk.

In equation (4), y_t is the value of the time series at time t,c is a constant, $\emptyset_1$, $\emptyset_2$, , ..., $\emptyset_p$, are the autoregressive coefficients that capture the dependence of y_t on its p past values, ε_t is a white noise error term with mean zero and constant variance σ^2, θ_1 , θ_2 , ... , θ_q is the moving average coefficients that capture the dependence of y_t on the q past error terms.

$$y_t = c + \emptyset_1 y_{t-1} + \emptyset_2 y_{t-2} + \ldots + \emptyset_p y_{t-p}\} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_q \varepsilon_{t-q} \quad (4)$$

$${\sigma_t}^2 = \omega + \alpha_1 {\varepsilon_{t-1}}^2 + \alpha_2 {\varepsilon_{t-2}}^2 + \ldots + \alpha_p {\varepsilon_{t-p}}^2 + \beta_1 {\sigma_{t-1}}^2 + \beta_2 {\sigma_{t-2}}^2 + \ldots + \beta_q {\sigma_{t-q}}^2 \quad (5)$$

In equation (5), ${\sigma_t}^2$ is the conditional variance of the time series at time t, ω is the constant term representing the unconditional variance of the time series, $\alpha_1, \alpha_2, \ldots, \alpha_p$ are the coefficients of the ARCH terms representing the impact of the past squared errors on the current conditional variance, ${\varepsilon_{t-1}}^2, {\varepsilon_{t-2}}^2, \ldots, {\varepsilon_{t-q}}^2$ are the squared error terms at the previous p lags, $\beta_1, \beta_2, \ldots, \beta_q$ are the coefficients of the GARCH terms representing the impact of the past conditional variances on the current conditional variance, ${\sigma_{t-1}}^2, {\sigma_{t-2}}^2, \ldots, {\sigma_{t-q}}^2$ are the past conditional variances at the previous q lags.

3. Empirical Results and Analysis

3.1. Order of VAR Model

Table 2 shows the results of identifying the appropriate lag order for a Vector Autoregression (VAR) model based on various criteria. The asterisks (*) indicate the selected lag order based on the criteria. In Table 2, the VAR model with lag six is selected as it has the lowest AIC, HQIC, and SBIC values, and the likelihood ratio test is significant at the 5% level for this lag order.

Table 2: VAR model identification.

Lag	LL	LR	df	p	AIC	HQIC	SBIC
0	2410.3				-11.3599*	-11.3523*	-11.3408*
1	2410.61	0.6248	4	0.960	-11.3425	-11.3199	-11.2852
2	2417.91	14.609	4	0.006	-11.3581	-11.3204	-11.2626
3	2418.87	1.9133	4	0.752	-11.3437	-11.2909	-11.21
4	2421.96	6.1847	4	0.186	-11.3395	-11.2715	-11.1675
5	2422.81	1.6832	4	0.794	-11.3246	-11.2415	-11.1144
6	2430.16	14.71*	4	0.005	-11.3404	-11.2423	-11.092
7	2434.82	9.3143	4	0.054	-11.3435	-11.2303	-11.0569
8	2438.93	8.2167	44	0.084	-11.344	-11.2157	-11.0192
9	2441.42	4.987	4	0.289	-11.3369	-11.1935	-10.9739
10	2442.48	2.1216	4	0.713	-11.323	-11.1645	-10.9219
11	2445.66	6.3658	4	0.173	-11.3192	-11.1456	-10.8798
12	2448.78	6.2293	4	0.183	-11.315	-11.1263	-10.8374

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The next step is to test whether the VAR model is stationary. Moreover, if it cannot be determined that the VAR model is stationary, then the impulse response function cannot converge to 0. The result illustrates the long-run effect of U.S. dollar index futures returns on Tesla stock returns.

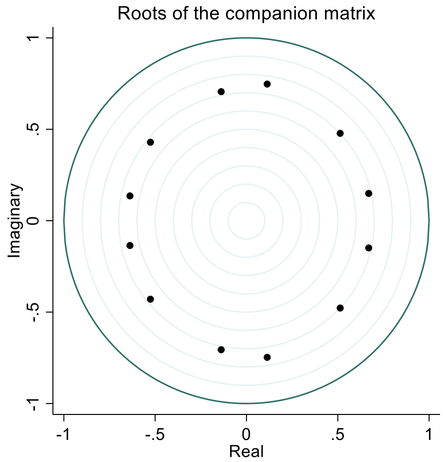

Figure 1: Unit circle test.
Photo credit: Original.

In contrast, after performing a unit root test on the Model and sketching the unit circle to obtain Figure 1, this output shows that all unit roots are within the circles of the unit circle, indicating that the bivariate VAR (6) is a stable model. Therefore, there is no need to re-evaluate the lag order.

3.2. Impulse Response

As the Fed's interest rate hike will cause the dollar to appreciate, this will lead to changes in the international capital markets, with more capital increasing its holdings in the dollar, preferring to go long on the dollar and short on other currencies. Moreover, this trend will be the appreciation of the dollar. The appreciation of the U.S. dollar could have several economic implications: (1) As international capital increases its holdings in the U.S. dollar, it may cause a large amount of U.S. dollars to flow into the U.S. stock market, a situation that raises share prices and yields in the U.S. stock market [11]; (2) An appreciating dollar means an increase in the dollar's purchasing power, which boosts U.S. imports and discourages exports by U.S. firms. An appreciating dollar hurts the interests of U.S. multinational corporations; (3) As a large multinational corporation, a stronger dollar would disguise a reduction in Tesla's operating income.

From the above possible economic outcomes, it is not straightforward to determine which economic consequences arising from the Fed's interest rate hike would be dominant. If the first economic consequence is dominant, then Tesla's share price or yield will increase in line with the increase in the U.S. dollar index. Otherwise, the latter two impact mechanisms are dominant, or these effects cancel each other out.

From the impulse response estimation results (Figure 2), a one-unit change in the U.S. dollar index in period t=0 will result in a positive net effect on future Tesla returns first in the future, with a negative effect dominating from period t=6 onwards. The cumulative effect of dollar appreciation cannot be estimated from the impulse response function alone, whereby the cumulative response function is further calculated in this paper. As can be seen from Figure 3, the cumulative effect of a 1 unit increase in the dollar index in period t=0 on Tesla's return over the following 30 periods is slightly more than 4%. Therefore, Tesla is the beneficiary of the current round of rate hikes.

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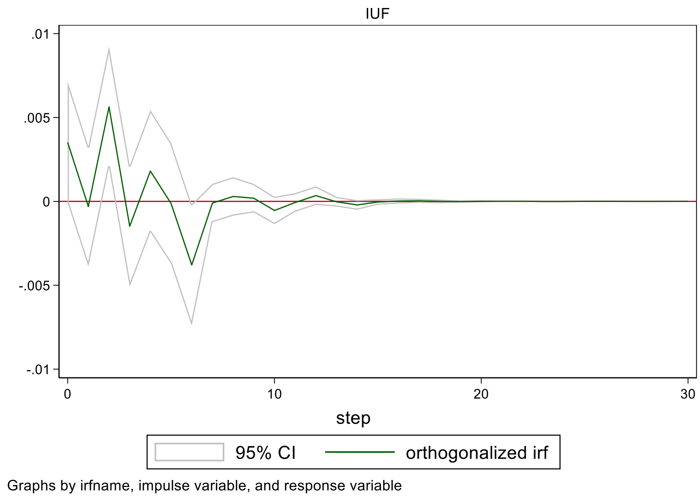

Figure 2: Impulse and response.
Photo credit: Original.

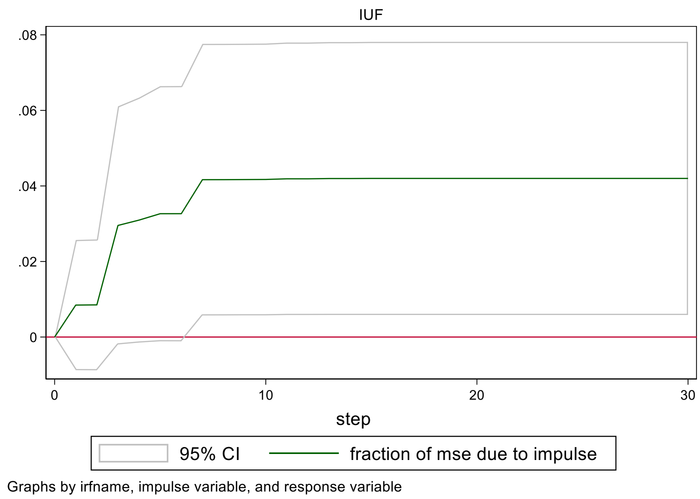

Figure 3: Cumulative response.
Photo credit: Original.

3.3. ARMA Specification

The log-return lag order must first be determined to output the ARMA-GARCH model results. The PACF and ACF (Figure 4) outputs allow the lag order to be determined and are denoted as A.R. (P) and M.A. (q), respectively. In Figure 4, the first part beyond the critical values is 4 for both PACF and ACF plots. Show that both A.R. (P) and M.A. (q) have order 4, so the values of p and q are both 4.

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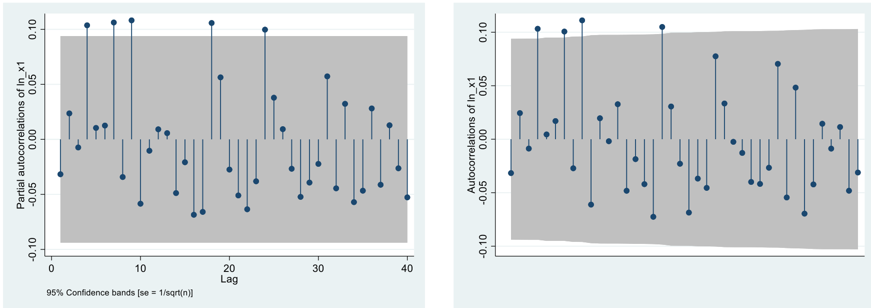

Figure 4: PACF and ACF.
Photo credit: Original.

3.4. Variance Equation of GARCHX

In Table 3, the coefficients of both the ARCH and GARCH terms in the 3-column Model are significant at the 5% significance level, indicating that there is statistically significant conditional heteroskedasticity in Tesla returns, satisfying the basic requirements of GARCH modelling. Estimating the external explanatory variables shows that the U.S. dollar index does not affect Tesla's volatility at the 5% significance level.

Table 3: ARMA-GARCHX estimation results.

	(1)		(2)		(3)	
	Coefficient	p>|Z|	Coefficient	p>|Z|	Coefficient	p>|Z|
			Mean equation			
AR, L4	-0.3246	0.2850	-0.3389	0.2530	-0.3311	0.2720
MA, L4	0.4456	0.1200	0.4606	0.0980	0.4530	0.1100
Constant	0.0015	0.4460	0.0015	0.4680	0.0017	0.4270
			Variance equation			
USD Index						
L0	--13.6920	0.0540	-13.9003	0.0610	-14.9189	0.0650
L1			-5.9487	0.4510	-8.2051	0.3070
L2					-5.8190	0.4650
GARCH (1, 1)						
ARCH	-0.0510	0.0180	-0.0515	0.0160	-0.0508	0.0190
GARCH	-0.5862	0.0010	-0.6382	0.0100	-0.6092	0.0240
Constant	-6.0090	0.0000	-5.9789	0.0000	-5.9949	0.0000

4. Conclusion

This paper focuses on the impact of international capital flows on Tesla's share price because of the Federal Reserve's interest rate hike. Spurred by the Fed's aggressive interest rate hike policy, international capital flows to the U.S. have accelerated, as the ever-higher U.S. dollar exchange rate undoubtedly illustrates. However, existing studies usually focus on the impact of international capital flows to the U.S. on the U.S. economy as a whole or a particular industry, but rarely on a specific company. Therefore, this paper analyses Tesla, which, as one of the most representative multinational companies in the U.S. in the last decade, is undoubtedly favoured by many investors. Therefore, this paper's results can help investors make some judgement. The results of this paper can be used to determine the impact that a subsequent Fed rate hike may have on Tesla's share price so that investment decisions can be better made.

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This paper aims to analyse whether there is a correlation between the U.S. dollar index futures price and Tesla's share price. This paper uses data on the U.S. dollar index futures price and Tesla's share price for the last two years for modelling analysis. The models used are the VAR model and the ARMA-GARCHX model, respectively. The VAR model is used to output impulse responses, while the ARMA-GARCH model is mainly used to assess stock returns and conditional variances. Furthermore, based on the results of the empirical analysis, the paper draws the following conclusions.

The price of the U.S. dollar index will significantly impact the volatility of Tesla's share price, so this paper argues that the Fed's interest rate hike has affected Tesla's share price. However, this impact is more towards the short term, and the market will correct this impact in the long term, so in the long term, Tesla's share price movement should be judged by focusing more on the intrinsic value of its company.

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