Wavelet Analysis on APPL and TSLA by Using R

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Abstract: In this paper, we created and analyzed the time series plots of Apple and Tesla stock prices over the past 2 years and wavelet coherence plots connecting them by using R. We found a causal relationship between AAPL and TSLA in different frequency bands: In the first half of 2020, and from 2022 to the present, TSLA and AAPL interact with each other in the 0-128 frequency bands, showing a positive correlation. From the second half of 2020 to the first half of 2021, there was a positive correlation interaction in the 32-128 frequency bands between AAPL and TSLA. Our study provides several significant supports for investors and scholars. For example, in the general environment of vigorous development of clean energy, helping to predict the trends of Apple, Tesla and other similar companies' stock prices in the future, providing a reference not only for Apple and Tesla to compete and develop in the future, but also for other companies with similar conditions to forecast, estimate the company's competitive strength and formulate long-term development strategies.

1   INTRODUCTION

In recent years, as the leader of new energy companies, Tesla stock price has soared, becoming the world's No.1 car company by market capitalization. More and more people are comparing it to Apple, which is the world's largest technology company, not to mention that Apple's plans to build cars and investments in clean energy are ongoing.

Tesla is an electric vehicle and clean energy company. It designs, develops, manufactures and markets all-electric and advanced automotive powertrain components and energy storage systems. In addition, it sells and leases solar systems and renewable energy to commercial and residential customers. As the world's first electric vehicle company to use lithium-ion batteries, it is gradually dominating the world automotive market and leading global automotive companies with emerging technologies and competitive strategies. On December 30, 2019, Tesla completed delivery of the first Model 3s from its Shanghai Super Factory to fifteen employee owners. On January 7, 2020, at the official delivery ceremony, Musk announced the delivery of the cars to the general public consumers and the launch of the project to manufacture Model Y in China. He initially said in twitter that the idea of the plant supplying only the Greater China region changed because the epidemic of COVID-19 in 2020

affects the resumption plans in the United State, and the excellent cost of production line capacity made in China. In the case of gradual expansion and beyond the demand of the local market, on October 26, Tesla's Shanghai Super Factory began exporting Chinese-made electric cars to more than a dozen advanced countries, including Europe and Australia (Wang and Peng, 2020).

Apple designs, develops, communicates and sells consumer electronics, computer software, online services and personal computers. Before making the iPhone, Steve Jobs wanted to produce an "Apple Car". since 2018, Apple has been opening new offices, investing in automotive engineering machines, hiring thousands of engineers and rehiring the former chief automotive engineer at Tesla. Meanwhile, to address the world's environmental issues, Apple has issued a total of $4.7 billion worth of green bonds between February 2016 and November 2019, to actively pursue low-carbon engineering, renewable energy, carbon sequestration, carbon saving and emission reduction. They plan to achieve carbon neutrality of overall company operations, manufacturing supply chain and product lifecycle by 2030. Currently, Apple's global business operations have achieved carbon neutrality. By 2030, the climate impact of every Apple device sold will be reduced to net zero (Apple's $4.7 billion green bond

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spend is helping to create 1.2 gigawatts of Clean Power, 2022).

In the face of increasing global pollution, the new energy industry will enable us to reduce industrial waste by replacing traditional energy sources with environmentally friendly ones, while ensuring the sustainability of the energy industry. More and more people are becoming aware of sustainability and the aim of reducing CO2 emissions. Therefore, the idea of vehicles without pollutant emissions is very promising now, especially in the future. These vehicles will be cheaper to maintain in the coming years and owning them will be better for society. State governments, as well as global organizations such as the United Nations, are also committed to increasing the number of electric vehicles. They have introduced many corresponding policies and regulations, such as:

1. Financial incentives. Through government subsidies, vehicle registration tax exemptions, making electric vehicles more attractive to private and corporate customers.

2. Urban access restrictions. Oxford proposes to ban all non-electric vehicles from the city centre from 2020,and Paris intends to ban all gasoline and diesel vehicles in the city centre (Fekete et al., 2021).

There is a growing overlap between Apple and Tesla, both in their strong promotion of clean energy and the development of electric vehicles. The economic shutdown caused by the epidemic of COVID-19 in 2020, which also hit the stock market hard. However, following with a $2 trillion fiscal stimulus package from the U.S. government and monetary stimulus from the U.S. Federal Reserve, the economy recovered and the stock market recovered (ODEDOKUN, 2021). Tesla was included in the S&P 500 on December 21,2020, and its performance rose to the top of the list, dominating US market trading. Meanwhile, Apple also has been performing well in recent years. Its market capitalization exceeded $1 trillion on August 2, 2018, exceeded $2 trillion by stock price on August 19, 2020, and on January 3, 2020, once exceeded $3 trillion dollars, although the stock price fell at the close of trading, failing to hold the $3 trillion market cap.

Our work in this paper is to explore the relationship between AAPL and TSLA. First, we discuss the recent situation and social background of Apple and Tesla, introduce AAPL and TSLA, and analyse the relationship between Apple and Tesla to prepare for the experimental analysis that follows. The third paragraph is our research methodology. We will use R to analyse price change of AAPL and TSLA in detail. The fourth section is the experimental analysis. We first perform a simple data analysis of the data components and data sources, as well as based on time series graphs. Then, we further describe the connection between AAPL and TSLA by analysing the wavelet correlation between the two based on the information from the graphs. In Section 5, I will summarize all of the above and provide an outlook on future research directions.

2 AAPL, TSLA, WAVELET COHERENCE

In recent years, many investors have been closely following the stock price trends of Apple and Tesla and the relationship between the two. Castro Caballero et al. have studied the feasibility of an Apple acquisition of Tesla, doing an extremely comprehensive strategic analysis, a potential acquisition ,which is one of the largest M&A's in the world (Castro Caballero et al., 2020). More and more research on stock forecasts is being published, with many reports using Tesla and Apple as examples. This shows that Apple and Tesla are often mentioned together to some extent, either as acquisitions or in comparison to each other, but the degree of correlation between Apple and Tesla's stock prices, i.e., the degree of correlation and the lead/lag relationship between Apple and Tesla, has not yet been explored.

Wavelet coherence can locate correlations between sequences and their evolution over time and across scales. He and Nguyen showed how the wavelet transform is an effective tool for decomposing time series into different frequency levels. This decomposition allows researchers to study the interaction of financial and economic variables at different levels: from the very short-term or high-frequency level to the very long-term or low-frequency level. Therefore, wavelet analysis is extremely important for studying the impact and correlation of economic variables (Nguyen and He, 2015).

Kim and In investigated the relationship that exists between stock returns and inflation using a wavelet multiscale approach to decompose a given time series on a scale-by-scale basis(Kim and In, 2005). Hamrita and Trifi used the wavelet transform to examine the multiscale relationships among interest rates, exchange rates, and stock prices. In particular, they apply the maximum overlap discrete wavelet transform (MODWT) to interest rates, exchange rates, and stock prices in the United States

for the period from January 1990 to December 2008 , and analyse the association of these series at different time scales and the lead/lag relationship by using the definitions of wavelet variance, wavelet correlation, and mutual correlation (Hamrita and Trifi, 2011). Andrieș, Ihnatov and Tiwari used cross-wavelet power, cross-wavelet coherence and phase difference methods to study and identify the patterns of linkage between interest rates, stock prices and exchange rates in India for the period July 1997 to December 2010 (Andrieș et al., 2014). Mohamed Dahir et al. investigated the dynamic link between Brazil, Russia, India, China and South Africa (BRICS) regarding the exchange rate and stock returns through using wavelet analysis (Mohamed Dahir et al., 2018). Liow, Huang and Song utilized wavelet-based multi-resolution analyses to investigate the relationship between the U.S. real estate and stock markets in the time-frequency domain (Liow et al., 2019). These previous studies have well demonstrated the great significance of wavelet analysis for studying the degree of correlation and lead/lag relationship between economic variables.

3 DATA AND METHODOLOGY

The data used in this study includes Apple stock price (AAPL) and Tesla stock price (TSLA). Both the AAPL and TSLA data were sourced from Kaggle and were collected from January 2, 2020 to September 1, 2022, with 673 valid data. We chose this period because we wanted to reduce the interference of the COVID-19 global pandemic on this study.

3.1 The Wavelet Coherence

we used R to create time series to analyse AAPL and TSLA separately. The correlation between AAPL and TSLA could be analysed by considering the widely implemented method that did not consider time series, i.e., wavelet coherence. Torrence and Compo showed that the cross-wavelet transform can be performed by two time series a(t) and b(t) articulated as:

$$N_{ab}(p,q) = N_a(p,q)N_b{}^*(p,q) \qquad (1)$$

In the formula, $N_a(p,q)$ and $N_b(p,q)$ described two continuous transforms of a(t) and b(t), with p was the position index, q denoting the measure. In addition, (*) represented the composite conjugate(Torrence and Compo, 1998). Torrence and

Webster stated the equation for the adjusted wavelet coherence coefficients:

$$W^2(p,q) = \frac{|MM^{-1}N_{ab}(p,q)MM^{-1}N_{ab}(p,q)|^2}{M(M^{-1}|N_a(p,q)|^2)M(M^{-1}|N_b(p,q)|^2)} \qquad (2)$$

M was the smoothing mechanism. $0 \le W^2(p,q) \le 1$, which denoted the range of square wavelet coherence coefficients. Close to zero indicates a lack of correlation, while close to one indicates high correlation (Torrence and Webster, 1998).

4 EMPIRICAL ANALYSIS

We analyse the time series chart of AAPL stock price, as shown in Figure 1.

In March 2020, the global epidemic was in full swing and the stock value dropped sharply to a trough of about $56.092. After a series of adjustments by the U.S. government, Apple and others, the stock value recovered and oscillated upward, reaching a peak of about $182.010 in recent years in January 2022, and then continued its oscillating trend. 32 months, from a start of $75.088 to a finish of $ 157.960, doubling the share value.

We analyse the time series chart of TSLA stock price, as shown in Figure 2.

The large-scale opening of the Chinese market in 2019 owing to the official establishment of the Tesla China Super Factory and the lower cost of the Chinese version of the Model 3. A sharp increase in sales had led to a continued rise in Tesla stock in 2020. After a brief decline to around $200 in the first half of 2021, Tesla shares soared again in September and October, reaching a peak of $409.970 in recent years in November 2021, a value that was more than 14 times the initial value of the analysis period, and then showed an oscillating decline.

The wavelet coherence between AAPL and TSLA showed in Figure 3.

There are two larger red islands from 2020 to the first half of 2021 (0 to 128), indicating a strong dependence on the 0 to 128 band for the corresponding sample period. The arrows to the right, top, and bottom indicate that TSLA and AAPL interact with each other, showing a positive correlation. The global outbreak of the epidemic was in full swing and U.S. stocks fell sharply, followed by a larger release of monetary liquidity from the Federal Reserve and a massive fiscal stimulus from the U.S. government, which led to a recovery in U.S. stock prices. At the same time, Tesla greatly opened up the Chinese market with the delivery of the Chinese version of Model 3, which made a sharp increase in

overall sales and a more than sevenfold increase in stock prices, dominating U.S. stock trading in 2020.For Apple, the closure of the epidemic has led to a shift from the traditional offline office and learning model to remote, online, driving public demand for new devices, such as mac and iPad, as of September 2020, net sales of both devices have increased by 11% over the same period, and share values have also increased (10-K 2020, 9.26 - s2.q4cdn.com, 2020). In addition, Apple has funded 17 green bond projects to promote carbon savings and clean energy development around the world.

2022 (0 to 128) also has two larger red hot areas. Particularly, the area in 0-32 frequency bands is darker in red, indicating the correlation is much stronger. Arrows in this region are up and down to the right, which means AAPL and TSLA influence each other. For the red island over the 64 to 128 days frequency bands, arrows to the right and down to the right, illustrating that AAPL leads TSLA. Both of two red hot areas show positive correlation. The government's support for clean energy and the establishment of laws and regulations favourable to electric vehicles have led shares of companies like Tesla, using new energy, and Apple, which is implementing solar energy investment plans, to rise. Apple has accelerated its development of fully autonomous electric vehicles in recent years, and while the Apple Car program has undergone several shifts and changes over the past few years due to internal conflicts and leadership issues, development is now on track. 26 percent of people surveyed by Strategic Vision of 200,000 new car owners said they liked the Apple brand and would consider buying a car if it made one. Apple also had the highest quality impression with a score of 24%, compared to 11% for Tesla. So, it's clear that Apple and Tesla will be in strong competition for the electric car.

There are many red islands of varying sizes in the 0 to 16 band with arrows to the right, top right, and bottom right, indicating that AAPL and TSLA are always mutually causal in both directions in the lower frequency bands.

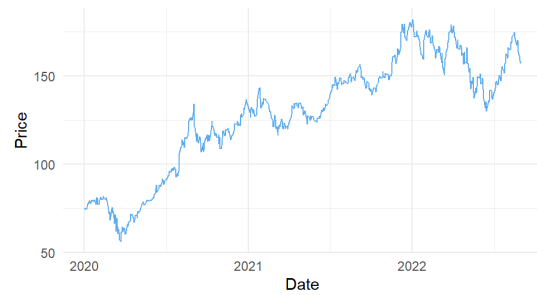In summary, AAPL and TSLA exhibit bidirectional causality in almost all frequency bands.

Figure 1: AAPL stock price from January 2, 2020, to September 1, 2022.
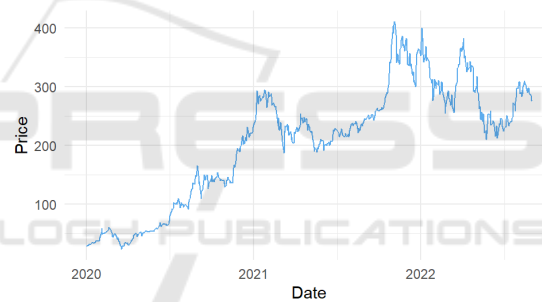

Figure 2:TSLA stock price from January 2, 2020, to September 1, 2022.
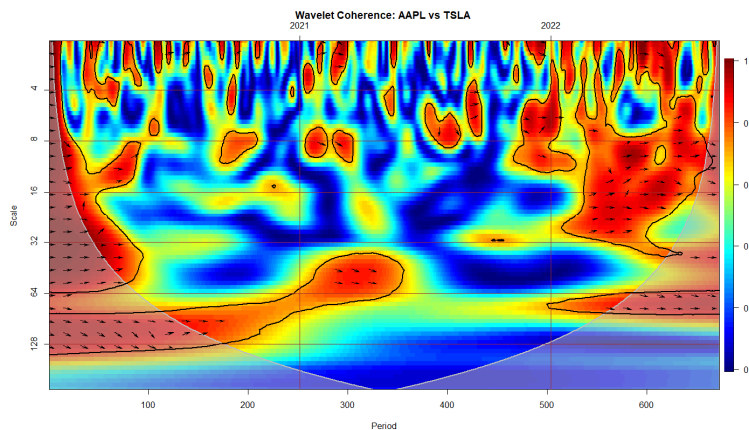

Figure 3. Wavelet Coherence: AAPL vs TSLA

5 CONCLUSIONS

In this study, we collected from 2020 to September 1, 2022 of daily data on AAPL and TSLA stock prices, used R to create time series plots and wavelet coherence plots, and analysed the interactive bootstrap lag interactions in the time-frequency domain.

We concluded that AAPL and TSLA exhibit bidirectional causality in almost all frequency bands: In the first half of 2020, TSLA and AAPL showed a positive correlation interaction over the 0 to128 days frequency bands; From the second half of 2020 to the first half of 2021, there was a positive correlation interaction in the 32-128 frequency bands between AAPL and TSLA; From 2022 to the present, TSLA and AAPL interact with each other in the 0-128 frequency bands, showing a positive correlation, and the correlation is much stronger from 0 to32 days; In particular, from 2020 to present, there are many red islands of different sizes in the 0-16 frequency bands with arrows to the right, upper right, and lower right, indicating that AAPL and TSLA always have a mutual two-way causality in the low frequency band.

We also found that U.S. policies and government investments, such as massive fiscal stimulus, investments in renewable energy and clean energy industries, not only affect the volatility of AAPL and TSLA stock prices, but more importantly, strengthen the correlation between AAPL and TSLA, making the dynamics of the two closely related.

In the future, scholars and investors can use this study on the degree of correlation between Apple and Tesla stocks as a reference basis to explore the degree of correlation between various companies, the impact of competition between various companies on stock prices, and the impact of external environment, such as policies, on competition and development between companies in the future, using R and the wavelet coherence, whether in the face of the continuous emergence of new viruses, the introduction of various new policies on economy and environment, or in the face of the general environment of promoting clean energy in various industries.

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